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LOWER CHURCHILL PROJECT

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July 6, 2011

Board of Commissioners of Public Utilities
Prince Charles Building
120 Torbay Road, P.O. Box 21040
St. John's, NL
A1A 5B2

**ATTENTION: Ms. Cheryl Blundon**
**Director of Corporate Services & Board Secretary**

Dear Ms. Blundon:

**Re: Reference to the Public Utilities Board in relation to Muskrat Falls**

Please find enclosed Nalcor's Submission to the Board explaining and providing context for the information provided to the Board in this matter to date, and for the additional information being provided to the Board today and in the near future.

This filing follows correspondence from the Board to Nalcor of June 17, 2011 and a meeting held that day between Nalcor and Board staff. With today's filings, Nalcor has filed 32 exhibits and has provided a response to each of the 19 items requested in the Board's letter. In addition, we have filed:

- a summary of the process used in the evaluation of Muskrat Falls as the least-cost option;
- appendices which explain the bases of the design of the proposed generating and transmission facilities; and
- additional exhibits in support of the process.

Further, there are five items being prepared for filing over the next few days which we believe will assist the Board by providing convenient references to some of the inputs used in the reports that have been filed.

At our meeting with Board staff on June 17, 2011, we discussed coordinating the release of information to the Board and its consulting engineer. While today's submission and the documentation filed to date provide essential information to the Board, as discussed, it can be supplemented by additional information to be identified in meetings to be scheduled among the consultant, the Board and Nalcor. It is probable that some of the information sought in those processes will be confidential and commercially sensitive and, in particular, they could include information that can be used by potential construction project bidders to their competitive advantage. We anticipate that appropriate measures such as non-disclosure agreements will be required to address that concern.

I trust this is satisfactory.

Yours truly,

Geoffrey P. Young
Senior Legal Counsel

cc. Mr. Thomas Johnson

A REPORT TO
THE BOARD OF COMMISSIONERS OF PUBLIC UTILITIES

# SYNOPSIS OF 2010 GENERATION EXPANSION DECISION

## NALCOR ENERGY

July 2011

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# 1 Introduction

The Government of Newfoundland and Labrador (the Province) announced on June 17, 2011

> *"As part of the comprehensive evaluation process to move the development of Muskrat Falls and the Labrador Island Link projects to final sanction, the Provincial Government has asked the Board of Commissioners of Public Utilities (PUB) to provide a supplemental review of the process used to determine that Muskrat Falls represents the least-cost option for the supply of power to Island Interconnected Customers compared to the Isolated Island development option."*

The Terms of Reference and Reference Question are attached as Appendix A. By way of letter on June 17, 2011, the Board requested that Hydro (Nalcor) provide an initial list of information and reports to enable the Board's consultant to advise the Board in relation to the reference question. Nalcor is providing information in response to this request, most of which information was filed on June 30, 2011.

Table 1 below addresses the Board's request.

**Table 1: Data Requested and Response**

| Requested Item | Nalcor Response |
|---|---|
| Load Forecast | • Filed as Exhibit 1. |
| Generation Expansion Plan | • Filed as Exhibit 14. |
| Feasibility Studies | |
| Muskrat Falls | • Appendix B provides summaries of the relevant studies and information used to determine the proposed structure since the initial study was issued in 1999.<br>• 1999 Feasibility Study (Exhibit 19) filed as background information. |
| HVdc Interconnection | • Appendix C is a summary of the evolution of the configuration for the Labrador-Island HVdc link since the initial study was issued in 1998.<br>• 1998 Feasibility Study (Exhibit 18) filed as background information. |

| | |
|---|---|
| Island Pond Development | • Filed as Exhibit 5b. |
| Portland Creek Development | • Filed as Exhibit 5c. |
| Round Pond Development | • Filed as Exhibit 5d. |
| Power and Energy Studies | • Optimized capacity and energy for each studied plant is included in each feasibility study. |
| Optimization Studies | • Optimization to the extent appropriate for the feasibility study has been included in individual feasibility study.<br>• Further optimization will be undertaken as part of detailed engineering. |
| Water Management Agreement | • Filed as Exhibit 17. |
| Power System Studies | • Power System data has been incorporated into the analysis of the least cost option, as described in the Generation Expansion Inputs Section below.<br>• Further information can be compiled and made available, if required. |
| Reliability Studies | • Reliability data has been incorporated into the analysis of the least cost option, as described in the Generation Expansion Section below.<br>• Further information can be compiled and made available, if required |
| Cost Estimates | |
| Combined Cycle Combustion Turbines | • Filed as Exhibit 5h. |
| Combustion Turbines | • The information included in the CPW analysis is included in Exhibit 5.<br>• Further information can be compiled and made available, if required. |
| Wind Farms | • The information included in the CPW analysis is included in Exhibit 5.<br>• Further information can be compiled and made available, if required. |
| Refurbishment of the Holyrood Thermal Generating Station (including the addition of scrubbers, electrostatic precipitators and $NO_x$ Burners) | • Please refer to Exhibit 5 for the data included in the CPW analysis.<br>• Additional data on scrubbers and precipitators is filed as Exhibit 5l-i. |
| Fuel Price Forecasts | • Filed as Exhibit 4. |
| Cumulative Present Worth of the two alternatives | • Filed as Exhibit 14. |
| All data and assumptions used to complete the CPW analysis | • This information is discussed in the remainder of this submission. |

This submission by Nalcor Energy (Nalcor) represents an initial package of information for the Board so as to explain the input data and methodology used by Nalcor in its analysis. This synopsis provides an overview of the process followed by Nalcor in evaluating the least cost supply option for the Island Interconnected system on the Island of Newfoundland. The document identifies the inputs to the process and will help provide focus on the data that is required by the Board and its consultant to complete its review.

Nalcor also anticipates that further information, including confidential information, may be required by the consultant, and is preparing a collection of such data for inspection and review by the consultant.

It should be noted that some activities in this study were completed by Newfoundland and Labrador Hydro (Hydro), a Nalcor subsidiary.

# 2 Generation Expansion Analysis

To prepare a least cost generation expansion plan for any given load forecast, Hydro uses Ventyx's Strategist software. Strategist is an integrated strategic planning computer program that allows modeling of the current and future generation system and that performs, among other functions, generation system reliability analysis, production costing simulation and generation expansion planning analysis. Given the current generation system, available resource options, a load forecast and other inputs, as will be described, algorithms within Strategist evaluate all of the various combinations of resources and produce a number of generation expansion plans, including the least cost plan, to supply the load forecast within the context of the power system reliability criteria and other technical limitations.

The outcome of the generation planning analysis is Cumulative Present Worth (CPW), which is the present value of all incremental utility capital and operating costs incurred Hydro to reliably meet a specific load forecast given a prescribed set of reliability criteria. Where the cost of one alternative supply future for the grid has a lower CPW than another, the option with the lower CPW will be recommended by Hydro, consistent with the provision of mandated least cost electricity service.

# 3 Generation Expansion Analysis – Reliability Criteria

Hydro's generation reliability criteria set the minimum level of reserve capacity and energy installed for the power system to ensure an adequate generation supply for firm load. Short-term deficiencies may be tolerated where a deficiency is determined to be of minimal incremental risk. Hydro's system planning criteria are:

> Capacity: The Island Interconnected System should have sufficient generating capacity to satisfy a Loss of Load Hours (LOLH) expectation target of not more than 2.8 hours per year.
>
> Energy: The Island Interconnected System should have sufficient generating capability to supply all of its firm energy requirements with firm System capability.

# 4 Generation Expansion Inputs

In preparing to carry out a generation expansion exercise, the inputs into the Strategist model are reviewed and updated as required. Key inputs and parameters are as follows:

1) Planning load forecast - This review utilizes the 2010 Planning Load Forecast (PLF) as prepared by the Market Analysis section of the Hydro System Planning department. (Exhibit 1)
2) Time period of study – The time period that the study will cover must be defined and all other inputs must be developed to cover this period. The time period for the 2010 expansion analysis is 50[1] years after in service of the Labrador – Island Transmission Link in order to cover its the economic life.
3) Load shape – Hourly load shapes for each month of the year are required. Nalcor uses a representative week to model each month, with inputs based on hourly system load readings. (Exhibit 2)
4) Escalation Series – Current escalation rates for capital and Operating and Maintenance (O&M) costs are developed annually based on external projections received from the Conference Board of Canada and Global Insight, consultant for escalation factors. Weighted cost indices for core assets are developed and projections on various producer price indices from Global Insight are used to drive each weighted index. The escalation rates used in the present analysis are attached as Exhibit 3.
5) Heavy Fuel Oil and distillate market prices– The PIRA Energy Group of New York, a leading international supplier for energy market analysis and forecasts, and oil market intelligence in particular, supplies the fuel price data, which is updated for long term projections at the beginning of each expansion analysis. Such fuel oil market based price forecasts are used in production costing for the existing Holyrood and combustion turbine (CT) thermal plants, plus for any new combined cycle combustion turbines

[1] 57 years total, seven years to in-service date.

(CCCTs) or CTs that would be constructed in future periods. The prices used in the present analysis are attached as Exhibit 4.

6) Discount Rate – The generation expansion analysis for 2010 used a discount rate of 8.0 percent, reflecting Hydro's projection for its weighted cost of capital as of January 2010. All costs were modeled in current (as spent) Canadian dollars, and the results discounted to the base year of 2010.

7) Capital Cost Estimates – Capital costs estimates for a portfolio of alternative generation assets are collected together for inputs based on formal feasibility studies and estimates as developed by consultants and Hydro's Project Execution and Technical Services (PETS) Department. In addition to the Muskrat Falls project, the portfolio used in this analysis was;
   a. Wind, (Exhibit 5);
   b. Island Pond (Exhibit 5b);
   c. Portland Creek (Exhibit 5c);
   d. Round Pond (Feasibility Study filed as Exhibit 5d);
   e. HVdc In-Service Capex (Exhibit 5e);
   f. Muskrat Falls Quarterly and Annual Capital Cost (Exhibit 5f);
   g. 50 MW CT (Exhibit 5);
   h. 170 MW CCCT (Holyrood Combined Cycle) (Exhibit 5h);
   i. 25 MW Wind Farm Replacement Hydro-constructed (Exhibit 5);
   j. Fermeuse Replacement Hydro-constructed (Exhibit 5);
   k. St. Lawrence Wind Farm Replacement Hydro-constructed (Exhibit 5);
   l. HTGS Environmental Improvements
      i. ESP and FGD (Exhibit 5Li), and
      ii. Low $No_x$ Burners (Exhibit 5);

8) Power Purchase Agreements (PPAs) – The annual power purchase expense incurred by Hydro under existing PPAs, and future PPAs as applicable, are accounted for. The listing of PPAs and rates is attached as Exhibit 6.

9) Service Life/Retirements – The service life and retirement dates for existing and new generation asset must be defined for the Strategist expansion analysis as thermal plant replacement is an important component of generation planning and costing. The service life assumptions used in the present analysis are attached as Exhibit 7.

10) Operating and Maintenance (O&M) Costs – Non-fuel O&M costs for the resource projects are derived from feasibility studies and Hydro's extensive operating experience. These O&M costs are comprised of fixed expenditures related to asset maintenance and variable costs driven by production output. The listing of O&M assumptions is attached as Exhibit 8.

11) Thermal Heat Rates – Per unit fuel consumption of existing and future thermal generation sources are important inputs in production costing. The heat rates utilized in Strategist reflect a combination of Hydro's operating experience, plus external studies and estimates. Details are attached as Exhibit 9.

12) Existing hydroelectric and wind energy – The monthly and annual average and firm energy production forecasts for all of the existing hydroelectric plants and wind farms are updated to incorporate the latest historical data and operational factors. Production forecasts from new renewable plants are based on engineering studies and/or estimates. Please see Exhibit 10.

13) Asset Maintenance Scheduling – Outages schedules to accommodate annual maintenance for each existing and future generation asset must be included in the Strategist analysis. Such maintenance scheduling is largely based on Hydro operational experience. Exhibit 11 is a listing of the outage schedules used in the present analysis.

14) Forced Outage Rates – All generation production units have an associated involuntary forced outage rates leading to the unavailability of a generating unit. The forced outage rates used in this analysis are based on Hydro's operations experience and/or industry norms as tabulated by the Canadian Electrical Association. Please see Exhibit 12 for details.

15) Generation Unit Capacities – the installed and net capacities of existing and future generation assets are reviewed and updated based on operational experience or

external inputs as applicable. Exhibit 13 shows the capacity assumptions used in this analysis.

16) No cost of carbon ($CO_2$, $NO_X$, $SO_X$ and $SO_2$ atmospheric emissions) has been included in base CPWs owing to prevailing uncertainties regarding the timing, scope, and design associated with possible future regulatory initiatives in this regard.

17) Energy efficiency is integrated into Hydro's PLF through the use of an efficiency trend variable. The success associated with utility sponsored energy efficiency remains modest and is taken as a subset of efficiency trends in the load forecast process.

# 5 Generation Expansion Plans – Isolated Island Option versus Labrador Interconnection Option

The 2010 Generation Expansion compared a continued Isolated Island Option to a Labrador Interconnection Option. The 57 year expansion plans associated with both options are presented in Exhibit 14 and the remaining sections of this synopsis will summarize these plans and highlight inputs and assumptions unique to each.

## *5.1 Isolated Island Expansion Plan*

The Isolated Island Expansion plan would see the addition of a third 25 MW wind farm in 2014. This would be a PPA, similar to the existing wind PPAs, followed by the 36 MW Island Pond hydro development in 2015, 23 MW Portland Creek hydro development in 2018 and 18 MW Round Pond hydro development in 2020. Feasibility studies for Island Pond, Portland Creek and Round Pond were completed by consultants in 2006, 2007, and 1988, (Exhibits 5b,c,and d) respectively. The expansion plans also includes environmental improvements at the Holyrood Thermal Generating station (see Generation Planning Issues July 2010 Update - Exhibit 16). These improvements include electrostatic precipitators (ESP) and a flue gas desulphurization (FGD) system in 2015 (a feasibility study was completed by a consultant in 2008 – Exhibit 5li) and the installation of low NOx burners in 2017 (an estimate was completed by Hydro). The isolated expansion plan post 2020 involves a predominately thermal future consisting of 50 MW CTs or 170 MW CCCTs fired by No. 2 diesel fuel. A feasibility study on CCCTs (see Exhibit 5h) was completed by a consultant in 2001 and estimates on CTs and CCCTs have been regularly updated by Hydro's Project Engineering and Technica*l* Services group, in consultation with industry.

## 5.2 Labrador HVdc Interconnection and Muskrat Falls Expansion Plan

For the Labrador Interconnection alternative, a 320 kV HVdc transmission link between Muskrat Falls and Soldier's Pond is brought into service in January 2017 as commissioning proceeds on the generating units at the Muskrat Falls hydroelectric plant for a commercial in-service target of mid-year. This transmission interconnection has a capacity to supply 900 MW of power and energy from Labrador to the Island and is treated by Strategist as an unrestricted thermal supply source. Thus it can displace Holyrood and meets the Island's incremental load growth for years to come.

Initially, Hydro plans to keep Holyrood available for production as the Labrador HVdc interconnection and power supply is integrated into the existing power system operations on the Island. Within two years, Holyrood will be in standby mode, and Hydro would expect, by the 5$^{th}$ year, to commence dismantling the majority of the thermal plant. The existing generators at the Holyrood plant will be retained for synchronous condenser operation for power grid voltage stability purposes. Following the commissioning of the Labrador HVdc transmission link, further additions will not be required until 2036 when additions are driven by the requirement to conform to the capacity reliability criterion referenced above. CTs would normally be used exclusively for such planning purposes, but there can be circumstances where Strategist may call on other resources depending on the extent and cost to address the capacity criterion violation.

In the Labrador Interconnection alternative, the in-service capital cost of the HVdc transmission asset itself is modelled as any other generating capital item for production costing purposes. The price for energy sourced to Muskrat Falls is an input to the Strategist Labrador supply expansion plan. This power purchase price for Hydro was derived by Nalcor (and its financial consultants) based on a long term financial analysis of Muskrat Falls as an investment opportunity assuming that the Island was the only customer for energy and that a return on capital was consistent with financial returns in the utility sector. Please refer to Exhibit 6b.

# PUBLIC UTILITIES BOARD TO REVIEW

# LOWER CHURCHILL PROJECT

## Press Release and Backgrounder

nalcor energy

**Appendix A: Natural Resources News Release**

Natural Resources

June 17, 2011

**Public Utilities Board to Review Lower Churchill Project**

As part of the comprehensive evaluation process to move the development of Muskrat Falls and the Labrador Island Link projects to final sanction, the Provincial Government has asked the Board of Commissioners of Public Utilities (PUB) to provide a supplemental review of the process used to determine that Muskrat Falls represents the least-cost option for the supply of power to Island Interconnected Customers compared to the Isolated Island development option.

"The Lower Churchill project is the most significant electrical generation and transmission project undertaken by this province in 50 years, and it is important to engage the PUB in a review of the fundamental question about developing the least-cost option to meet our energy needs," said the Honourable Shawn Skinner, Minister of Natural Resources. "Our government chose to request this review to provide another perspective on the soundness of the assumptions and principles used in the analysis. This review is one element of fulfilling best practice processes aimed at ensuring this investment decision benefits from rigorous input from multiple sources prior to sanction."

The PUB will initiate a review on the development of the Muskrat Falls generation facility and the Labrador-Island Link transmission line as the least-cost option to supply power to the Island compared to the Isolated Island development option, and will establish the process for this review including public engagement. The report will be submitted by December 30, 2011, in time for input into the sanction decision, and will be made public as part of the sanction decision process. The terms of reference are noted in the backgrounder below.

Consumer advocate Tom Johnson has been appointed to represent consumer interests during the PUB review.

"The Consumer Advocate will play an invaluable role in supporting an independent and transparent review, and we look forward to Mr. Johnson's participation," said Minister Skinner. "We have made a commitment to be open, transparent and accountable to the people of the province, and want to ensure they are engaged, informed and confident in the decision to develop the Lower Churchill."

## BACKGROUNDER

### Terms of Reference and Reference Question

In the Energy Plan, 2007, Government committed to the development of the Lower Churchill hydro resource. It has been determined that the least-cost option for the supply of power to the Island interconnected system over the period of 2011-2067 is the development of the Muskrat Falls generation facility and the Labrador-Island Link transmission line, as outlined in Schedule “A” attached hereto (the “Projects”), as compared to the isolated Island development scenario, as outlined in Schedule “B” attached hereto (the “Isolated Island Option”), both of which shall be outlined further in a submission made by Nalcor Energy (“Nalcor”) to the Board of Commissioners of Public Utilities (the “Board”). It is contemplated that Newfoundland and Labrador Hydro (“NLH”) would enter into a long-term power purchase agreement and transmission services agreement with Nalcor, or its subsidiaries, the costs of which would be included in NLH’s regulated cost of service with the full cost of the Projects being recovered from NLH’s Island interconnected system customers (the “Island Interconnected Customers”).

Pursuant to section 5 of the Electrical Power Control Act, 1994 (the “EPCA”), Government hereby refers the following matter to the Board:

**The Reference Question**

The Board shall review and report to Government on whether the Projects represent the least–cost option for the supply of power to Island Interconnected Customers over the period of 2011-2067, as compared to the Isolated Island Option, this being the “Reference Question”.

In answering the Reference Question, the Board:

shall consider and evaluate factors it considers relevant including NLH’s and Nalcor’s forecasts and assumptions for the Island load, system planning assumptions, and the processes for developing and comparing the estimated costs for the supply of power to Island Interconnected Customers; and

shall assume that any power from the Projects which is in excess of the needs of the Province is not monetized or utilized, and therefore the Board shall not include consideration of the options and decisions respecting the monetization of the excess power from the Muskrat Falls generation facility, including the Maritime Link project.

Where Nalcor or NLH determine that any information to be given to the Board for this review is commercially sensitive as defined in the Energy Corporation Act, it shall advise the Board, and the Board and its experts and consultants may use such information for this review but shall not release such information to any party.

For the purposes of this review, a consumer advocate shall be appointed pursuant to section 117 of the Public Utilities Act.

Any costs of the Board in respect of this review, including the costs of the consumer advocate, shall be paid by Nalcor.

The Board's report shall be provided to the Minister of Natural Resources by December 30, 2011. The Minister shall make this report public.

# LOWER CHURCHILL PROJECT

# MUSKRAT FALLS GENERATION FACILITY
# 1998 TO DECISION GATE 2

## Technical Note

Date: 5-July-2011
Rec. No. 202-120142-00012

## 1. Purpose

The purpose of this technical note is to explain the changes that have occurred in the layout of the Muskrat Falls Generation Facility from 1998 to Decision Gate 2 (2010) (including the transmission connection to the existing HVac transmission system in Labrador).

## 2. Description

In 1999, a feasibility study was completed for the generation facility at Muskrat Falls. The study included a number of layout variants and concluded with a shortlist of three variants: 7, 10 and 11. After analysis of comparative costs, schedule and risk, Variant 7 was selected as the layout of choice for further development. The conceptual development for Variant 7 was described in the January 1999 report by SNC-AGRA. (Exhibit 19)

Variant 7 is an 824 MW development comprising a four unit powerhouse, including three (3) propeller turbines and one (1) Kaplan turbine and a three (3) bay gated spillway constructed in the river channel, a north overflow dam with a partial fixed crest and an inflatable rubber dam, and a south closure dam. Permanent access to the powerhouse is from the north side of the river, around the rock knoll of the North Spur and across the top of the dams, and the spillway and intake structures.

By 2007, a bridge was constructed across the Churchill River as part of the Trans Labrador Highway. The Blackrock Bridge is located approximately 18 km downstream of Muskrat Falls and provides the possibility of access to the Muskrat Falls site along the south side of the river. This merited a further review of the variants for the development of Muskrat Falls. This review was carried out in 2007 by SNC (MF1010).

Variant 7 includes diversion tunnels through the rock knoll of the North Spur. Structures include a powerhouse and spillway, constructed in the river channel, an overflow dam on the north side of the river and a closure dam on the south side of the river.

Variant 11 is similar to Variant 7, except that it does not have diversion tunnels. It requires a three stage diversion of the river. The first stage would be via a channel cut through the north shore of the river, allowing the river to be coffer-dammed for construction of the powerhouse and spillway in the river channel. The second stage would then be via a partially completed spillway while the north overflow dam and south closure dam are being completed and, the third stage would be via the north overflow dam, while the spillway is being completed.

Variant 10 has the powerhouse and spillway on the south side of the river so that excavation can start on dry land. River diversion is not required until year 3 of the construction schedule. Similar to Variant 11, it does not require diversion tunnels. River diversion would be through a partially completed spillway on the south shore, while the north overflow dam is being built in the river channel and on the north shore, and the south closure dam is being built on the south shore.

A comparison of costs and risks ranked Variant 10 as the most attractive layout, followed by Variant 7 and then Variant 11. A comparison of schedules showed Variant 10 would achieve first power 9 months ahead of Variant 11 and 10 months ahead of Variant 7. Considering equalization costs for schedule and risk, Variant 10 was the least cost alternative.

With Variant 10 now ranked as the least cost alternative, a further study (MF1050) was carried out in 2007 to evaluate spillway alternatives. The gates in the spillway, included in MF1010 were larger than any known installations. This study considered a gate array that utilized current maximum gate sizes, in surface and submerged configurations, including vertical and radial gate types. Based on this study, a shortlist of four spillway gate schemes was derived: 1a, 1b, 1f and 3b. Scheme 3b, with four (4) radial gates was determined to be the least costly and the least complicated arrangement for constructability, requiring no rubber dam or overhead service bridge.

In 2008, a subsequent numerical modeling study of the Muskrat Falls concept (MF1250) recommended some changes in the 2007 concept. These changes were not implemented until 2010 when it was decided to proceed with the development of Muskrat Falls prior to Gull Island.

In 2010, further studies were completed based on the decision to build the Muskrat Falls development prior to the Gull Island development. These studies have confirmed the Variant 10 arrangement. Optimization of the Variant 10 layout continues as detailed design progresses.

In addition because of the decision to build Muskrat Falls prior to Gull Island it was necessary to reassess the AC transmission line configuration. The original HVac transmission system proposed two 735 kV transmission lines from Gull Island to Churchill Falls and a 230 kV double-circuit from Muskrat Falls to Gull Island. The transmission line length between Muskrat Falls and Gull Island is approximately 60 KM making 230 kV a practical transmission voltage. In the current configuration Muskrat Falls will connect directly to Churchill Falls a distance of approximately 230 KM making transmission at 230 kV prohibitive because of the increased distance.

Based on this change, preliminary transmission system analysis was completed by the System Planning Department of Newfoundland and Labrador Hydro (NLH) to investigate ac transmission system in Labrador. Results of this analysis indicated a requirement for two 345 kV transmission lines between Muskrat Falls and Churchill Falls.

## 3. Reference Reports

For further details, a one to four page description of each of the following reports is attached:

MF1010 - Review of Variants
MF1050 - Spillway Design Review
MF1130 - River Operation during Construction and Impounding
GI1140 - PMF and Construction Design Flood Study (2008)
GI1190 - Dam Break Study (2008)
MF1250 - Numerical Modeling of the Muskrat Falls Structures (2008)
MF1300 - 2010 Site Investigations Geotechnical Report
MF1310 - Site Access Review
MF1320 - Estimate the Firm Generation Potential of the Muskrat Falls Development
MF1330 - Report 1: Hydraulic Model of the River - 2010 Update
MF1330 - Report 2: PMF & Construction Design Flood Study
MF1330 - Report 3: Dam Break Study
MF1330 - Report 4: Ice Study
MF1330 - Report 6: Regulation Study

## MF1010 – Review of Variants

The most recent study of the Muskrat Falls Hydroelectric Project was titled "Muskrat Falls Hydroelectric Development Final Feasibility Study Volume 1" (MF 1999 Study). This study reviewed a number of layout variants which resulted in three (3) variants being selected for further analysis; Variants 7, 10 and 11. After analysis of comparative costs, schedule and risk, Variant 7 was selected as the proposed alternative.

Variants 7, 10 and 11 all appeared feasible and were close in the final evaluation. The main deciding factor was the lack of early access to the south bank. Since the MF 1999 Study, a bridge has been constructed across the Churchill River, approximately 18 km downstream of the site. This would allow for a construction road to be built on the south shore, thereby enabling south shore access within three (3) months of commencing construction. The purpose of this study was to re-evaluate the variants based on this change in site access.

The final report based on this study was submitted to the NE-LCP group in March 2008.

## Major Findings

The design of Variants 10 and 11 is considered to be similar to that of Variant 7. All three (3) variants would utilize the same three (3) bay gated spillway and rubber dam on the overflow Roller Compacted Concrete (RCC) dam.

The powerhouse/spillway for variant 10 is located in the south abutment, allowing excavations to begin immediately after the south side access is afforded. No river diversion is necessary until Year 3 of the schedule, when the river flow would be passed through the spillway sluices temporarily without rollways. Variant 10 is characterized by large rock excavations from the approach and discharge channels. It would require a larger upstream cofferdam, but no diversion tunnels. Since the powerhouse/spillway structures are on the south abutment, the overflow section is located entirely on the north dam, comprising of both a fixed crest and rubber dam.

Variant 10 has several possibilities for optimization due to the spillway capacity being on the north dam. Submerged gates without rollways in the spillway would increase the flow capacity and negate the requirement for the rubber dam on the north dam. If a rubber dam is not needed on top of the overflow section, there would be no necessity for a service road to allow access to the top of the north dam. If the permanent access road is relocated to the south shore, the north side access road and its excavation in the steep rock hillside can be eliminated.

In its completed state, Variant 11 is the same as Variant 7 except that it would not have a diversion tunnel facility. Flows are diverted from a channel excavated through the north abutment, allowing the river channel to be cofferdammed for construction of the powerhouse and spillway. The river closure would be completed during a third stage diversion when the river is passed through the spillway sluices, temporarily without rollways. Variant 11 avoids the same tunnel diversion as that of Variant 7 and the large excavations of Variant 10, but the diversion channel completion is on the critical path. The powerhouse and gated spillway are the same as those for Variant 7.

## Conclusions and Recommendations

When comparing the costs of all three (3) variants, Variant 11 was ranked as the most economic option by less than 5%. Including equalization costs for differences in schedule and risk, Variant 10 was the most economic option by 21%.

Variant 10 was also considered to be the option with the least risk, followed by Variant 7 and then Variant 11.

Comparative schedules were developed for each of the Variants. It was found that Variant 10 had the shortest schedule duration and would achieve first power in 55 months and full power in 61.5 months. Variant 11 would achieve first power in 64 months and full power in 70.5 months, whereas Variant 7 would achieve first power in 65 months and full power in 72 months.

Variant 10 was recommended for further development based on having the least amount of risk, the lowest overall cost, and the shortest schedule duration.

It was also recommended in the MF 1999 study that a rubber dam should be used. Subsequent to this study it was concluded that there would be long term advantages for the Muskrat Falls plant to avoid the use of a rubber dam.

Note:
The NE-LCP group is no longer considering a rubber dam on the north overflow RCC dam due to concerns regarding its long term cost.

## MF1050 – Spillway Design Review

Variant 7 was recommended for the layout in the MF 1999 study; however, a further review of the Variant was required due to the construction of a highway bridge across the Churchill River. In MF1010, variants 7, 10 and 11 were re-evaluated and Variant 10 was recommended as the best selection.

Variant 10 included a three-bay gated spillway, an inflatable rubber dam and a fixed crest overflow spillway. The river diversion would be through the gated spillway structure. The purpose of this study was to review the Variant 10 spillway facilities.

The final report based on this study was submitted to the NE-LCP group in December 2007.

## Major Findings

The gates included in Variant 10 were larger than any known installation, therefore an array of gate sizes were identified which conformed to current maximum gate size parameters. This included both surface and submerged gates, vertical and radial types.

The design parameters for the spillway facilities were as follows:

- The gated spillway must pass the construction design flood without overtopping the upstream cofferdam required for the north dam construction;
- The gated spillway must control the winter diversion flows to maintain a forebay level at an elevation of 24 m for frazil ice control;
- The gated spillway must be able to pass the PMF along with the overflow facilities on the north dam, which may include a rubber dam and/or fixed crest spillway, without exceeding a forebay level of elevation 44 m.

The study of a number of alternative spillway layouts resulted in a shortlist of the following cases:

- Scheme 1a – a three bay gated spillway with surface vertical gates 13.75 m wide by 19.4 m high, a rubber dam 330 m long, and a fixed crest 115 m long;
- Scheme 1c – a five bay gated spillway with surface vertical gates 10.4 m wide by 21.5 m high, no rubber dam, and a fixed crest 429.5 m long;
- Scheme 1f – a five bay gated spillway with surface vertical gates 13.75 m wide by 17.7 m high, no rubber dam, and a fixed crest 409.3 m long;
- Scheme 3b – a four bay gated spillway with submerged radial gates 12.5 m wide by 14.8 m high, no rubber dam, and a fixed crest 433.2 m long.

## Conclusions and Recommendations

It is recommended that Scheme 3b be utilized as it is the most economic case and it has the least complicated arrangement for constructability. Scheme 3b does not require a rubber dam or an overhead service bridge; therefore it has lower operational costs.

To determine if detailed engineering should proceed on the basis of Scheme 3b, it is recommended to:

- Adjust the location of the spillway and powerhouse on the right bank in order to minimize the overall construction cost;
- Optimize the length of the spillway side walls upstream of the control structure for cofferdam abutment and secondary eddies in front of the intakes;
- Optimize the length of the spillway chute downstream of the control structure with 3D numerical hydraulic modeling;
- Establish the detailed spillway layout with a submerged radial gate, including the embedded pre-stressed cable system with the intermediate spillway piers;
- Review the cofferdam requirements around the spillway for its construction;
- Maintain the integrity of the foundation under the right wall of the spillway during both construction and operation.

## MF1130 – River Operation during Construction and Impounding

The purpose of this study was to determine the routing effect of the discharge facilities under flood conditions, analyze the average water levels expected during construction of the spillway, and determine reservoir impoundment times.

The final report based on this study was submitted to the NE-LCP group in January 2008.

## Major Findings

The reservoir filling scheme for Muskrat Falls involves no cessation of flow, as the strategy is to have spillway capacity available during reservoir impoundment. Therefore, dewatering of the downstream reach and potential salt water intrusion during reservoir filling is not expected to have the same level of concern as noted for the Gull Island development. It is recommended that these concerns be reviewed if any changes are made in the reservoir filling scheme.

The attenuating effect on the reservoir during construction has been investigated. In each of the three flood scenarios considered (1999 historic peak, 1/20 Annual Exceedance Probability (AEP) Construction Design Flood, and the 1/40 AEP Construction Design Flood), the peak water level was less than the current upstream cofferdam design elevation. Based on these results, if similar flow conditions are encountered during construction, the proposed cofferdam elevation of 25 m should be adequate.

The discharge capacity of the diversion facilities and storage curve for the Muskrat Falls reservoir has been provided by Hydro. It is proposed that diversion flows will be controlled by the sluiceway and have a total discharge capacity of 5,300 $m^3/s$ at an elevation of 21.7 m.

The objective of this analysis was to determine the routing effect of the discharge facilities, taking into account the attenuating effect of the local storage behind the upstream cofferdam, and the capacity of the diversion facilities.

For this analysis, three 31-day inflow hydrographs have been developed for the following scenarios:

- 1999 Historic Peak Inflow Hydrograph
- 1/20 Annual Exceedance Probability (AEP) Construction Design Flood (CDF) Inflow Hydrograph
- 1/40 AEP CDF Inflow Hydrograph

## Conclusions and Recommendations

The results indicate that, for all scenarios, the current cofferdam design elevation of 25 m would not be exceeded. A summary of the results is shown below:

- Peak Elevation 1999 Flows of 6220 $m^3/s$ is 22.8 m
- Peak Elevation 1/20 AEP CDF Flows of 5930 $m^3/s$ is 22.7 m
- Peak Elevation 1/40 AEP CDF Flows of 6500 $m^3/s$ is 23.8 m

The number of days required to fill the reservoir during impoundment has been calculated for each month. The total time ranged from 7 days (May) to 19 days (September).

## GI1140 – PMF and Construction Design Flood Study (2008)

The purpose of this study was to determine the Probable Maximum Flood (PMF) for both the Gull Island and Muskrat Falls sites. PMF hydrographs were developed and routed dynamically through the reservoirs formed by the dams. These hydrographs were developed in order to estimate the spillway design capacity required at each site. The scope included a review of previous studies on the Upper and Lower Churchill Basins and a meteorology study to estimate the contributors to the PMF. The scope also included detailed hydrological modeling of the entire Churchill River Basin to estimate the Gull Island and Muskrat Falls PMF peaks.

This study also reviewed the diversion discharge capacity requirements at each site during the periods of construction.

The final report based on this study was submitted to the NE-LCP group in February 2008.

### Major Findings

A watershed model of the Churchill Basin was used to test various combinations of extreme rainfall, temperature and snowpack. This was recommended by the Canadian Dam Association (CDA) to determine the governing PMF case.

The critical PMF scenario for the Upper and Lower Churchill Basin was a combination of:

- A 100-year snowpack;
- A severe temperature sequence; and
- A spring Probable Maximum Precipitation (PMP)

PMF hydrographs developed from the watershed model for the Upper Churchill Basin were routed through the Churchill Falls complex using a decision based operation model to implement the flood handling procedures for Smallwood and Ossokmanuan Reservoirs. A dynamic hydraulic model was then used to route the resulting Upper Basin outflow hydrographs, and the Lower Basin inflow hydrographs from the major tributaries, through the lower Churchill River. The hydraulic model was calibrated using survey data and historical flood data, and then run with the critical PMF hydrographs for the pre-project and post-project conditions on the river.

## Conclusions and Recommendations

Addition of the dams, with the configurations given in the feasibility studies, resulted in dynamically routed PMF peaks of 20,800 $m^3/s$ and 22,420 $m^3/s$ at Gull Island and Muskrat Falls, respectively.

The current flood handling procedures for the Churchill Falls project were established in 1989 using a 1969 estimate of the PMF. Based on this PMF study, it was suggested that these flood handling procedures could be revised to reduce the flood peaks at Gull Island and Muskrat Falls by approximately 2000 $m^3/s$.

A review of the construction design floods at the project sites yielded the following conclusions:

- No spill from the Upper Basin would be required during a 40-year design flood in the Lower Basin.
- Diversion discharge capacities at the project sites must be capable of passing the 40-year local inflow peak at each site plus the minimum acceptable powerhouse flow from Churchill Falls.
- The 40-year local inflow flood peaks have been estimated as 4,480 $m^3/s$ at Gull Island and 4900 $m^3/s$ at Muskrat Falls.
- The 20-year local inflow flood peak has been estimated as 4,510 $m^3/s$ at Muskrat Falls.

The following recommendations were also made:

- Any new variants to the project configurations should be tested with the post-project dynamic hydraulic model for their ability to safely pass these floods.
- The Churchill Falls 1989 Flood Handling procedures should be updated before the start of construction of the Lower Churchill Project.
- The minimum acceptable turbine flow at Churchill Falls during construction should be established with CF(L)Co.
- A flood forecasting procedure should also be developed for the lower Churchill River, coupled with a unit shut down procedure at Churchill Falls, to minimize the flood peaks at each site during the construction period.
- Upon completion of these recommendations, the capacity of the diversion tunnels should then be reviewed.

## GI1190 – Dam Break Study (2008)

The purpose of this study was to analyze various dam breach scenarios, the results of which were used to prepare inundation mapping for the potential flood areas. In addition, an assessment of potential environmental, structural, economic and social impacts on downstream property and inhabitants was carried out. The maps and completed assessment were based on the PMF, "Fair Weather" condition and the assumption that dam breaches would occur in cascade. All of these factors are specified by the 2007 Canadian Dam Association Dam Safety Guidelines.

These studies involved the use of GIS tools and various data sources in the setup of a hydrodynamic routing model. The model developed for GI1110 "Hydraulic Model of the River" and the work completed by GI1140 "PMF and Construction Design Flood Study", formed inputs for this study.

The model developed is capable of simulating dam breach flood waves and was used to model hypothetical dam breaches at both Gull Island and Muskrat Falls. The results of the dam breach modeling were used to prepare inundation mapping for Emergency Preparedness Plans and to assess the overall consequences of failure for both Gull Island and Muskrat Falls.

The final report based on this study was submitted to the NE-LCP group in April 2008.

## Major Findings

Several scenarios were required to adequately represent the number of potential dam breach combinations that could occur along the lower Churchill River. Three (3) conditions were investigated:

<u>Dam breach during the Inflow Design Flood (PMF for Gull Island and Muskrat Falls)</u>
For the PMF breach scenarios, it was assumed that each dam would fail at the peak of the passage of the development's Inflow Design Flood (IDF) – the Probable Maximum Flood (PMF).

<u>Dam breach during "Fair Weather" conditions</u>
For the "Fair Weather" breach scenarios, it was assumed that each dam would fail during a normal or typical operating condition. Inflows from the Upper Churchill project and local tributaries would be held constant during the dam failure and resulting flood wave progression.

Dam breaches in cascade

Dam breaches in cascade would include a dam failure at Gull Island, which causes a cascade failure at Muskrat Falls.

To estimate the impact a dam breach would have on downstream water levels, the following scenarios were selected for simulation for both the PMF and "Fair Weather" conditions:

- a breach at Gull Island prior to the construction of Muskrat Falls
- a breach at Gull Island after the construction of Muskrat Falls
- a breach at Muskrat Falls
- a breach at Gull Island causing a cascade failure at Muskrat Falls

## Conclusions and Recommendations

It is recommended that:

- The NE-LCP group should coordinate dam breach studies with CF(L)Co with regards to Upper Churchill failure scenarios.
- The dam break model and inundation mapping should be updated prior to the preparation of Emergency Preparedness Plans. This update would take into consideration any changes to the project layouts.
- The NE-LCP group should conduct a dam breach analysis for construction activities (cofferdams). The CDA Guidelines note that for significant cofferdams, Emergency Preparedness Plans would be required.

## MF1250 – Numerical Modeling of the Muskrat Falls Structures (2008)

The purpose of this study was to review the various structures of the variant proposed in MF1050 by numerical modeling. The proposed variant was Variant 10.

The various facilities related to Variant 10 were analyzed and improved where necessary. These facilities include:

- Diversion channels;
- Powerhouse (approach channel and tailrace channel);
- Spillway (sluices and overflow crest).

The final report based on this study was submitted to the NE-LCP group in May 2008.

### Major Findings

Numerical modeling has indicated that the proposed approach channel for the diversion facilities should be modified to improve flow conditions for the left sluices. The addition of a curved wall improves the flow conditions and increases the discharge capacity of the system.

The flow pattern of unit No. 1 (near the spillway) at the power intake is disturbed by a strong lateral velocity, which could reduce the unit efficiency. Following consideration of various configurations, it appears that a longer and higher retaining wall would be required, combined with an increase in excavation of the approach channel. This alternative improves hydraulic conditions at the power intake considerably; however, it should be further optimized to minimize the construction costs.

An analysis of the spillway facilities indicated the presence of a vortex upstream of sluice No. 1. This vortex disturbs the flow pattern and would most likely reduce the discharge capacity of the system.

### Conclusions and Recommendations

Final optimization of the layout should be performed by numerical and/or physical modeling following the review of the layout based on an update of the hydraulic conditions at Muskrat Falls.

## MF1300 – 2010 Site Investigations Geotechnical Report

These reports present the field data and laboratory test results obtained during the 2010 site investigation program carried out at the site of the proposed Muskrat Falls Hydroelectric Development on the Churchill River in Labrador. It consists of 10 volumes in total:

| | |
|---|---|
| Volume 1 | Muskrat Falls 2010 Site Investigations – Geotechnical Report General Report |
| Volume 2A | Muskrat Falls 2010 Site Investigations – Geotechnical Report North RCC Dam, Spillway and Channels |
| Volume 2B | Muskrat Falls 2010 Site Investigations – Geotechnical Report Powerhouse and Channels, South RCC Dam |
| Volume 2C | Muskrat Falls 2010 Site Investigations – Geotechnical Report Switchyard, Converter Station, Accommodations Complex |
| Volume 2D | Muskrat Falls 2010 Site Investigations – Geotechnical Report Borrow Areas GR-5, GD-7, GD-8, GD-10, GD-11, TD-4, TD-5, TD-6, TD-7, TD-8, and TD-11 |
| Volume 3A | Muskrat Falls 2010 Site Investigations – Geotechnical Report Acoustic and Optical Televiewer Surveys Text, Appendix I Appendix II |
| Volume 3B | Muskrat Falls 2010 Site Investigations – Geotechnical Report Acoustic and Optical Televiewer Surveys Appendix III |
| Volume 4 | Muskrat Falls 2010 Site Investigations – Geotechnical Report Air Photo Interpretation Report Resistivity Surveys |
| Volume 5 | Muskrat Falls 2010 Site Investigations – Geotechnical Report Laboratory Testing Results |
| Volume 6 | Muskrat Falls 2010 Site Investigations – Geotechnical Report Drawings |

The field investigation program involved drilling through overburden and bedrock, test pitting, portable hammer sounding (Pionjar) and resistivity surveys at the proposed sites of the dam and related structures (powerhouse, spillway and channels, switchyard and converter station), at the site of the accommodations complex and at borrow areas on the south side of the river. Also included were topographic surveys of the north spur and major stream crossings on the proposed access road to the project site from the Trans Labrador Highway.

## Major Findings

The site investigations were intended to collect all the outstanding data needed for the project design. The field work started August 3, 2010 and was completed on October 19, 2010.

The soils investigations focused on the stratigraphic nature and the geotechnical characterization of the overburden, and bedrock investigations focused on rock mass structures and permeability that could affect underground and open pit excavations. Sampling and testing were carried out with modern procedures, which are defined in the various volumes of the report. Sampling and testing included the following:

- Resistivity surveys at the proposed sites for the powerhouse and the switchyard at Muskrat Falls.
- 120 test pits, excavated at the sites of the main structures (dam, powerhouse, switchyard, converter station, spillway and channels) at the accommodations complex and at the borrow areas (granular and till).
- 15 soundings with a portable hammer drill (Pionjar) were carried out at the sites of the north RCC dam (3 soundings), and at the accommodation complex (12 soundings).
- 51 vertical, or inclined, boreholes drilled during the course of the 2010 site investigation at Muskrat Falls. This includes three boreholes along the Churchill River's north bank for the investigation of the north RCC dam, and 48 boreholes drilled on the south bank, for the investigation of the structures and channels distributed as follows: the powerhouse and channels (13), the south RCC dam (9), the switchyard (7), the converter station (11) and the accommodations complex (8).
- A partial characterization of the soil, as well as the profile of soil resistance, was obtained by standard penetration tests at 38 borehole locations. SPT results are presented with the respective borehole logs in Volumes 2A, 2B and 2C.
- The determination of soil resistance was also obtained by dynamic cone penetration tests (DCPT) in 20 boreholes. Shelby tubes were used to recover intact clay samples at the site of the converter station, on the south shore.
- Water pressure tests, in 17 boreholes, were conducted with the objective of evaluating the rock mass permeability in almost all the inclined boreholes.
- Special camera equipment was used in order to better define the rock mass structure. This equipment enabled the viewing of discontinuities, such as joints, faults and intrusions, as well as the presence of gouge and discontinuity openings.
- Televiewer surveys using acoustic and optical probes were carried out inside 17 boreholes in order to measure the position, thickness and orientation (strike and dip) of structural features.
- Laboratory tests were carried out on rock samples recovered from boreholes. The objectives of these tests were to:
    - Determine mechanical properties of rock as required for cut and support design; and
    - Validate the use of crushed rock as concrete coarse aggregate.

- Some 13 borrow areas were also investigated for characterization of available construction materials (till and granular materials).

## Conclusions and Recommendations

The Muskrat Falls site is located approximately 30 km west-southwest of Goose Bay. Bedrock is present on both sides of the river, forming extensive outcrops. A bedrock ridge crosses the river parallel to the projected dam axis, forming the falls. Summarized results of the investigations at the sites of the dam and related structures, at the site of the accommodations complex and at the borrow areas are shown in Tables 1 and 2.

**Table 1: Summary of Borehole and Test Pit Results (Minimums and Maximums only)**

| Location | Overburden | Sand and/or Gravel, Clay | Bedrock | RQD | | Absorption (l/min/m) | | Hammer Blows (Pionjar) |
|---|---|---|---|---|---|---|---|---|
| | (Thickness in m) | Depth from surface to top (m) | Depth from surface to top (m) | Depth from surface to reading (m) | Value (%) | Depth (m) | Value | Refusal Depth (m) |
| North RCC Dam | 0.00 – 7.03 | | 0 – 7.03 | 0.77 - 180.27 | 0 - 100 | 3.6 – 169.31 | 5 – 12.5 | 1.34 – 8.10 |
| South RCC Dam | 0.00 – 5.19 | 0 – 5.19 | 3.82 – 15.15 | 2.16 – 17.05 | 43 - 100 | 5.70 – 11.98 | 0.1 – 2.2 | - |
| Spillway and Channels | 0.00 – 0.85 | 0 – 2.43 | 0 – 2.43 | 0 – 55.09 | 25 - 100 | 3.00 – 53.58 | 0 – 12.7 | - |
| Powerhouse and Channels | 0.05 – 8.60 | 0 – 5.18 | 0.05 – 8.98 | 3.26 – 71.03 | 40 - 100 | 5.26 – 69.04 | 0 – 12.3 | - |
| Converter Station | 0.61 – 4.27 | 0 – 3.05 | 0.47 - 14.72 | 0.47 – 25.59 | 59 - 96 | - | - | 2.06 – 18.26 |
| Switchyard | 0.00 – 3.05 | 0.00 – 6.40 | 12.85 | 4.61 – 23.00 | 65 - 100 | - | - | 2.69 – 5.89 |
| Accommodations Complex | 0.23 – 4.88 | 0.23 - 1.83 | - | - | - | - | - | 4.27 - 6.71 |

In 2010, a total of 13 borrow areas were investigated, consisting of 8 till deposits (TD-4 to TD-11) and 5 granular material deposits (GD-6, GD-7, GD-8, GD-10, GD-11 and GR-5). Of those, 2 till deposits (TD-9, TD-10 and TD-11) were rejected, due to the presence of numerous rock outcrops at the surface; see Table 2 below:

## Table 2: Summary of Borehole and Test Pit Results (Minimums and Maximums only)

| **Borrow Area** | **Distance from Churchill River (km)** | **Distance from Muskrat Falls (km)** | **Shortest Distance to TLH (Trans Lab. Highway) or AR (Access Road)** | **Soil Type(s)** S(Sand),SS(Silty Sand) G(Gravel),C(Cobbles) B(Boulders),T(Traces) CL(Clay) | **Area ($m^2$)** | **Thickness of Suitable Material (m)** | **Volume ($m^3$)** |
|---|---|---|---|---|---|---|---|
| GR-5 | 5.5 (NW) | 10 (W) | 1.2 (TLH) | G, S, C | 417,000 | 1.5 – 1.8 | 285,000 |
| GR-7 | 2.5 (S) | 8.5 (SE) | 0 (AR) | SS, S, G, C, B | 900m x (150 to 200m) | Not suitable for fill or concrete fine aggregate | |
| GR-8 | 3.3 (S) | 7.3 (SE) | 2.7 (S) (AR) | G, S, C, B | 162,500 | 1.8 | 117,000 |
| GR-10 | 2.5 (S) | 3.3 (SE) | 2.0 (AR) | S, SS, TG | 650m x 250m | Not suitable for fill or concrete aggregate | |
| GR-11 | 1.7 (S) | 2.6 (SE) | 1.3 (S) (AR) | S, SS, TG, C | 218,000 | 2.0 | 207,000 |
| TD-4 | 3.5 (S) | 11.6 (E) | 0.650 (N) (AR) | SS, G | 212,400 | 2.30 | 220,000 |
| TD-5 | 4.1 (S) | 10.4 (E) | 0.320 (S) (AR) | S, G, TSS,C,B | 850m x 200m | Not suitable for impervious fill | |
| TD-6 | 3.3 (S) | 10.0 (E) | 0.10 (N) (AR) | SS, G, TCL, C, B | 39,200 | 2.10 | 37,000 |
| TD-7 | 3.0 (S) | 9.2 (S) | 0 (AR) | SS, TG, C, B | 105,000 | 2.20 | 110,000 |
| TD-8 | 1.6 (S) | 7.2 (SE) | 0.15 (S) (AR) | S, SS, TG, C, B | 600m x (120 to 80m) | Not suitable for impervious fill | |

## MF1310 – Site Access Review

The purpose of this report is to review the following:

- The docking facilities in Cartwright to determine if they can accommodate the transport of a 250 tonne load.
- The Trans Labrador Highway (TLH) from Cartwright to the proposed Muskrat Falls access road to determine if the highway bridges and culverts can accommodate the transport of a 250 tonne heavy load.
- Routing for the permanent Muskrat Falls access road from the TLH to the Muskrat Falls project site.

## Major Findings

Due to the findings from the MF 1090 study, NE-LCP has decided that access to the Muskrat Falls project site shall be via a new permanent access road from the TLH along the south side of the Churchill River to the project site.

With the completion of the TLH between Happy Valley Goose Bay and Cartwright, another option to transport heavy loads to the Muskrat Falls dam site is now available. This option includes utilizing the dock in Cartwright and transporting heavy loads via the TLH and the new permanent access road.

The transport of a 250 tonne transformer was modeled, as it is assumed to be the heaviest load which will need to be transported.

With respect to the dock at Cartwright, it was concluded that the transformer can be offloaded but it will be necessary to provide a temporary ramp when offloading the transformer.

A general condition assessment should be performed on the ferry terminal, prior to offloading, to evaluate the condition of all fenders, mooring bollards and sheet piles present at the docking facility. Any deficiencies should be repaired and any assumptions used in the analysis should be confirmed.

Any vessel used during offloading of the transformers, or any other material, should be of sufficient length to engage the waterside mooring dolphin. If not, alternate mooring arrangements will be required.

The dock at Cartwright is owned by the Department of Transportation and Works (T&W) and they will do their own assessment before giving permission to offload the transformer.

The TLH between Cartwright and the proposed access to Muskrat Falls has eight bridges. Starting at Cartwright and proceeding toward the west, the bridges are located on Dykes River, Southwest Brook, Beaver Brook, Paradise River, Otter Brook, Kenamu River, Traverspine Tributary, and Traverspine River. The Paradise River and Kenamu River bridges are both constructed of steel while the rest are constructed from concrete. The analysis revealed that the concrete bridges have sufficient strength to allow the passage of the truck and transformer.

The Paradise River Bridge is not capable of supporting the required load. The bridge is only capable of supporting a maximum of 190 tonnes of cargo for the assumed trailer weight of 48 tonnes. Initially, Mabey Johnson (designer and supplier of the steel truss bridge) stated that the bridge could not be strengthened because of the unique design of the steel panels. Subsequently, they said they would be willing to look at using temporary supports but not guarantying that it would be possible.

The Kenamu River Bridge is not capable of supporting the transformer load, and is only capable of supporting a maximum load of 130 tonnes of cargo for the assumed transporter weight of 48 tonnes. It may be possible to reinforce the structure to support larger loads but it would require further analysis.

The bridges are owned by T&W and they will do their own assessment before giving permission to transport the transformer.

The recommended access road route is Route 2A, at a cost of $9,690,300 due to lower user costs, proximity to granular deposits for road building materials, till for the cofferdams and a safer intersection with the TLH.

## Conclusions and Recommendations

Sheet pile thicknesses should be checked to confirm corrosion rates assumed in the analysis.

The Provincial Government has recently announced that the ferry service into Cartwright is being terminated. If this is so, long term maintenance of the ferry terminal, and in particular to RoRo aspect of the dock, may become an issue. NE-LCP should liason directly with the Department of Transportation and Works to discuss long term plans for the maintenance of the dock.

## MF1320 – Estimate the Firm Generation Potential of the Muskrat Falls Development

This study assessed the firm energy delivery that the Muskrat Falls (MF) plant could yield at two different delivery points, under the critical hydrologic sequence, while subject to inflow patterns produced from a Churchill Falls (CF) Plant production profile and co-ordinated operation of the two plants. The study accounted for both the presence and/or absence of the Gull Island (GI) reservoir. Within each simulation that included, or omitted, the GI reservoir, two scenarios were evaluated. The first scenario estimated the firm deliveries to the Hydro Quebec (HQ) system, which included HQ's demand requirements as specified by the Guaranteed Winter Availability Contract (GWAC). The second undertakes a similar analysis with the firm determined at the MF high voltage bus.

## Major Findings

Five runs were performed. The first used the long term weekly model (LT Vista) to identify the critical period over the 50-years of hydrology (1957 to 2007). This critical sequence was determined to be October 1984 to April 1996. The remaining four runs were performed using the hourly AUTO Vista model to provide detail within the critical period identified. Of these, the first two runs included operations with the Gull Island Reservoir in place (but without the GI plant) along with MF and CF. The subsequent two runs excluded the GI Reservoir.

A summary of results is provided in Table 1.

**Table 1: Summary of Run Results**

| Scenario | TwinCo Load MWc | Recall Load MWc | HQ Load MWc | Stn. Loss MWc | Line Loss | Firm Est. MWc | Generation MWc (TWh) | | Outcome |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | CF | MF | |
| **LT Vista Run** Both CF and MF Plants can be used to meet Load Req. | 225 | 270 | 3053 | 11.9 | Not Applied | 620 | 3640 (31.88) | 540 (4.73) | Critical period identified as Oct. 1984 to Apr 1996 |
| | 1.97 TWh | 2.37 TWh | 26.75 TWh | 0.10 TWh | | 5.43 TWh | | | |
| | 31.09 TWh | | | | | | | | |
| **Coordinated** Both CF and MF Plants can be used to meet | 225 | 270 | 3053 | 11.9 | Yes | 510 | 3599 (31.53) | 521 (4.56) | MF firm lower than in LT because of line losses |
| | 1.97 TW | 2.37 TWh | 26.75 TWh | 0.10 TWh | | 4.47 TWh | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| load Req. Firm calculated at **MF Bus With GI reservoir(GI Plant not included)** | h | | | | | | | | and more refined estimation. |
| | 31.09 TWh | | | | | | | | |
| **Coordinated** Both CF and MF Plants can be used to meet load Req. Firm calculated at **HQ Bus With GI reservoir(GI Plant not included)** | 225 | 270 | 3053 | 11.9 | Yes | 505 | 3599 (31.53) | 521 (4.56) | MF firm lower than in the previous scenario because of additional line losses in meeting the firm at Montagnais bus. |
| | 1.97 TWh | 2.37 TWh | 26.75 TWh | 0.10 TWh | | 4.42 TWh | | | |
| | 31.09 TWh | | | | | | | | |

**Table 1: Summary of Run Results (Continued)**

| Scenario | TwinCo Load MWc | Recall Load MWc | HQ Load MWc | Stn. Loss MWc | Line Loss | Firm Est. MWc | Generation MWc (TWh) | | Outcome |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | CF | MF | |
| **Coordinated** Both CF and MF Plants can be used to meet load Req. Firm calculated at **MF Bus Without GI reservoir** | 225 | 270 | 3053 | 11.9 | Yes | 515 | 3609 (31.61) | 523 (4.58) | MF firm lower than in LT because of line losses and more refined estimation |
| | 1.97 TWh | 2.37 TWh | 26.75 TWh | 0.10 TWh | | 4.51 TWh | | | |
| | 31.09 TWh | | | | | | | | |
| **Coordinated** Both CF and MF Plants can be used to meet load Req. Firm calculated at **HQ Bus Without GI reservoir** | 225 | 270 | 3053 | 11.9 | Yes | 510 | 3609 (31.61) | 523 (4.58) | MF firm lower than in the previous scenario because of additional line losses in meeting the firm at Montagnais bus. |
| | 1.97 TWh | 2.37 TWh | 26.75 TWh | 0.10 TWh | | 4.47 TWh | | | |
| | 31.09 TWh | | | | | | | | |

## Conclusions and Recommendations

### With and Without the Gull Island Reservoir

- Overall production at CF was approx. 3600 MWc (31.54 TWh) with the GI Reservoir.
- Overall production at CF was approx. 3610 MWc (31.62 TWh) without the GI Reservoir.
- The GI Reservoir resulted in a slight reduction in production at CF due to head loss at CF.
- With the backwater effect caused by the GI Reservoir, the CF plant head is roughly reduced on average by about 1.45 m, with a power loss equivalent of about 10 MWc. This loss in energy output at CF results in a higher contribution requirement by the MF plant to meet load and ultimately less export (firm delivery) capability. (Note: This conclusion assumes a legal interruption of parties' rights which has not been adopted by Nalcor.)
- Firm Energy at MF is slightly higher without the presence of the GI reservoir.

### Firm Delivery Point

- Two firm energy delivery points were assessed, these included delivery at the MF bus and delivery at the HQ bus. For both scenarios, results with and without the GI Reservoir indicated that delivery to the HQ bus would result in an additional transmission loss of approximately 5 MWc.
- The system firm delivery is generally independent of the location of the delivery point for the transmission line configuration chosen, save losses, and slightly dependent on the presence of the GI Reservoir.
- Overall production at MF was approx. 521 MWc (4.56 TWh) with the GI Reservoir.
- Overall production at MF was approx. 523 MWc (4.58 TWh) without the GI Reservoir.
- With respect to the delivery point and the presence / absence of the GI reservoir, the firm energy delivery of the system under coordinated operations is summarized below:

**Table 2: Firm Energy Delivery (Coordinated Operation)**

| | Delivery to MF bus | Delivery to HQ bus |
|---|---|---|
| With Gull Island Reservoir | 510 MWc (4.47 TWh) | 505 MWc (4.42 TWh) |
| Without Gull Island Reservoir | 515 MWc (4.51 TWh) | 510 MWc (4.47 TWh) |

- With the GI reservoir in place the average spills at MF over the critical hydrologic sequence are 56.50 $m^3/s$ and 56.72 $m^3/s$, for delivery to the MF bus and HQ Transmission bus respectively.
- Without the GI reservoir in place the average spills at MF over the critical hydrologic sequence are 57.01 $m^3/s$ and 56.69 $m^3/s$ for delivery to the MF bus and HQ Transmission bus respectively.

## Recommendation

The results presented in the report were dictated by the parameters of the system (such as, line limits, line losses, unit efficiencies, unit capabilities) defined in the Vista model. The system parameters used in the present study are the planning stage values available at the commencement of the study. It was recommended to rerun the model, with parameters firmed up in the detail design phase, to obtain more representative results.

## MF1330 – Report 1: Hydraulic Model of the River – 2010 Update

Nalcor Energy – Lower Churchill Project (NE-LCP) is undertaking preliminary engineering studies for the development of the hydroelectric potential on the Lower Churchill River at Gull Island and Muskrat Falls. As part of these studies, Hatch has developed a numerical geo-referenced HEC-RAS open water hydraulic model of the Lower Churchill River. The model was originally developed in 2007 under GI1110 and had been used to analyse the hydraulic regime in several other studies. Since 2007 there have been updates to project layouts and additional bathymetry, and nautical charts and hydrometric data have become available. The objective of this study was to update the hydraulic model based on this new information.

## Major Findings

Eighty new cross sections were added to the model, based on bathymetric surveys completed in 2006 and 2007. Calibration of the model for a range of flows provided for a successful calibration over the entire modeled reach. In some regions the updated model provided a better representation of measured water levels than the original model, and in some regions there was no difference. Hatch now has a greater level of confidence in the model geometry as a result of sections, based on 1970s bathymetric surveys, having been replaced with sections from the 2006 and 2007 surveys.

In addition to the new survey information, the hydraulic model was extended at the downstream end to the coast of Labrador, based on nautical charts. Also updated structure details (see table 1) were incorporated into the hydraulic model to assess the hydraulic regime at every stage of development of the two projects, whether Muskrat Falls or Gull Island is constructed first.

**Table 1: Structures Details**

| Structure | Dam Crest Elevation | Discharge Facility | Sill Elevation |
|---|---|---|---|
| Muskrat Falls Cofferdam | 26 m | 4 Spillway Gates<br>(12.5 m wide x 14.8 m high) | Gates: 5 m |
| Muskrat Falls Main Dam | 45.5 m South<br>39.5 m North | 4 Spillway Gates<br>(12.5 m wide x 14.8 m high)<br>Overflow North Dam (430 m long) | Gates: 5 m<br>Overflow North Dam: 39.5 m |
| Gull Island Cofferdam | 61.4 m | 2 inverted U-shaped Diversion Tunnels<br>(14m wide x 20.15 m high) | Tunnels: 16 m |
| Gull Island Main Dam | 129 m | 8 Spillway Gates<br>(12.9 m wide x 20.1 m high) | Gates: 105.1 m |

Both steady state and unsteady state versions of the GI1110 hydraulic model were updated as part of this work. In a steady state model, flow does not vary with time. In an unsteady model, the variation of flow over time is simulated. For example; in the propagation of a natural or dam breach flood.

There are areas in which simulated water levels differed from observed levels. These discrepancies have not been a concern for the studies completed to date, but were noted.

## Conclusions and Recommendations

The hydraulic model, originally developed under GI1110, had been updated to include additional project layout options and newly available bathymetric and hydrometric data. In total, eighty new cross sections were added to the model. These sections replaced some sections in the original model that were based on much older bathymetric data, and filled data gaps for some parts of the river where bathymetry data was not previously available. A successful calibration was achieved for the updated model over the entire modelled reach.

The result of this study was an up-to-date hydraulic model that can be used for the prediction of velocities and water levels throughout the Lower Churchill River. The model will be used for other MF1330 studies including the following:

- Report 2 - Muskrat Falls Probable Maximum Flood (PMF) and Construction Design Flood (CDF) Study – 2010 Update
- Report 3 - Muskrat Falls Dam Break Study – 2010 Update
- Report 4 - Muskrat Falls Ice Study – 2010 Update
- Report 5 - Gull Island Construction Design Flood Study

## MF1330 – Report 2: PMF & Construction Design Flood Study

Hatch had originally developed estimates of the probable Maximum Flood (PMF) and Construction Design Flood (CDF) at the Muskrat Falls site, as part of GI1140. In GI1140 it was assumed that the Muskrat Falls (MF) hydroelectric facility would be constructed after the Gull Island (GI) hydroelectric facility. The objective of the present study was to revisit the PMF and CDF for Muskrat Falls, assuming that Muskrat Falls is constructed before Gull Island.

## Major Findings

The study simulated the dynamic hydraulic routing of the PMF and CDF inflows along the Lower Churchill River, using the HEC-GeoRAS model as updated in MF1330 – Report 1: Hydraulic Modeling of the River. Updates included the latest revised project layouts and enhancements of the HEC-GeoRAS model geometry. Using information from GI1140, in conjunction with the updated model, Hatch created the following simulations:

Probable Maximum Flood

- **Pre-project PMF routing**

The pre-project scenario was run to verify consistency with the pre-project PMF estimates in GI1140 (Hatch 2007). The resulting simulated pre-project peak flows are shown in Table 1 and are comparable to the pre-project peak flows from GI1140.

**Table 1: Pre-Project PMF Peak Inflows**

| Location | MF1330 (2010) Peak Inflow ($m^3/s$) | GI1140 (2007) Peak Inflow ($m^3/s$) |
|---|---|---|
| Gull Island | 24,230 | 24,260 |
| Muskrat Falls | 26,060 | 26,020 |

- **Muskrat Falls PMF routing without Gull Island**

In this scenario, it was assumed that the water level at MF would be maintained at the Full Supply Level (FSL) of 39.0 m, by opening spillway gates until the gate capacity was exceeded, at which time the reservoir surcharged and the north dam overflow came into play. The plant discharge capacity was excluded from the simulation.
The resulting simulated peak outflow at MF was 25,060 $m^3/s$, at a water level of 44.78 m. With the MF dam in place, there was a downstream reduction in the pre-development peak flow of 1,000 $m^3/s$, or 4 percent.

- **Post-Project PMF routing**

The post-project scenario with both GI and MF was run to determine the further attenuation that would result from the GI reservoir. It was assumed that the water level at GI would be maintained at a FSL of 125.0 m for as long as possible, by opening gates and allowing the reservoir to surcharge once the spillway capacity is exceeded. The plant discharge capacities of both facilities were omitted from the simulation. The resulting simulated peak outflow at MF was 23,270 m³/s and the simulated peak water level was 44.29 m.

The simulated peak outflows and water levels at MF are summarized in Table 2. Without the GI reservoir the peak water level at MF is 0.49 m higher, and the peak outflow is approximately 8 percent larger, than with the GI reservoir.

**Table 2: Muskrat Falls PMF**

| **Scenario** | **Pre-Project** | **MF without GI** | **Post-Project (MF with GI)** |
|---|---|---|---|
| Peak Outflow (m³/s) | 26,060 | 25,060 | 23,270 |
| Peak WL (m) | - | 44.78 | 44.29 |

- **Estimated Required Spill Capacity**

The estimated peak water level of 44.78 m (without GI) is of concern, as it exceeds the target design maximum flood level (MFL) of 44.0 m (SNC-Lavalin 2007). However, the target MFL was met, using a model simulation with five gates, each with a design capacity of 3,200 m³/s, and an overflow section with a design capacity of 8,800 m³/s, for a total design capacity of 24,800 m³/s, at a MFL of 44.0 m.
The simulated peak outflows and water levels at MF, with increased spill capacity, are summarized in Table 3 below.

**Table 3: Muskrat Falls PMF with Increased Spill Capacity**

| **Scenario** | **Pre-Project** | **MF without GI** | **Post-Project (MF with GI)** |
|---|---|---|---|
| Peak Outflow (m³/s) | 26,060 | 24,770 | 23,080 |
| Peak WL (m) | - | 43.93 | 43.42 |

Construction Design Flow

- **Pre-project Flood Routing**

Statistical flood frequency analysis was done on a 30-year data set of annual maximum instantaneous flows for the Churchill River, at the MF hydrometric station (03OE001), to estimate the annual exceedance probability (AEP) flood peaks.

The estimated 1:20, 1:40 and 1:60 AEP flood peaks at MF are shown in Table 4 below.

**Table 4: Muskrat Falls AEP Flood Peak Frequency Estimates**

| **Peak Inflow (Pre-Project)** | **1:20 AEP** | **1:40 AEP** | **1:60 AEP** |
|---|---|---|---|

| | | | |
|---|---|---|---|
| Local | 4,520 $m^3/s$ | 4,830 $m^3/s$ | 5,000 $m^3/s$ |
| Total | 5,910 $m^3/s$ | 6,250 $m^3/s$ | 6,430 $m^3/s$ |

- **Muskrat Falls CDF Routing without Gull Island**

The resulting simulated peak outflow at the MF diversion, without the GI facility in place, was estimated to be 5,890 $m^3/s$, with a simulated peak water level of 22.78 m.

- **Muskrat Falls CDF Routing with Gull Island**

With the GI facility in place, and with the water level maintained at a FSL of 125.0 m, the peak outflow at the MF diversion would be 6,020 $m^3/s$, with a simulated MF peak water level of 23.04 m.

## Conclusions and Recommendations

The conclusions of the study are as follows.

- The simulated pre-project PMF peak inflow at the Muskrat Falls site is 26,060 $m^3/s$;
- For the current (MF1050) Muskrat Falls configuration, but without the upstream Gull Island facility, the simulated PMF peak outflow is 25,060 $m^3/s$ and the peak water level is 44.78 m;
- For the current (MF1050) Muskrat Falls configuration, with the upstream Gull Island facility, the simulated PMF peak outflow is 23,270 $m^3/s$ and the peak water level is 44.29 m. Therefore, without the attenuating effect of the Gull Island reservoir, the peak water level at Muskrat Falls is 0.49 m higher, and the peak outflow at Muskrat Falls is approximately 8 percent larger than with the Gull Island reservoir;
- To limit the peak water level at Muskrat Falls in the PMF (without Gull Island) to 44.0 m, the estimated required spillway design discharge capacity is 24,800 $m^3/s$;
- The estimated CDF (1:20 AEP peak inflow) at the Muskrat Falls site is 5,910 $m^3/s$; and
- For the Muskrat Falls construction diversion, without the upstream Gull Island facility, the simulated CDF peak outflow is 5,890 $m^3/s$ and the peak water level is 22.78 m.

## MF1330 – Report 3: Dam Break Study

The objective of this study was the completion of a dam break analysis, inundation mapping, and consequence assessment for the Muskrat Falls (MF) Dam, assuming the upstream Gull Island development was not yet constructed. Updates to the project layout and spillway capacity that have been made since the 2008, GI1190 - Dam Break Study (Completed for the Nalcor Energy – Lower Churchill Project (NE-LCP) by Hatch) were included in the current study.

## Major Findings

The HEC-GeoRAS hydraulic model, updated as part of MF1330, and the MF project layout Variant 10, Scheme 3b configuration from MF1050 – Spillway Design Review, were used to simulate the dam breach flood wave downstream of the MF Dam. Two MF dam breach scenarios were simulated: “Fair Weather” conditions and Inflow Design Flood (Probable Maximum Flood - PMF) conditions.

The MF project layout, from MF1050 included:

- South Roller Compacted Concrete (RCC) Dam – Approximately 315 m long with a crest elevation of 45.5 m.
- North RCC Overflow Dam – 430 m long with a crest elevation of 39.5 m, capable of passing approximately 8,800 $m^3/s$ at a maximum flood level (MFL) of 44.0 m.
- Four (4) bay gated spillway with submerged radial gates (12.5 m wide by 14.8 m high) with a permanent sill elevation of 5.0 m, capable of passing 13,305 $m^3/s$ at a MFL of 44.0 m.
- Four (4) unit powerhouse capable of passing 2,667 $m^3/s$ at full load.

With the dam structures being constructed using RCC, it is much more likely that the mode of failure would be monolithically, by overturning or by sliding. The breach at Muskrat Falls was assumed to be fully formed within 1 hour of breach initiation. A “Fair Weather” dam breach would increase the outflow, immediately downstream of the dam, from an initial flow of approximately 1,800 $m^3/s$ to a peak flow of approximately 70,500 $m^3/s$.

Conditions at other key downstream locations after a “fair Weather” MF Dam breach are summarized below in Table 1.

**Table 1: HEC-GeoRAS Results – "Fair Weather" Conditions, Muskrat Falls Dam Breach**

| Distance Downstream of MF Dam | Cross Section Description | Maximum Water Level No Breach | Breach Flood Summary | | | | |
|---|---|---|---|---|---|---|---|
| | | | Breach Flood Arrival Time | Peak Water Level | Incremental Depth of Flooding | Maximum Discharge m³/s | Time To Peak Water Level |
| 1.5 km | D/S Muskrat Falls Dam | 2.6 m | 0 hr | 15.4 m | 12.8 m | 62,200 | 3.4 hr |
| 18.7 km | U/S Blackrock Bridge | 1.6 m | 0.6 hr | 11.7 m | 10.1 m | 42,000 | 3.8 hr |
| 33.6 km | Happy Valley - Goose Bay | 0.7 m | 1.4 hr | 6.4 m | 5.7 m | 38,200 | 6.8 hr |
| 40.0 km | Mud Lake | 0.5 m | 1.7 hr | 5.2 m | 4.7 m | 35,200 | 7.3 hr |

Simulations were undertaken to estimate the impacts of a breach at Muskrat Falls on downstream water levels during PMF conditions. A PMF breach at Muskrat Falls would increase the outflow, immediately downstream of the dam, from an initial flow of approximately 25,100 m³/s to a peak flow of approximately 110,900 m³/s.

Table 2 below, summarizes the results for a number of key downstream locations after a PMF Muskrat Falls Dam breach.

**Table 2: HEC-GeoRAS Results – PMF Conditions, Muskrat Falls Dam Breach**

| Distance Downstream of MF Dam | Cross Section Description | Maximum Water Level without Breach | Breach Flood Summary | | | | |
|---|---|---|---|---|---|---|---|
| | | | Breach Flood Arrival Time | Peak Water Level | Incremental Depth of Flooding | Maximum Discharge (m³/s) | Time To Peak Water Level |
| 1.5 km | D/S Muskrat Falls Dam | 11.4 m | 0 hr | 21.1 m | 9.7 m | 101,600 | 3.2 hr |
| 18.7 km | U/S Blackrock Bridge | 8.2 m | 0.3 hr | 17.3 m | 9.1 m | 66,900 | 3.4 hr |
| 33.6 km | Happy Valley - Goose Bay | 5.4 m | 0.8 hr | 8.8 m | 3.4 m | 62,700 | 5.9 hr |
| 40.0 km | Mud Lake | 4.2 m | 1.2 hr | 7.5 m | 3.3 m | 60,900 | 6.3 hr |

The Population at Risk (PAR) and the potential for Loss of Life (LOL), during a MF Dam breach, are shown in Table 3 for both PMF and "Fair Weather" conditions.

**Table 3: Potential Loss of Life Assessment**

| Scenario | # of Incrementally Inundated Buildings | PAR in Incrementally Inundated Area | Warning Time (WT) (hours) | Incremental Loss of Life (LOL) | Incremental LOL (WT = 0 hrs) |
|---|---|---|---|---|---|
| PMF - MF Breach | 40 | 112 | 0.8 | 5 | 33 |
| "Fair Weather" - MF Breach | 350 | 980 | 1.4 | 3 | 136 |

Table 4 shows potential economic losses due to a dam breach.

**Table 4: Potential Economic Loss Assessment**

| Condition | Incremental Loss of Homes $M ($135,000 / house; Stats Canada 2006) | Area of Incremental Flooding | Overtopping Blackrock Bridge | Access and Transportation routes in and around Happy Valley – Goose Bay | Transmission line Infrastructure in and around Happy Valley – Goose Bay | MF Hydroelectric Station and Energy |
|---|---|---|---|---|---|---|
| PMF | (40) $5.4 | 45 km² | Yes | Loss | Loss | Loss |
| Fair Weather | (350) $47.25 | 120 km² | Yes | Loss | Loss | Loss |

## Conclusions and Recommendations

A HEC-RAS model capable of simulating dam breach floods was updated and used to model hypothetical dam breaches at Muskrat Falls under "Fair Weather" and PMF Conditions. The results of the dam breach modeling were used to prepare inundation mapping for Emergency Preparedness Plans and to assess the overall consequences of failure of the Muskrat Falls Dam.

It was recommended that the dam break model, and inundation mapping, be updated prior to the preparation of any Emergency Preparedness Plans. This update would take into consideration any changes to the project layouts.

## MF1330 – Report 4: Ice Study

In 2008 Hatch issued the GI1070 - Ice Study (Gull Island and Muskrat Falls) to Nalcor Energy – Lower Churchill Project (NE-LCP). Its objectives were the review of existing ice conditions in the Lower Churchill River, identify how these conditions might change as a result of the project, identify potential concerns during the construction phases of the project and propose measures to alleviate those concerns. In that study, it was assumed that the Gull Island project would be constructed before the Muskrat Falls project. The objective of the current study is the evaluation of ice conditions at Muskrat Falls during and post construction, assuming Muskrat Falls is developed before Gull Island.

## Major Findings

An analysis of historic water levels was completed, as part of GI1070, to determine whether or not ice control would be required to protect the south side construction site, for the Muskrat Falls Variant 10 layout (MF1050), from flooding. It was assumed water levels adjacent to the construction site would have to reach a level of approximately 20 m to cause a flooding concern. Hatch determined that a water level exceeding 20 m in winter is unlikely, but noted, water levels have exceeded 20 m at the upstream gauge during spring runoff (open water conditions) at a frequency of approximately once every two years.

An ICESIM model using the 1:20 annual exceedance probability (AEP) monthly flows, for a severe climate winter (1972-73) was used to determine minimum water levels to initiate stable ice cover. It was determined that a minimum water level of 25 m (governed by a constricted hydraulic condition in the approach channel) is required at the Muskrat Falls cofferdam to initiate a stable thermal/juxtaposed ice cover upstream.

A 25 m forebay water level suggested that no ice will be passed downstream (analyses during FEED studies is required). The model predicted a small accumulation of ice appearing just upstream of the construction site, at the physical narrowing of the river at Upper Muskrat Falls (approximate chainage 44 km, just upstream of the project structures). This narrow channel increases the velocity through this short reach, and this in turn increases the hydrodynamic forces applied to the cover. If the accumulation is deemed to be a concern, the forebay level could be raised to 26 m, and/or an ice boom could be installed just upstream of this location to ensure a stable ice cover is initiated in the upstream river reach.

Post Muskrat Falls construction and without the Gull Island reservoir upstream, there is likely to be a change in the frequency and magnitude of water level fluctuation in the Muskrat Falls reservoir. This has been studied as part of the MF1330 - Report 6: Muskrat Falls Regulation Study.

Downstream of Muskrat Falls, ice conditions are expected to be similar to existing conditions. However, a delay in the progression of the ice cover is likely, and there will be no hanging dam downstream of Muskrat Falls since the supply of ice will be physically cut off by the dam and reservoir upstream.

Results of the Ice Dynamics Study (Hatch 2007) for the post-project (Gull Island and Muskrat Falls) condition indicated a delay in the progression of the ice cover, from Goose Bay to Blackrock Bridge, of between three and six weeks as compared to the pre-project condition. This delay is expected to be reduced to between one and two weeks for the condition with the Muskrat Falls reservoir in place, but prior to construction of the Gull Island project. The estimated delay for the Muskrat Falls only scenario is less than that predicted for the post-project (Gull Island and Muskrat Falls) scenario, because in the latter scenario, the Gull Island reservoir provides added thermal capacitance to the system. Although ice conditions in the immediate vicinity of Muskrat Falls will obviously be much different with the elimination of the hanging dam, and the release of water through the project's powerhouse, it is expected that in areas farther downstream, ice thicknesses will be similar to existing conditions.

## Conclusions and Recommendations

The objectives of the current study included analyzing the ice conditions at the Muskrat Falls site during construction and post-construction of the Muskrat Falls facilities, assuming the Gull Island facilities have not been constructed. In this case, the ice-generating reach is extended upstream to the outlet of Lake Winokapau, which is the primary difference from the conditions analyzed under GI1070.

The main conclusions of the study are as follows:

- The analysis completed under GI1070 related to potential flooding of the spillway construction site remains valid. It is very unlikely that water levels would rise to 20 m, which is the assumed level above which flooding is a concern;
- Though there is an increased volume of ice expected at the Muskrat Falls construction site, in the case without the Gull Island facilities in place, the ice management strategy has not changed from that proposed under GI1070. The water level required at the cofferdam to provide appropriate hydraulic conditions for this cover to form was determined (through ice modeling) to be 25 m, which is the same level determined in GI1070; and
- During post-construction of the Muskrat Falls facilities, but before construction of the Gull Island facilities, an ice cover is expected to form on the Muskrat Falls reservoir. Inflowing ice is expected to accumulate at the upstream end of the reservoir; conditions near the Muskrat Falls dam are expected to consist of a thermal cover with a thickness of approximately one metre.

Recommendations arising from this study are as follows:

- Due to the complexity of the velocity regime expected at the Muskrat Falls cofferdam, and the small ice accumulation predicted just upstream of the cofferdam, it is recommended that the 25 m water level determined in this study be optimized during the FEED studies.
- The implications of part of the upstream ice cover being lost during the winter should also be considered during future studies. In the event that even a part of this upstream cover breaks up and passes through the spillway, it could lead to rapid water level increases downstream of the plant that may impact any ongoing construction activities in that area.

## MF1330 –Report 6: Regulation Study

The Muskrat Falls (MF) plant is the most downstream plant in the Lower Churchill River System.

Storage in the MF reservoir is very small, between a Low Supply Level (LSL) of 38.5 m and a nominal Maximum Operating Level (MOL) of 39.0 m. Inflow to the reservoir can be regulated by the upstream Gull Island (GI) reservoir. However, without the GI reservoir, peak inflows to MF are expected to be higher and more frequent. Nalcor Energy – Lower Churchill Project (NE-LCP) initiated this study into the inflow regime at Muskrat Falls with and without the GI reservoir, as it relates to optimal operation of the MF reservoir and plant.

## Major Findings

The 50 year daily inflow sequence (1957 to 2006) for the Lower Churchill basin, developed under H328041 (Lower Churchill AUTO Vista Study, a long term planning model), was used for the current study.

A number of scenarios were developed to evaluate the operations with, and without, the GI reservoir, and with an increase in the allowable fluctuation range at MF. The scenarios evaluated are summarized in Table 1 below.

**Table 1: Scenario Definition**

| Scen. | CF | GI | MF | MF LSL | MF MOL | MF Range (m) | Min CF Gen (MW) | Min MF Gen (MW) | Coordinated Operations With CF(L)Co | Coordination Level expressed as the CF(L)Co Minimum Generation Requirement | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | HQ Load | Trans. Loss | Stn. Load | TwinCo | Recall |
| 1 | X | 0 | X | 38.5 | 39.0 | 0.5 | 1400 | 170 | No | X | X | X | X | X |
| 2 | X | | X | 38.5 | 39.0 | 0.5 | 1400 | 170 | No | X | X | X | X | X |
| 3 | X | | X | 38.5 | 39.0 | 0.5 | 1400 | 170 | Partial | X | X | X | | |
| 4 | X | | X | 38.5 | 39.5 | 1.0 | 1400 | 170 | Partial | X | X | X | | |
| 5 | X | X | X | 38.5 | 39.0 | 0.5 | 1400 | 170 | Yes | | | | | |
| 6 | X | | X | 38.5 | 39.0 | 0.5 | 1400 | 170 | Yes | | | | | |

Scen. - Scenario
CF – Churchill Falls
Stn. - Station
0 excludes GI plant only (includes the GI reservoir)
X includes plant and reservoir
Trans. - Transmission

Scenarios 1-4 simulated an extreme Hydro Quebec (HQ) load pattern, and were initially completed and results reviewed by NE-LCP, prior to definition of scenarios 5 and 6. The Coordination Level represents the ability for both the MF and Churchill Falls (CF) plants to meet the load imposed on the system. In the no coordination case, CF is required to meet all the loads in the system which included:

- HQ load, transmission loss;
- Station load;
- TwinCo: and
- Recall (Labrador Load and Export);

MF only supplies energy for export. This requirement is implemented as a minimum generation obligation at CF. In the case of coordinated operations, both plants (CF and MF) work together in an optimal fashion to meet load and maximize export.

Results for the scenario evaluation are summarized in Table 2.

**Table 2: Summary Results**

| Scen. No. | CF | GI | MF | Coordinated Operations With CF(L)Co | MOL (m) | Allowable Fluctuation Above LSL (m) | Simulated Daily WSL | | % of Time Above MOL | % of time Spill | 50-yr Avg. Spill cms | Avg. Spill MCM/yr | Avg. WSL (m) | MF Energy MWc | MF Energy TWh | Sys. Gen TWh |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Min (m) | Max (m) | | | | | | | | |
| 1 | X | 0 | X | No | 39.0 | 0.50 | 38.5 | 41.20 | 5.8 | 3.2 | 59.1 | 1864 | 39.01 | 556.7 | 4.877 | 38.95 |
| 2 | X | | X | No | 39.0 | 0.50 | 38.5 | 41.98 | 9.2 | 7.4 | 64.9 | 2048 | 38.93 | 552.2 | 4.837 | 38.92 |
| 3 | X | | X | Partial | 39.0 | 0.50 | 38.5 | 40.92 | 8.2 | 5.5 | 44.7 | 1410 | 38.98 | 556.8 | 4.878 | 38.98 |
| 4 | X | | X | Partial | 39.5 | 1.00 | 38.5 | 40.92 | 7.1 | 7.1 | 47.0 | 1484 | 39.42 | 561.3 | 4.917 | 39.05 |
| 5 | X | X | X | Yes | 39.0 | 0.50 | 38.5 | 41.00 | 5.8 | 4.2 | 28.7 | 906 | 38.89 | 553.3 | 4.847 | 50.40 |
| 6 | X | | X | Yes | 39.0 | 0.50 | 38.5 | 40.88 | 7.9 | 5.7 | 45.3 | 1430 | 38.98 | 555.9 | 4.870 | 39.10 |

0 excludes the GI plant only includes GI reservoir
LSL - Low Supply Level
MCM – Million Cubic Meters
MOL Maximum Operating Level
WSL - Water Surface Level
Note: MWc (MW continuous) can be converted to TWh by multiplying by 8,760 hours per year and subsequently dividing by 1,000,000.

## Conclusions and Recommendations

Six scenarios were evaluated to assess operations with and without the GI reservoir, with and without coordination and with an increase in the allowable fluctuation range at the MF reservoir. The scenario parameters are summarized in Table 1, shown previously. Summary results are tabulated in Table 2 above.

Generic efficiency curves for the Muskrat Falls units were produced based on information on rated head, efficiency and flow taken from the 1999 SNC report. The average annual efficiency was determined to be approximately 90 percent (0.8994).

The results indicated that:

- With <u>no coordination,</u> between MF and CF, the GI reservoir provides regulation control for a spill at MF. With GI in place, to provide regulation upstream, the average water level in MF was maintained closer to MOL and there was a slight gain in MF energy due to a gain in head **(Scenarios 1 and 2)**.
- **Scenarios 3 and 4** were run with <u>partial coordination</u>; that is, the CF minimum generation was set equal to HQ load, station service and transmission loss. <u>No Gull Island reservoir</u> or plant was modeled. Results indicated that with an increase in the fluctuation range at the top of the reservoir (i.e. the MOL of 39 m was increased to 39.5 m) the 50-yr average spill actually increased. The increased head yielded higher energy production at MF. This is indicative of the model objective which was to maximize energy output. However, this operation strategy also leads to a slight increase in the likelihood of spill, and average magnitude of spill, at MF.
- With <u>full coordination</u> between MF and CF the GI reservoir and plant can provide significant regulation control for spill at MF. The GI reservoir was able to reduce the 50-yr average spill at MF. However, with the GI plant in place, the average water level in MF was slightly reduced, as water was held back at the Gull Island reservoir to yield energy benefits at that plant. As a result, the overall energy production at MF was slightly reduced (Scenarios 5 and 6).

# LOWER CHURCHILL PROJECT

# LABRADOR – ISLAND TRANSMISSION LINK

# 1998 TO DECISION GATE 2

## Technical Note

Date: 5-July-2011
Rec. No. 203-120143-00014

LOWER CHURCHILL PROJECT

## 1. Purpose

The purpose of this technical note is to provide a summary of the evolution of the configuration for the Labrador-Island HVdc link proposed as part of the Basis of Design for the Lower Churchill Project.

## 2. Description

The original configuration of the Labrador-Island HVdc Link was based on the system proposed in 1998 with an 800 MW transmission system from Gull Island to Soldiers Pond having an overload capacity of 200% (800 MW) for 10-minutes and 150% (600 MW) continuously. Consideration was also given to a transmission system that would transmit 1600 MW from Gull Island to 800 MW converter stations located at both Soldiers Pond and Salisbury, New Brunswick.

As part of the Voltage and Conductor Optimization Study (DC1010), voltages of ± 400, ± 450 and ± 500 kV dc were considered and Mass Impregnated (MI) cables were considered for the Strait of Belle Isle (SOBI) and Cabot Strait crossings. Generic designs were used to estimate the tower and conductor costs.

Extensive interconnection studies for the proposed HVdc system (HVdc System Integration Study (DC1020) and HVdc System Sensitivity Analysis (DC1210)) were executed from 2007 to 2010 with assistance from Hatch and TransGrid Solutions. Major study tasks included power flow, short circuit, and transient stability analyses. As a result of these studies proposed island upgrades were identified. These upgrades included the conversion of Holyrood Units #1 and #2 to synchronous condensers and the provision of two (plus one spare) 150 MVAR high-inertia synchronous condensers.

In 2010, Newfoundland and Labrador Hydro was faced with a decision relating to generation expansion for the Island Interconnected System for the timeframe ranging from 2015 to 2020. As ensuing analysis indicated that the least-cost expansion option would involve a Labrador-Island HVdc infeed, it was determined that priority should be given to the Muskrat Falls Development. This development would be sufficient to meet forecasted demand for the Island Interconnected System, while providing some additional capacity for potential export to the Maritimes.

Based on this change, the proposed 1600 MW multi-terminal HVdc scheme was replaced with a smaller point-to-point system from Muskrat Falls to Soldiers Pond. With an estimated annual plant capacity of 4.9 TWh at Muskrat Falls and up to 300 MW of available recall capacity from the Upper Churchill, it was determined that the HVdc link should be sized at 900 MW.

Analysis was carried out in June and July of 2010 to confirm that a 900 MW HVdc link between Labrador and the Island would require a minimum operating voltage of ±320 kV to ensure that transmission losses for the proposed HVdc system would be in the order of 10% over peak.

## 3. Reference Reports

For further details, a one to two page description of each of the following reports is attached:

DC1010 - Voltage and Conductor Optimization
DC1020 - HVdc System Integration Study
DC1210 - HVdc System Sensitivity and VSC Risk Analysis

## DC1010 – Voltage and Conductor Optimization

The purpose of this study was to determine the optimum operating voltage and conductor size for the HVdc overhead lines. These lines would run from a converter station at Gull Island, to converter stations at Soldiers Pond, Newfoundland and possibly Salisbury, New Brunswick.

The final report based on this study was submitted to the NE-LCP group in April 2008.

## Major Findings

Two transmission scenarios were evaluated to determine if there would be any impact on the operating voltage and conductor selection. Scenario One included an 800 MW transmission from Gull Island and an 800 MW to Soldiers Pond. Scenario Two included a 1,600 MW transmission from Gull Island and an 800 MW to both Soldiers Pond and Salisbury.

Upon completion of the NE-LCP, the existing thermal generation at Holyrood could be retired. Without the HVdc link there may be insufficient reserve in the Island system to allow for the loss of one pole's transmission capability (400 MW). Therefore, in monopolar operation, each pole and its associated conductors and submarine cables must be capable of transmitting 200% (800 MW) of single pole power for 10-minutes, and 150% (600 MW) of single pole power continuously.

The HVdc link must be capable of power flow in any direction. Therefore, the Soldiers Pond and Salisbury Converter stations, although normally operating as Inverters, would also be capable of Rectifier operation.

HVdc Converter Stations and overhead transmission lines, operating at voltages of ± 400, ± 450 and ± 500 kV dc, are well proven technologies and will therefore be considered for the NE-LCP.

Self Contained Oil Filled (SCOF) submarine cables could be used at ± 400, ± 450 and ± 500 kV dc for the SOBI crossing, but are limited by oil-pumping requirements to have a maximum route length of 50 km. Therefore, SCOF cable could not be used for the Cabot Strait crossing. In the event of cable damage, the possibility of long term oil discharge while waiting for cable repairs may cause environmental concerns.

Mass Impregnated (MI) cables could be used at ± 400, ± 450 and ± 500 kV dc for the SOBI crossing and the Cabot Strait crossing. 1,600 MW could be effectively transmitted from Gull Island to Soldiers Pond and to Salisbury at ± 400, ± 450 and ± 500 kV dc.

The corona analysis showed that a single, 58 mm diameter conductor per pole could be used for ± 400, ± 450 kV dc. Additional analysis showed that a twin conductor configuration would be required for ± 500 kV dc.

Generic tower designs were used to estimate the tower weights (and costs) for each operating voltage with a range of conductors that would meet meteorological loading and corona requirements. The analysis showed that tower weights would be most affected by the Rated Tensile Strength of the conductors, which determines the sag and therefore the tower height and spans.

## Conclusions and Recommendations

For both Scenario 1 and Scenario 2, the differences between the total project costs for the ± 400, ± 450 or ± 500 kV dc transmission are within the level of accuracy of the comparative cost estimates. Therefore, the most economic options for the HVdc overhead lines would be:

- Scenario 1: ± 400 kV dc with a single, 50.4 mm diameter conductor.
- Scenario 2: ± 450 kV dc with a single, 58 mm diameter conductor.

If there is a reasonable probability that Scenario 2 will proceed, then the GI Converter Station and the SOBI submarine cables should be installed with the full 1,600 MW rated capacity during Scenario 1 construction. In addition, the Taylors Brook switching station should be constructed with isolation capabilities to minimize power disruption to Soldiers Pond when the line to Cape Ray is constructed and commissioned.

Operating at ± 400, ± 450 kV dc gives the option of using a single conductor per pole, which would be beneficial in regions of heavy ice loads. This single conductor per pole option is not possible for ± 500 kV dc because of manufacturing and corona limitations.

## DC1020 – HVdc System Integration Study

The installation of a three-terminal HVdc system would link Labrador, Newfoundland and New Brunswick together. The proposed HVdc system would be bipolar and each converter station would have the ability to run as either a rectifier or an inverter. It would include cables and overhead lines, with approximately 30 km of cable between Labrador and Newfoundland and approximately 480 km between Newfoundland and New Brunswick.

The purpose of this report was to present a summary of all work completed as a part of DC1020 HVdc System Integration Study. The report provided a summary of the individual study tasks completed followed by an overall discussion of results and conclusions.

The major study tasks conducted as part of DC1020 included:

- Power flow and short circuit analysis;
- Comparison of the performance of conventional and Capacitor Commutated Converter (CCC) HVdc technologies;
- Transient stability analysis;
- Cursory evaluation of alternate HVdc configurations;
- Development of a multi-terminal HVdc model for future PSSE studies.

The final report based on this study was submitted to the NE-LCP group in May 2008.

## Major Findings

This report was completed to:

- Demonstrate the feasibility of a multi-terminal HVdc link connecting Labrador, Newfoundland, and New Brunswick. This was based on the performance specification of the Newfoundland system.
- Determine the system additions required for integrating the proposed three-terminal HVdc system into the Labrador and Newfoundland systems. A separate system impact study is to be performed by the New Brunswick System Operator to assess the requirements in New Brunswick.
- Determine the limitations of the proposed HVdc system.
- Determine feasible mitigation steps to ensure that the integrated system performs in an acceptable manner.
- Ensure that the integrated system design minimizes the need for load shedding in Newfoundland.

## Conclusions and Recommendations

Upgrades and additions required in the Newfoundland ac system to support the HVdc in-feed included:

a. Conversion of all three units at Holyrood to synchronous condenser operation;
b. Installation of five combustion turbines that can operate as synchronous condensers at the Pipers Hole 230 kV bus;
c. One 300 MVAr high inertia synchronous condenser in-service at the Soldiers Pond 230 kV bus at all times;
d. One 300 MVAr high inertia synchronous condenser in-service at the Pipers Hole 230 kV bus at all times;
e. 50% series compensation of both 230 kV lines to avoid potential overloads;
f. Upgrades to a number of 230 kV lines east of Bay d'Espoir;
g. Replacement of a number of circuit breakers in Stony Brook, Bay d'Espoir, and Holyrood;
h. Modification of the existing under-frequency load shedding scheme to avoid unnecessary load shedding;
i. Implementation of a special protection system to cross trip the proposed refinery load at Pipers Hole in the event of a fault.

It was recommended that:

- High inertia synchronous condensers be used due to the low inertia of the Newfoundland system;
- Additional system impact studies involving proposed industrial loads be completed to define more exact requirements of connecting the new loads separate from the impacts of the HVdc in-feed into Soldiers Pond;
- The existing under-frequency load shedding scheme in the Newfoundland system be modified in order to operate only when the HVdc frequency controller is not able to provide the necessary control for under-frequency conditions;
- Additional studies be completed to determine the impact on the New Brunswick ac system of reversing the Salisbury converter from inverter to rectifier.

## DC1210 – HVdc System Sensitivity and VSC Risk Analysis

The purpose of this study was to expand the findings of DC1020; two sensitivity studies were completed as a part of this report. The first study was an HVdc system sensitivity analysis which comprised of LCC studies. The second study was a Voltage Source Converter (VSC) risk assessment, which looked at the possibility of using VSC technology for the Soldiers Pond terminal.

The final report based on this study was submitted to the NE-LCP group in April 2009.

## Major Findings

<u>HVdc System Sensitivity Analysis</u>
A new synchronous condenser model with a very high inertia constant (7.84) was tested. The high inertia machine showed significant improvement in system performance over the synchronous condenser models with a lower inertia constant (2.2) used in the DC1020 studies.

Without synchronous condensers at Pipers Hole, either a Static Var Compensator (SVC) at Sunnyside or a new 230 kV circuit between Bay d'Espoir and Western Avalon would provide acceptable system performance for all contingencies, except the three-phase fault at Bay d'Espoir. The results were highly dependent on the type of synchronous condenser that was modeled.

The high inertia Toshiba synchronous condenser would significantly reduce the number of synchronous condensers that were required to be installed at Soldiers Pond. In order to meet criteria for a fault at Sunnyside on one of the Bay d'Espoir-Sunnyside lines, a single 300 MVAr high inertia synchronous condenser, along with a 300 MVAr SVC at Sunnyside or a new 230 kV circuit between Bay d'Espoir and Western Avalon was required. Approximately 200 MVAr was required in steady state from the Soldiers Pond synchronous condensers to maintain the 1.0284 pu voltage setpoint that was used in the studies.

Upon re-visiting the three-phase Bay d'Espoir fault, it was found that in order to design the system to survive a three-phase fault, the only option that recovered within the specified criteria was a case with the new 230 kV circuit between Bay d'Espoir and Western Avalon. If this new circuit, along with two circuits between Bay d'Espoir and Sunnyside were 50% series compensated, and if 2 x 300 MVAr high inertia Toshiba synchronous condensers were in service at Soldiers Pond, (3 x 300 MVAr installed to account for maintenance outages), the system would be able to recover within criteria from a three-phase fault at Bay d'Espoir.

A preliminary evaluation was performed to look at the impact of relocating a portion of the inertia from Soldiers Pond to Bay d'Espoir by changing out the rotor on Bay d'Espoir Unit 7 and installing a high inertia 150 MVAr synchronous condenser on Bay d'Espoir Unit 8. The analysis was performed with only 1 x 150 MVAR high inertia synchronous condenser operating at Soldiers Pond instead of 2 x 150 MVAr. The results indicated a poorer performance of the Island system when the synchronous condensers were moved away from Soldiers Pond due to poorer performance of the HVdc infeed. This system configuration would require the addition of the 230 kV circuit between Bay d'Espoir and Western Avalon with 50% series compensation as well as 50% series compensation on the two Bay d'Espoir - Sunnyside 230 kV lines. If the series compensation from the new Bay d'Espoir - Western Avalon line was removed, the system would become unstable for a fault at Sunnyside on one of the Bay d'Espoir lines (TL202 or TL206). In addition, the HVdc infeed was on the verge of a second commutation failure for a three phase fault on the Soldiers Pond synchronous condenser.

<u>VSC Risk Assessment</u>
The rating at Gull Island could be achieved using an LCC converter, while the rating at Soldiers Pond and Salisbury could use a VSC converter. The HVdc cable would be a mass impregnated cable. Results of preliminary transient stability simulations showed an overall improvement in system performance for all ac and dc faults that were studied with fewer synchronous condensers than required for the LCC technology.

## Conclusions and Recommendations

Since the loss of the Soldiers Pond synchronous condenser becomes the worst case contingency if only a single 300 MVAR unit is installed, it is recommended to have 2x150 MVAr high inertia synchronous condensers in-service at all times. Therefore 3x150 MVAr synchronous condensers are required to account for maintenance outages. The added benefit to a synchronous condenser rating of 150 MVAr is that it would match the Holyrood synchronous condenser ratings and their spare transformer. These solutions both provide sufficient steady state VAR support to maintain system steady state voltages during the 800 MW monopolar 10-minute 2.0 pu overload condition.

Based on promising results seen from preliminary transient stability simulations, it is recommended that a complete performance evaluation of VSC technology be performed for the Soldiers Pond terminal.