nalcor energy

THE Lower Churchill PROJECT

August 2009

GI1141 - Upper Churchill PMF and Flood Handling Procedures Update

prepared by

HATCH™

in association with

RSW inc. Statnett

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Executive Summary

Nalcor Energy (Nalcor) is undertaking preliminary engineering studies of the development of the hydroelectric potential of the Lower Churchill River at Gull Island and Muskrat Falls. As part of these feasibility studies, Hatch has carried out a study entitled GI1141—Upper Churchill PMF and Flood Handling Procedures Update for the existing Churchill Falls hydroelectric development (i.e., Upper Churchill Basin).

The objectives of this study were to update the previous 1969 estimate of the Probable Maximum Flood (PMF) for the Upper Churchill Basin, and review the flood handling procedures for Churchill Falls, established in 1989. The updated PMF estimate was used to review the pre-spill target level and rule curve used for reservoir routing during the PMF. The study then reviewed the sensitivity of the Lower Churchill PMF estimates (previously determined in GI1140—PMF and Construction Design Flood Study) to potential changes in the Upper Churchill flood handling procedures. The scope included a review of previous studies and analysis using the three models (watershed, reservoir operation, and dynamic river hydraulic) used previously in the GI1140 study.

The PMF is defined by the Canadian Dam Association (CDA) as "an estimate of hypothetical flood (peak flow, volume and hydrograph shape) that is considered to be the most severe 'reasonably possible' at a particular location and time of year, based on relatively comprehensive hydrometeorological analysis of critical runoff-producing precipitation (snowmelt if pertinent) and hydrologic factors favourable for maximum flood runoff".

For the original Upper Churchill PMF estimate developed in 1969, the Probable Maximum Precipitation (PMP) was combined with a Probable Maximum Snowpack Accumulation (PMSA) and maximum snowmelt temperatures. However, current dam safety practice is to define the PMF as the largest flood that can reasonably be expected to occur, rather than the largest flood that could possibly be expected to occur. As a result, current PMF calculations are based on a less severe combination of meteorological inputs than were used in the past. This forms the basis for reducing the PMF estimate for the Upper Churchill.

For the GI1140 study, a calibrated watershed model for the entire Churchill River Basin was created. The model uses precipitation, temperature and snowpack information and relationships that describe the runoff response of the watershed to predict flows in the Churchill River. For the present study (GI1141), the model was re-run for various storm events to derive the updated PMF estimate for the Upper Churchill Basin.

The critical PMF scenario for the Upper Basin results from a combination of the following meteorological inputs.

- A spring Probable Maximum Precipitation (PMP) event. A critical spring PMP would have a 66-hour rainfall depth of 286 mm over the central 10 km^2 and would be centered over the area draining directly into Smallwood Reservoir, with an orientation along a WNW to ESE axis. This PMP would have an average depth of 130 mm in the Upper Basin. It would commence four days after the critical melt temperature sequence.

- A severe temperature sequence, combining a cool early May to preserve the extreme snowpack into the spring, a warm front with a maximum temperature of 24 °C to prime and melt the snowpack, and a cool front with a maximum temperature of 16 °C bringing the PMP rainfall.

- A snowpack of 1/100 annual exceedance probability (AEP), 536 mm.

The estimated PMF inflow at Smallwood Reservoir is characterized by an instantaneous peak of 24,800 m^3/s (16,540 m^3/s maximum daily) resulting from direct rainfall and snowmelt on the reservoir surface, followed by a secondary instantaneous peak of 16,400 m^3/s (15,170 m^3/s maximum daily) from the runoff from the full drainage area to the reservoir. The estimated instantaneous peak at Ossokmanuan/Gabbro Lake is 5,860 m^3/s (5,798 m^3/s maximum daily). (The original 1969 PMF estimate was 30,764 m^3/s maximum daily inflow to the total Upper Basin, which includes Smallwood Reservoir, Ossokmanuan/Gabbro Lake, and the East and West Forebays.)

To determine potential changes in flood handling procedures, PMF hydrographs from the watershed model were routed through the Churchill Falls hydroelectric development using a decision-based reservoir operation model. With the significant decrease in the Upper Basin PMF estimate from 1969 to the present study, the existing flood handling procedures for the Churchill Falls project have been shown to be overly conservative at the PMF level, yielding a simulated peak level in Smallwood nearly 2 m lower than for the 1969 estimate.

[redacted]

[redacted] The resulting Upper Basin outflows were then routed through the Lower Churchill River using a dynamic hydraulic model. The dynamic hydraulic model of the Lower Churchill River was used in GI1140 and refined in the Lower Churchill Dam Break Study (GI1190). The model was further updated for the present study with the most recent dam layouts (GI1061 and MF1050).

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1. Introduction

Nalcor Energy (Nalcor) is undertaking preliminary engineering studies of the development of the hydroelectric potential of the Lower Churchill River at Gull Island and Muskrat Falls. These sites are located downstream 225 km and 285 km respectively from the Churchill Falls hydroelectric facility that was developed in the early 1970s. The total potential capacity at the two sites is approximately 3000 MW (megawatts); the Gull Island site being the larger at 2250 MW. In addition to the development of these sites, the overall concept includes various potential alternative power transmission arrangements involving combinations of AC and DC lines of various capacities.

In April, 2007, Nalcor contracted Hatch Ltd. of St. John's to undertake a program of studies to address aspects of this development relating primarily, but not exclusively, to hydrology/hydraulics and transmission components. Approximately thirty such studies have been carried out by Hatch and its associated subconsultants (RSW of Montreal, Statnett of Oslo, and Transgrid of Winnipeg). The program has been managed from Hatch's office in St. John's using the company's project management tools and a project services team that has liaised throughout with a similar group in Nalcor.

This report presents the updated Probable Maximum Flood (PMF) estimate and review of flood handling procedures for the Churchill Falls Hydroelectric System (i.e., the Upper Churchill Basin). The updated PMF estimate was used to review the pre-spill target levels and rule curves used for reservoir routing during the PMF. The study then reviewed the sensitivity of the Lower Churchill PMF estimates to the potential changes in the Upper Churchill flood handling procedures.

This report has been prepared for Nalcor based on existing conditions and procedures in the Churchill Falls Hydroelectric System as Hatch understands them from the currently available information.

1.1 Background

1.1.1 Project Location

The Churchill Falls Hydroelectric System is located in western Labrador, in the province of Newfoundland and Labrador. The existing generation complex is operated by Churchill Falls (Labrador) Co. (CF(L)Co) and regulates two-thirds of the Churchill River basin and has a capacity of 5428.5 MW. Figures 1.1 to 1.3 show the location of the existing and proposed Churchill River facilities.

1.1.2 Summary of GI1140 Study

In 2007, Nalcor engaged Hatch Ltd. to determine the PMF for the Gull Island and Muskrat Falls Projects in accordance with guidelines and recommendations of the Canadian Dam Association (CDA). The PMF study included the total Churchill River drainage basin areas of 89,099 km^2 upstream of the Gull Island Project site and 92,355 km^2 upstream of the Muskrat Falls Project site. Results of the 2007 study were presented in the report GI1140 – PMF and Construction Design Flood Study.

The Upper Churchill Basin was included in the area studied to determine the Lower Churchill PMF. In the course of the GI1140 study, it was concluded that the original Upper Basin PMF estimate made in 1969 is now overly conservative, based on new CDA guidelines. A smaller estimate for the Upper Basin PMF could permit changes in pre-spill target levels and flood handling procedures in the Upper Basin. Changes to the flood handling procedures in the Upper Basin could in turn influence the estimate of the Lower Churchill PMF.

1.1.3 Rationale for Smaller PMF Estimate

Current dam safety practice is to define the PMF as the largest flood that can *reasonably* be expected to occur, rather than the largest flood that could *possibly* be expected to occur. This change in thinking is reflected in the severity of the individual meteorological components that are combined to generate the PMF. For the original Upper Churchill PMF estimate developed in 1969, the Probable Maximum Precipitation (PMP) was combined with a Probable Maximum Snowpack Accumulation (PMSA) and maximum snowmelt temperatures.

The current CDA Dam Safety Guidelines (2007) limit the maximum size of any event combined with a "Probable Maximum" event to 1/100 AEP (annual exceedance probability). For example, a PMP might be combined with a 1/100 AEP snowpack, or a PMSA could be combined with a 1/100 AEP rain.

As a result, current PMF calculations would be based on a less severe combination of meteorological inputs than were used in the past. This in turn would be expected to produce a smaller PMF estimate.

1.2 Probable Maximum Flood Definition

The CDA (2007) defines the PMF as the:

"Estimate of hypothetical flood (peak flow, volume and hydrograph shape) that is considered to be the most severe 'reasonably possible' at a particular location and time of year, based on relatively comprehensive hydrometeorological analysis of critical runoff-producing precipitation (snowmelt if pertinent) and hydrologic factors favourable for maximum flood runoff".

The CDA Dam Safety Guidelines (2007) require that:

"A Probable Maximum Flood (PMF) study shall consider the most severe 'reasonably possible' combination of the following phenomena on the watershed upstream of the structure under study:

- rainstorm;
- snow accumulation;
- melt rate;
- initial basin conditions (e.g. soil moisture, lake and river levels); and
- pre-storm."

For dams with high consequences of failure, either social, environmental or loss of life, the PMF is the inflow design flood to use in design of hydraulic facilities, e.g. dams and spillways, and for dam safety studies.

The CDA Dam Safety Guidelines (2007) outline the following PMF scenarios to be considered:

- A combination of a 1/100 AEP snow accumulation with the spring PMP and a 1/100 AEP temperature sequence;
- A combination of the PMSA with a 1/100 AEP rainstorm and a 1/100 AEP temperature sequence; and
- A summer/autumn PMF resulting from a summer/autumn PMP, with no snow on the ground, preceded by a 1/100 AEP pre-storm.

For the total Churchill River Basin it was expected that the PMF would occur during the snowmelt season. Higher rainfall depths could occur later in the year, but the percentage of annual runoff from the basin that is a result of snowmelt suggests that a spring PMP in combination with snowmelt will give the maximum flow in the river.

1.3 Approach

The work included a review of previous studies, and analysis using the three models used previously for GI1140:

- SSARR (Streamflow Simulation and Reservoir Regulation) watershed model of the Churchill River Basin;
- ARSP (Acres Reservoir Simulation Package) operational model of the Upper Churchill Basin; and
- HEC-RAS (Hydrologic Engineering Center – River Analysis System) hydraulic model of the Churchill River, including the Gull Island and Muskrat Falls Projects.

1.3.1 Review of Previous Studies

The following previous flood studies were reviewed.

1. Acres Canadian Bechtel of Churchill Falls, Churchill Falls Snowmelt and Frequency Studies for Design Floods, September 1969 including meteorological studies by Sparrow (Department of Transport Meteorological Branch, 1968).
2. Acres International Limited, Flood Handling Study of the Churchill Falls System, March 1989.
3. Hatch Ltd., The Lower Churchill Project, GI1140 – PMF and Construction Design Flood Study, December 2007.

1.3.2 Update of PMF Estimate

For GI1140, a calibrated watershed model for the entire Churchill River Basin was created using the SSARR (Streamflow Simulation and Reservoir Regulation) model. The model uses precipitation, temperature and snowpack information and relationships that describe the runoff response of the watershed to predict flows in the Churchill River. For the present study, the model was re-run for various storm events to derive the updated PMF estimate for the Upper Churchill Basin.

Reservoir discharge rating and elevation-storage curves were consolidated in the model to develop preliminary estimates of reservoir level and outflow while routing the upper basin floods through Smallwood Reservoir and Ossokmanuan/Gabbro Lake. The location, orientation and timing of the storm events were manipulated to maximize the PMF estimate.

1.3.3 Review of Flood Handling Procedures for Upper Churchill

The ARSP (Acres Reservoir Simulation Package) operational model was used to route the SSARR generated PMF inflows through Smallwood Reservoir and Ossokmanuan/Gabbro Lake and determine potential changes in flood handling procedures for the updated Upper Churchill PMF estimate.

1.3.4 Lower Churchill PMF Re-Estimate

The Upper Churchill PMF and the Lower Churchill PMF do not occur as part of the same event. They are separate, unrelated events caused by different storm centre locations and hydrometeorological conditions. The re-estimate of the Upper Churchill PMF does not change the estimate of the Lower Churchill PMF already established in the GI1140 study.

However, if changes in the Upper Basin flood handling procedures were implemented by CF(L)Co in response to a decreased Upper Churchill PMF estimate, such changes in procedures could impact the estimate of the Lower Churchill PMF. This is because the Lower Churchill PMF inflow occurs partly in the Upper Basin as well, and the Upper Basin flood handling procedures would affect how this inflow is routed to the Lower Basin.

To determine how changes in Upper Basin flood handling procedures could impact the Lower Churchill PMF estimates at Gull Island and Muskrat Falls, the component of the Lower Churchill PMF inflow occurring in the Upper Basin was simulated in the Upper Basin ARSP model, using the changed flood handling procedures. The resulting Upper Basin outflow was then routed through the HEC-RAS hydraulic model of the Lower Churchill River for combination with the local PMF hydrographs in the Lower Basin.

The HEC-RAS model of the lower Churchill River had been used previously in the GI1140 study and refined in the Lower Churchill Dam Break Study (GI1190). The model was further updated for the present study with the most recent project layouts. The model was used to combine and route the local Lower Churchill PMF inflow hydrographs generated by the SSARR model and the Upper Churchill outflows from the ARSP model, with the reservoirs created by Gull Island and Muskrat Falls generating stations. The model was used to determine the sensitivity of the Lower Churchill PMF estimates to the changes in Upper Churchill flood handling procedures.

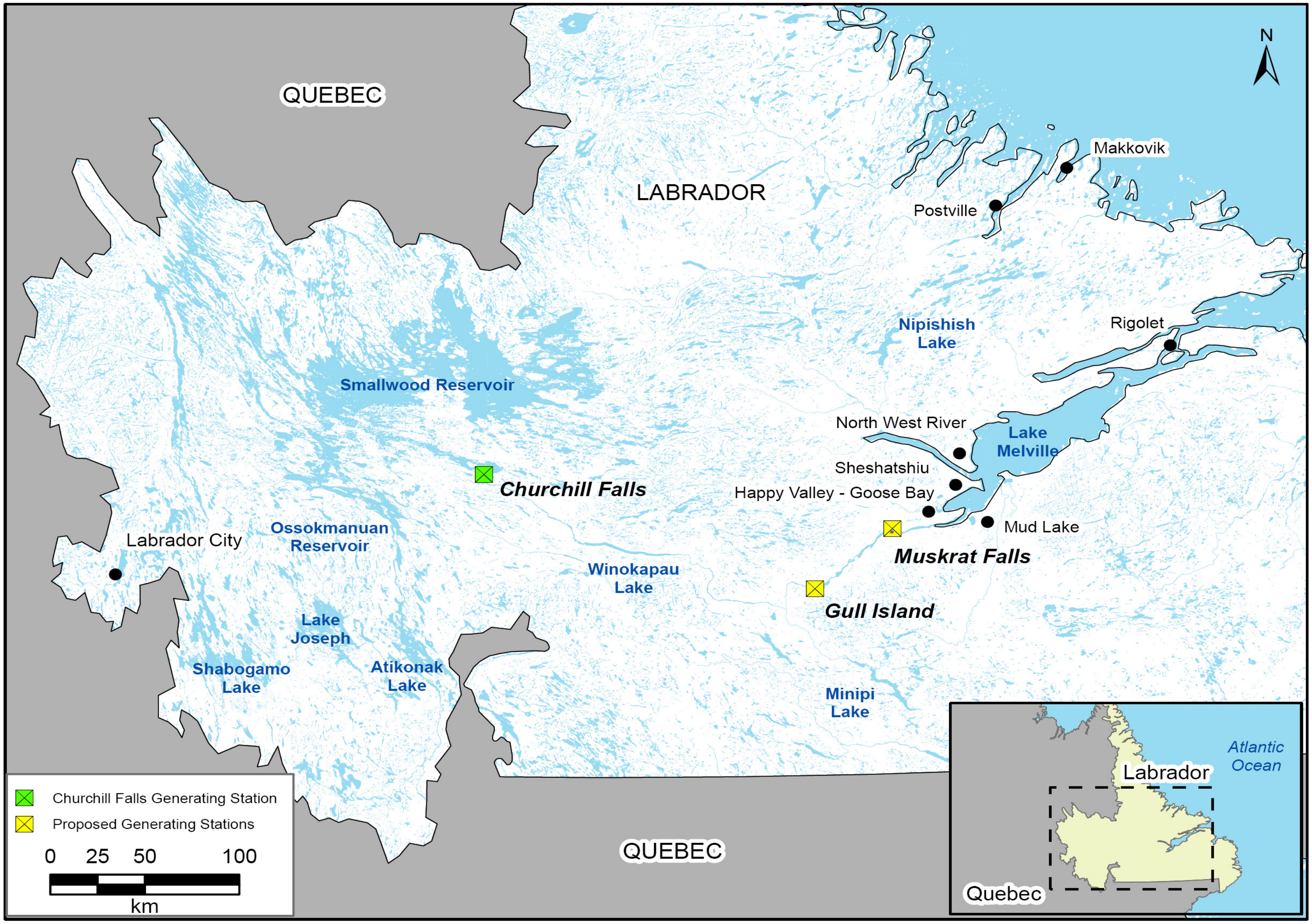

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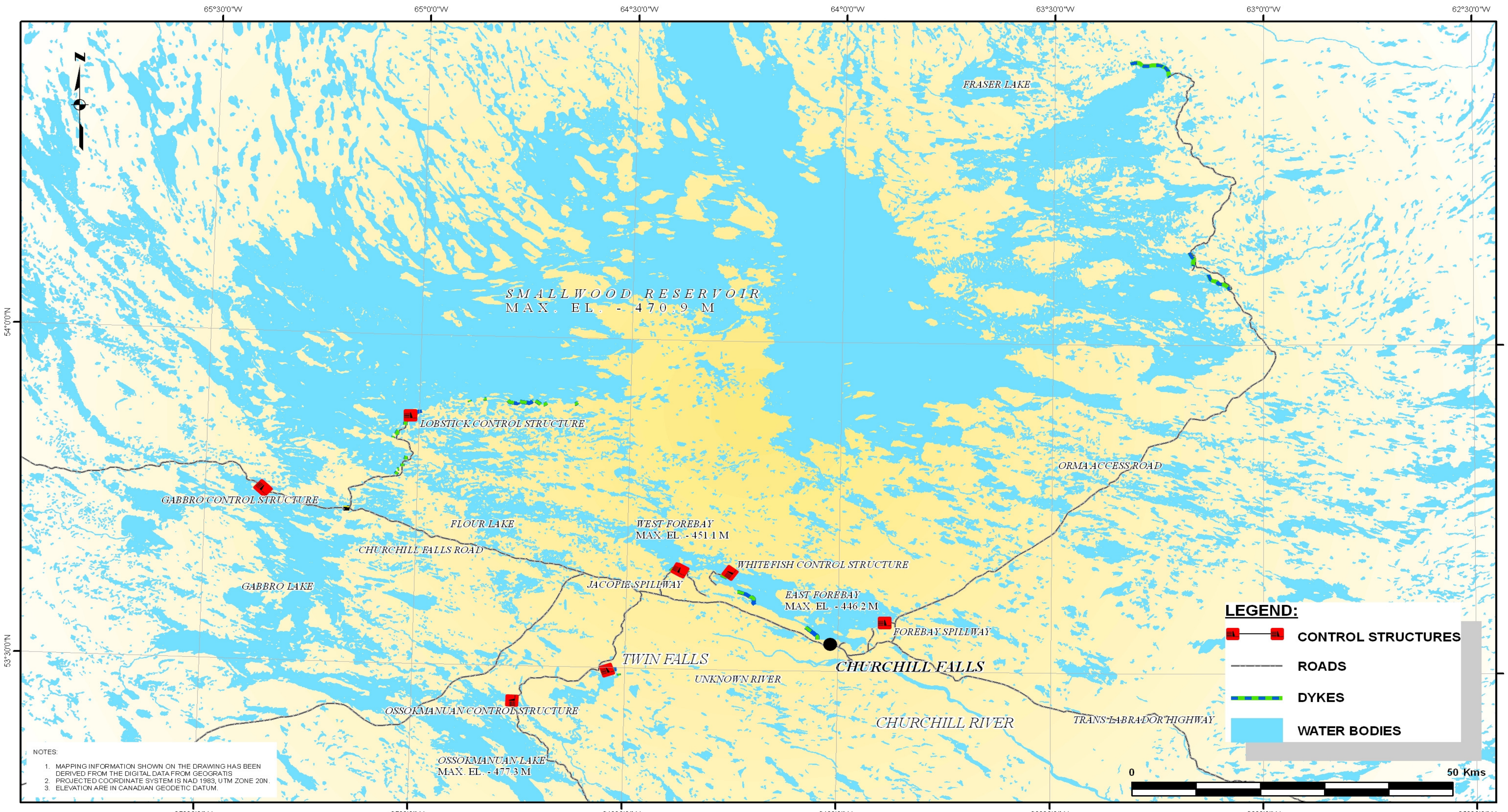
Figure 1.1
Project Location
Nalcor Energy - Lower Churchill Project
GI1141 - Upper Churchill PMF and Flood Handling Procedures Update



Note: not all dykes in the Upper Churchill system are shown.

Figure 1.2
Upper Churchill River System
Nalcor Energy - Lower Churchill Project
GI1141 - Upper Churchill PMF and Flood Handling Procedures Update

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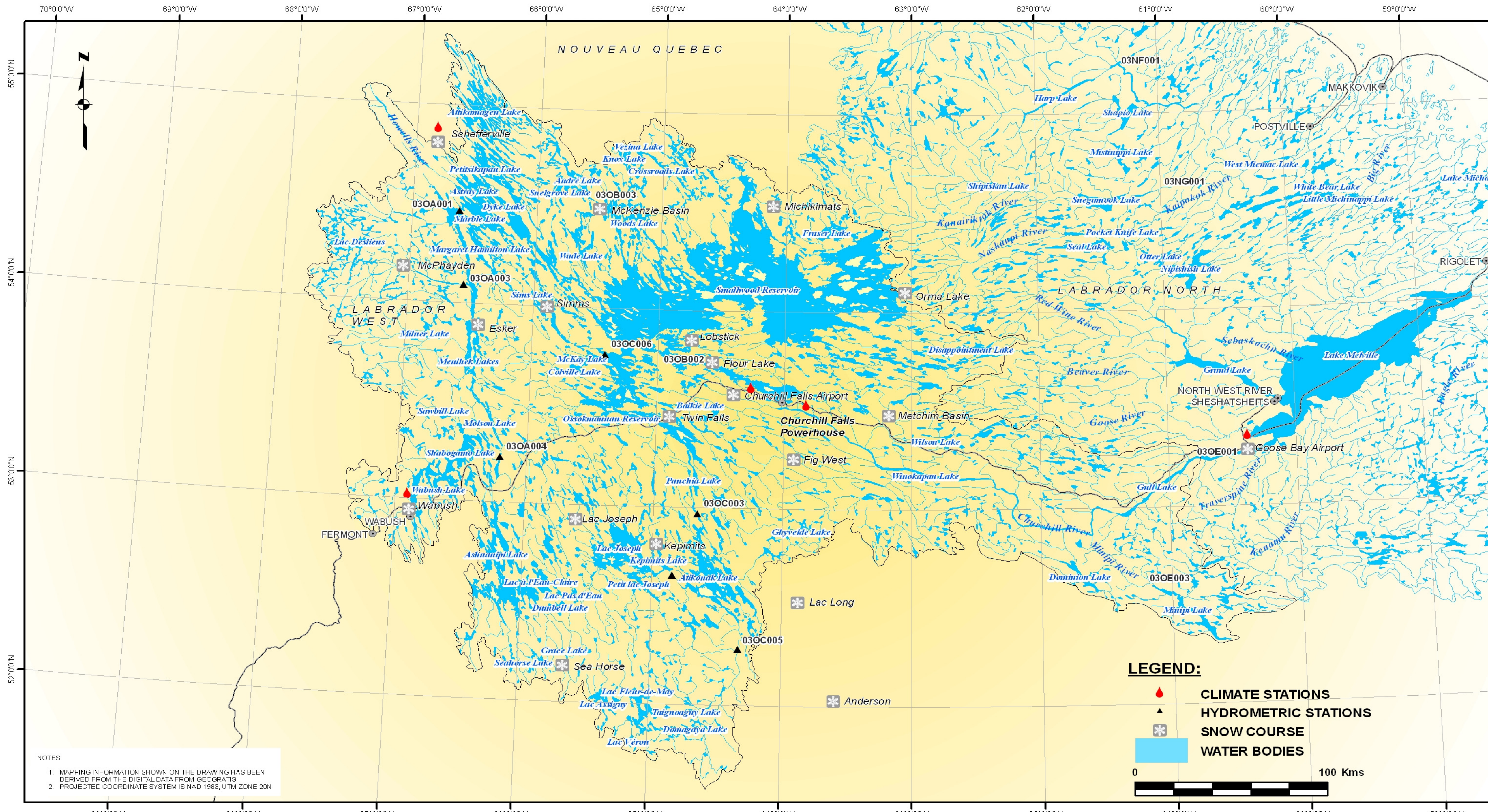

Figure 1.3
Upper and Lower Churchill Basins
Nalcor Energy - Lower Churchill Project
GI1141 - Upper Churchill PMF and Flood Handling Procedures Update

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2. Updated PMF Estimate

A review and discussion of the previous studies on the Upper Churchill PMF is provided in Chapter 2 of the Lower Churchill Project report GI1140 – PMF and Construction Design Flood Study. A discussion of the physiography and climate of the Upper Churchill Basin is provided in Chapter 4 of the same report. Hydrometeorological parameters (precipitation, temperature and snowpack) required for the updated PMF estimate are taken from Chapter 5 of the same report.

A SSARR watershed model of the Churchill River Basin was calibrated using meteorological data from Environment Canada (EC) climate stations at Goose Bay, Churchill Falls, Schefferville and Wabush, snow course, precipitation and lake level data from CF(L)Co and hydrometric data from eleven EC streamflow stations. The model was then used to test the various combinations of extreme rainfall, temperature and snowpack recommended by the CDA to determine the governing PMF case. Figure 2.1 shows the location of the SSARR model sub-basins and, in particular, Smallwood Reservoir, which is of principal interest in this review.

The CDA Dam Safety Guidelines (2007) outline the following PMF scenarios to be considered:

- A combination of a 1/100 AEP snow accumulation with the spring Probable Maximum Precipitation (PMP) and a 1/100 AEP temperature sequence;
- A combination of the Probable Maximum Snow Accumulation (PMSA) with a 1/100 AEP rainstorm and a 1/100 AEP temperature sequence;
- A summer/autumn PMF resulting from a summer/autumn PMP, with no snow on the ground, preceded by a 1/100 AEP pre-storm.

In GI1140, ten different storm centres for the spring and summer PMP and the two 1/100 AEP rainfall sequences were modelled using the SSARR watershed model to determine the critical PMF scenarios and storm centres for Gull Island and Muskrat Falls projects in the Lower Churchill River Basin. Three of these storm centres C-5, C-7 and C-9 (Figure 2.2) were located in the Upper Churchill Basin and the SSARR modelling results for these three storm centres formed the starting point for the current study.

The 1/100 AEP snow accumulation with the spring PMF and a 1/100 AEP temperature sequence was the critical PMF scenario for the Lower Basin and this was expected to be the case in the Upper Basin as well. However, the other two PMF scenarios, the PMSA with a 1/100 AEP rainstorm and a 1/100 AEP temperature sequence and the summer/autumn PMP preceded by a 1/100 AEP rainfall, were also modelled for the critical storm centre location to confirm this assumption.

2.1 Analysis

The objective of the GI1140 study was to determine the critical PMF at the proposed hydro projects in the Lower Basin. As such the critical hydrometeorologic parameters for the Upper Basin may be different from those for the Lower Basin. Thus the first step in the Upper Churchill PMF update was to define the critical hydrometeorologic parameters for the Upper Basin and select locations for new storm centres to be modelled.

Hydrometeorologic parameters affecting the PMF include:

1. Initial snowpack water equivalent conditions.
2. Melt temperature sequence.
3. Storm centre location.
4. Storm rainfall timing.
5. Storm orientation.

Items 1 and 2 of these hydrometeorologic parameters are independent of the critical PMP location. As reported in the GI1140 study, the 1/100 AEP Upper Basin average snowpack is 536 mm, and the maximum temperatures would be 24 °C during the melt period and 16 °C during the PMP.

However, items 3 to 5 are variable and the values that proved critical for the Lower Basin may not be critical for the Upper Basin.

2.2 Preliminary Analysis

2.2.1 Storm Centre Location

As reported in the GI1140 study, the critical spring PMP would have a 66-hour rainfall depth of 286 mm over the central 10 km^2.

Storm centre location and orientation affect the total depth of rainfall received during the PMP and/or the 1/100 AEP rainfall. Table 2.1 shows the spring PMP averages for the twelve sub-basins comprising the Upper Basin, for the ten storm centres C-1 through C-10 that were modelled for the total Churchill River Basin in the GI1140 study.

As expected, the storms centered the furthest north and west in Figure 2.2 result in the greatest rainfall over the upper basins.

Table 2.1
Spring PMP Variation with Storm Centre

Sub-Basin No.	Sub-Basin Name	Area (km^2)	Total Storm Depth over Sub-Basin (mm)									
			C-1	C-2	C-3	C-4	C-5	C-6	C-7	C-8	C-9	C-10
15	Smallwood South	5209	131	139	156	203	162	157	120	111	188	109
16	Smallwood Surface	6285	115	118	128	153	205	128	115	99	173	118
17	Smallwood North	9346	94	97	105	120	206	104	104	84	141	118
18	Ashuanipi Mouth	6714	78	82	90	109	162	101	116	86	135	103
19	Ashuanipi 03OA001	7296	79	88	98	117	121	117	196	131	140	83
20	McPhayden 03OA003	3609	72	80	90	110	124	107	148	108	132	68
21	Ashuanipi 03OA004	8309	70	78	83	93	69	104	135	140	97	70
22	Atikonak 03OC003	4458	101	111	116	117	80	139	125	190	111	69
23	Kepimits 03OC004	6968	86	98	104	110	80	125	147	201	110	73
24	Atikonak 03OC005	4023	66	73	73	73	35	86	89	113	68	94
25	Gabbro Lake	5547	101	112	123	153	135	153	226	157	208	81
26	Ossokmanuan Lake	1436	114	126	138	161	116	205	180	246	164	64
Basin Avg.	Atikonak River	22432	91	101	107	119	88	133	154	175	130	77
	Ashuanipi River	25928	75	82	90	106	115	107	149	119	124	82
	Smallwood Direct	20840	110	114	125	151	195	125	111	95	163	116
	Upper Basin	69200	91	98	106	124	130	121	139	130	138	91

The PMP storm centres most likely to yield the highest flows in the Upper Churchill basin are those that produce the greatest precipitation in the Upper Churchill sub-basins, i.e.:

- The Atikonak River Basin to Ossokmanuan/Gabbro Lakes (sub-basins 22-26).
- The Ashuanipi River Basin to Smallwood Reservoir (sub-basins 18-21).
- Direct runoff to Smallwood Reservoir (sub-basins 15-17).
- The total Upper Basin (sub-basins 15-26).

If the ten storm centres are ranked in order of maximum rainfall (1 for highest, 10 for lowest) over these four basins and then summed, the storms with the smallest sum (highest rank) would likely represent the critical storm centre location in the Upper Basin. Table 2.2 shows the highest ranked storm centres for the four basins above.

Table 2.2
Spring PMP Ranking of Storm Centres

Storm Centre	Atikonak River	Ashuanipi River	Smallwood Direct	Upper Basin	Sum
C-5	9	4	1	3	17
C-7	2	1	4	1	8
C-8	1	3	5	3	12
C-9	4	2	2	2	10

The sum of the spring PMP storm centre ranks and the rank for the upper basin as a whole suggest that a storm centered between C-7 (lowest sum, highest rank), the centroid of the upper basin, and C-9 (second lowest sum, second highest rank), at Churchill Falls, would likely result in the critical upper basin PMF.

However, when the peak outflow from Jacopie Spillway and the maximum water level in Smallwood Reservoir resulting from the SSARR PMF modelling are examined, the critical storm centre location shifts further north. Table 2.3 shows the maximum water levels in Smallwood Reservoir for the three PMF scenarios and the four storm centre locations in Table 2.2.

Table 2.3
Variation of Maximum Smallwood Reservoir Levels with PMF Scenario and Storm Centre

Storm Centre	PMF Scenario		
	1/100 AEP Snowpack + Spring PMP[1]	PMSA + 1/100 AEP Spring Rainfall[1]	1/100 AEP Rainfall + Summer PMP[2]
C-5	471.793 m	470.905 m	472.880 m
C-7	471.570 m	470.843 m	472.786 m
C-8	471.374 m	470.792 m	472.768 m
C-9	471.690 m	470.877 m	472.783 m

[1] Starting water level 469.68 m
[2] Starting water level 472.74 m

The maximum levels reached in Smallwood Reservoir by the summer PMF scenario are more than one metre higher than the two spring PMF scenarios. This is because the previous modelling of Smallwood Reservoir used a May 1 PMF starting level of 469.68 m, whereas the summer PMF modelling started at the full supply level (472.74 m). This means that the starting level in Smallwood Reservoir ahead of the spring PMF could be raised by approximately one metre without exceeding the maximum level expected from a summer PMF.

Table 2.4 shows the ranking of the four storm centres from highest to lowest for each of the PMF scenarios.

Table 2.4
Storm Centre Ranking by Maximum Smallwood Reservoir Levels

Storm Centre	PMF Scenario			
	1/100 AEP Snowpack + Spring PMP[1]	PMSA + 1/100 AEP Spring Rainfall[1]	1/100 AEP Rainfall + Summer PMP[2]	Overall Ranking
C-5	1	1	1	1
C-7	3	3	2	3
C-8	4	4	4	4
C-9	2	2	3	2

Table 2.4 shows that the critical storm centre ranking at Smallwood Reservoir for the two spring PMF scenarios (and the overall ranking of all three PMF scenarios) is:

1. C-5
2. C-9
3. C-7
4. C-8

This ranking is different from the average rainfall ranking and suggests that maximizing total basin precipitation is less critical in terms of the PMF at Smallwood Reservoir than maximizing the precipitation over the area draining directly to Smallwood Reservoir.

The reason for this effect lies in the extensive natural and man-made storage in the Ashuanipi and Atikonak River Basins. Rainfall running off from these basins is significantly attenuated by large lakes such as Ashuanipi, Shabogamo and Wabash Lakes on the Ashuanipi River and Lac Joseph, Atikonak and Ossokmanuan/Gabbro Lakes on the Atikonak River, whereas the basins draining directly to Smallwood Reservoir includes only smaller lakes.

This preliminary analysis of critical storm centre location in determining the Upper Churchill PMF suggests that PMP and 1/100 AEP rain storms should be centred over Smallwood Reservoir itself.

2.2.2 Storm Rainfall Timing

A second variable that can affect the magnitude of the PMF is the timing of the PMP or 1/100 AEP rainfall relative to extreme melt temperatures or preceding rainfall. This timing is constrained in terms of how soon the storm can occur due to maximum dew point temperatures during the PMP or minimum durations between major storm events. However, there are no constraints on delaying the storm rainfall by a few hours or days, so this was also reviewed using the SSARR modelling results from the Lower Churchill PMF Study.

Analysis of the results for the summer PMF scenario shows that a PMP commencing as soon after the 1/100 AEP rainfall as possible always yields the maximum summer PMF.

The earliest the spring PMP can start while not exceeding the World Meteorological Organization recommended maximum temperature of 16° C during the PMP is 0600 hours on June 1. Table 2.5 shows the maximum Smallwood Reservoir levels for spring PMP storm centres C-5 and C-9 for a range of PMP start times after this minimum time-date constraint.

Table 2.5
Maximum Smallwood Reservoir Level Variation with Spring PMP Start Time-Date

Start Time-Date	Storm Centre	
	C-5	C-9
0600 June 1st	471.751 m	471.653 m
0600 June 2nd	471.775 m	471.675 m
1200 June 2nd	471.783 m	471.683 m
1800 June 2nd	471.792 m	471.690 m
2400 June 2nd	471.793 m	471.690 m
0600 June 3rd	471.789 m	471.686 m
0600 June 4th	471.737 m	471.633 m

Table 2.5 shows that, for both storm centres, the maximum spring PMF water level in Smallwood Reservoir would result from a PMP commencing 42 hours after the minimum time-date constraint at 2400 hours on June 2.

2.2.3 *Storm Orientation*

The PMP storm orientation developed for the Lower Churchill PMF Study was WNW to ESE along the major axis of the elliptical storm isohyets, the same orientation as the Lower Churchill River Basin. Having established that the maximum PMF impact in Smallwood Reservoir would result from a PMP centered over the area draining directly to the reservoir, the critical PMP storm orientation should also maximize precipitation over this area.

Reference to Figure 2.2 shows that the area draining directly to Smallwood Reservoir (sub-basins 15, 16 and 17) is also oriented WNW to ESE, so no change in the PMP storm orientation is required for the Upper Churchill Basin PMF.

2.2.4 Preliminary Analysis Summary

The preliminary analysis of the Lower Churchill PMF Study indicated that the Upper Churchill Basin PMF should comprise the following:

- the 1/100 AEP snowpack and spring PMP and summer PMF scenarios;
- additional storm centres located in the area draining directly to Smallwood Reservoir;
- a spring PMP commencing at 2400 hours on June 2; and
- the same storm orientation as the Lower Churchill PMF Study (WNW to ESE).

2.3 Additional Analysis

2.3.1 Storm Centres

Figure 2.2 shows additional storm centres U-1 to U-5 which were evaluated for the Upper Churchill Basin PMF analysis.

The sub-basin average spring PMP depths from these new storm centres are shown in Table 2.6, together with storm centres C-5, C-7, C-8 and C-9 that were previously evaluated for the total Churchill River Basin in the GI1140 study.

Table 2.6
Upper Basin Spring PMP Variation with Storm Centre

Sub-Basin No.	Sub-Basin Name	Area (km^2)	Total Storm Depth over Sub-Basin (mm)								
			U-1	U-2	U-3	U-4	U-5	C-5	C-7	C-8	C-9
15	Smallwood South	5209	137	181	191	197	151	162	120	111	188
16	Smallwood Surface	6285	166	198	230	226	207	205	115	99	173
17	Smallwood North	9346	189	162	179	171	210	206	104	84	141
18	Ashuanipi Mouth	6714	204	155	134	124	135	162	116	86	135
19	Ashuanipi 03OA001	7296	136	134	112	102	102	121	196	131	140
20	McPhayden 03OA003	3609	143	135	114	103	107	124	148	108	132
21	Ashuanipi 03OA004	8309	74	86	69	62	57	69	135	140	97
22	Atikonak 03OC003	4458	77	94	83	78	70	80	125	190	111
23	Kepimits 03OC004	6968	82	100	84	77	70	80	147	201	110
24	Atikonak 03OC005	4023	35	58	52	37	31	35	89	113	68
25	Gabbro Lake	5547	146	178	132	121	115	135	226	157	208
26	Ossokmanuan Lake	1436	114	136	119	111	101	116	180	246	164
Basin Avg.	Atikonak River	22432	91	113	92	83	76	88	154	175	130
	Ashuanipi River	25928	135	124	104	95	97	115	149	119	124
	Smallwood Direct	20840	169	178	197	194	195	195	111	95	163
	Upper Basin	69200	131	137	128	121	119	130	139	130	138

The SSARR model for the Upper Basin was run with these new storm centre PMP averages to determine the impact on Smallwood Reservoir. A spring PMP commencing at 2400 hours on June 2 with the same storm orientation (WNW to ESE) was used for these new PMF simulations.

Table 2.7 shows the maximum spring PMF water levels in Smallwood Reservoir from these and the previous storm centres.

Table 2.7
Maximum Spring PMF Levels in Smallwood Reservoir vs. Storm Centre

Storm Centre	Maximum Smallwood Reservoir Level[1]
C-5	471.793 m
C-7	471.570 m
C-8	471.297 m
C-9	471.690 m
U-1	471.782 m
U-2	471.751 m
U-3	471.747 m
U-4	471.699 m
U-5	471.712 m

[1] Starting water level 469.68 m

Table 2.7 shows that storm centre C-5 results in the highest spring PMF water level in Smallwood Reservoir from the SSARR model routing. Since storm centres in all directions around storm centre C-5 yield lower water levels in Smallwood Reservoir, storm centre C-5 can be adopted as the critical storm centre for the Upper Churchill PMF.

To confirm that the 1/100 AEP snowpack plus spring PMP is the critical PMF scenario for this storm centre, the PMSA, spring PMF and summer PMF scenarios were also simulated for storm centre C-5.

Table 2.8 shows the maximum water levels in Smallwood Reservoir for the three PMF scenarios, using storm centre C-5.

Table 2.8
Maximum Smallwood Reservoir Levels vs PMF Scenario for Storm Centre C-5

Storm Centre	PMF Scenario		
	1/100 AEP Snowpack + Spring PMP[1]	PMSA + 1/100 AEP Spring Rainfall[1]	1/100 AEP Rainfall + Summer PMP[2]
C-5	471.793 m	470.905 m	472.880 m

[1] Starting water level 469.68 m
[2] Starting water level 472.74 m

2.3.2 *PMF Hydrographs*

The operating rules used in the SSARR model to route flows through Ossokmanuan/Gabbro Lake and Smallwood Reservoir are only an approximation of the flood handling procedures for the Churchill Falls Project. The detailed PMF routing requires the use of the decision-based ARSP model. The ARSP model requires PMF inflow hydrographs to Ossokmanuan/Gabbro Lake and Smallwood Reservoir to model the detailed PMF flood handling procedures.

Figure 2.3 shows the spring PMF inflow hydrographs generated by the SSARR model for storm centre C-5. The hydrograph values were generated by SSARR using a six hour time step and are tabulated in Appendix A.

The peak instantaneous inflow to Smallwood Reservoir (24,800 m^3/s) results from direct rainfall (plus snowmelt) on the reservoir surface, where there is no travel time to reach the reservoir. This is followed by a peak of 16,400 m^3/s caused by runoff from the full drainage area that feeds the reservoir. The peak inflow to Ossokmanuan/Gabbro Lake is 5,860 m^3/s.

The previous PMF estimate was presented in the 1989 Acres study as one daily flow hydrograph for the entire Upper Basin, having a maximum daily inflow of 30,764 m^3/s. The updated PMF estimate is compared to the previous PMF estimate on a daily flow basis in the next chapter (Section 3.2).

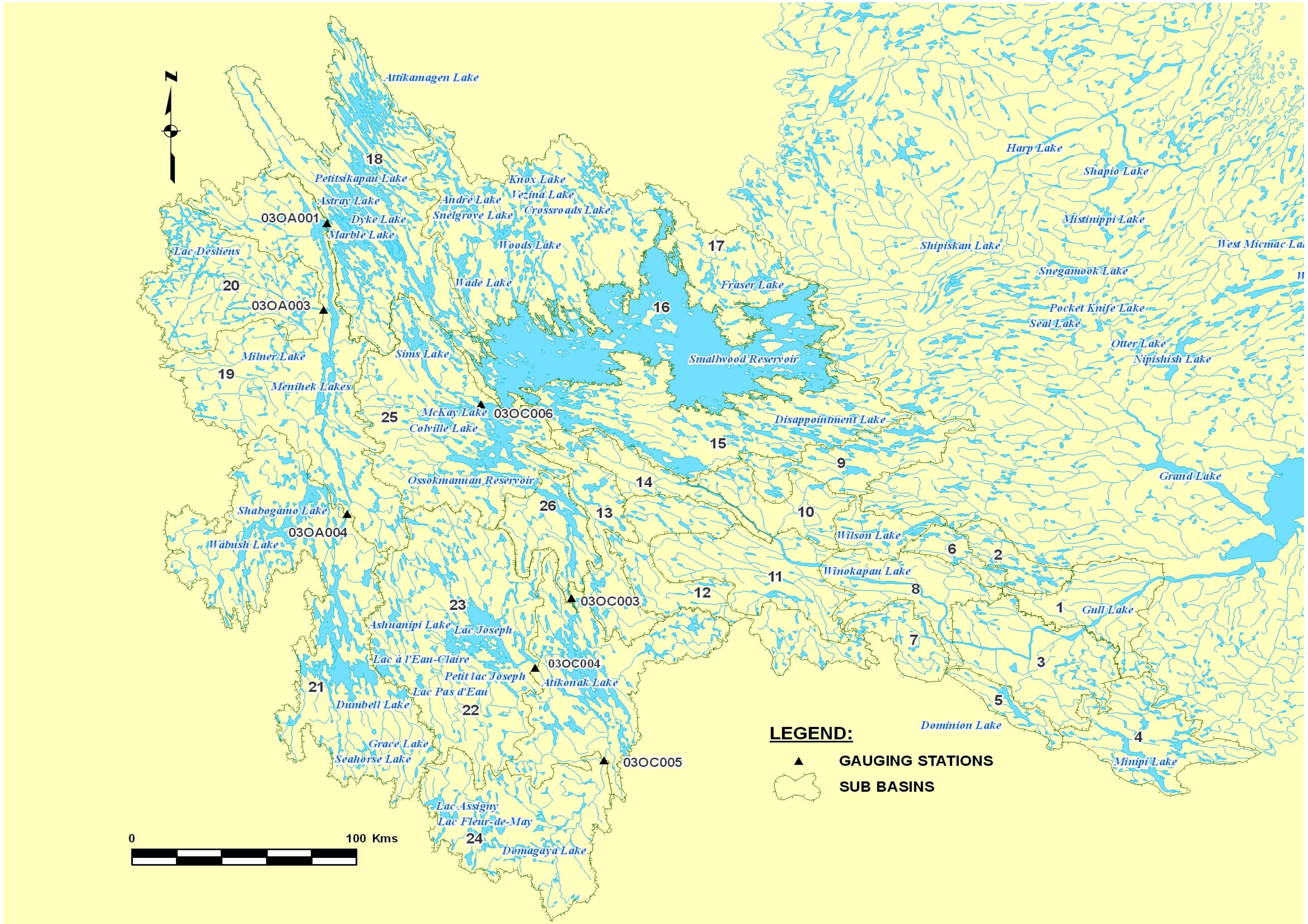

Figure 2.1
River Basin Locations
Nalcor Energy - Lower Churchill Project
GI1141 - Upper Churchill PMF and Flood Handling Procedures Update

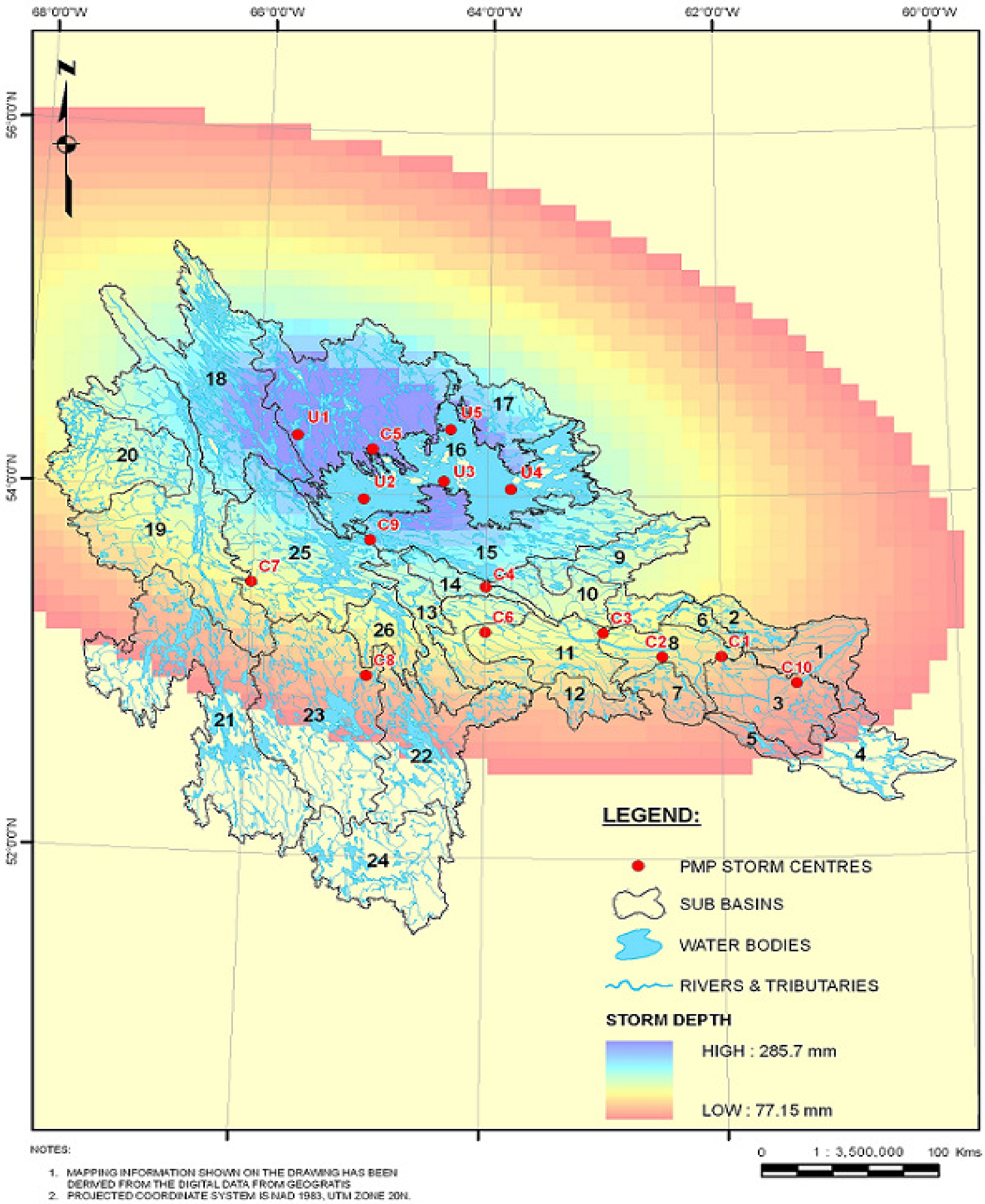

Figure 2.2
PMP Storm Centres
Nalcor Energy - Lower Churchill Project
GI1141 - Upper Churchill PMF and Flood Handling Procedures Update

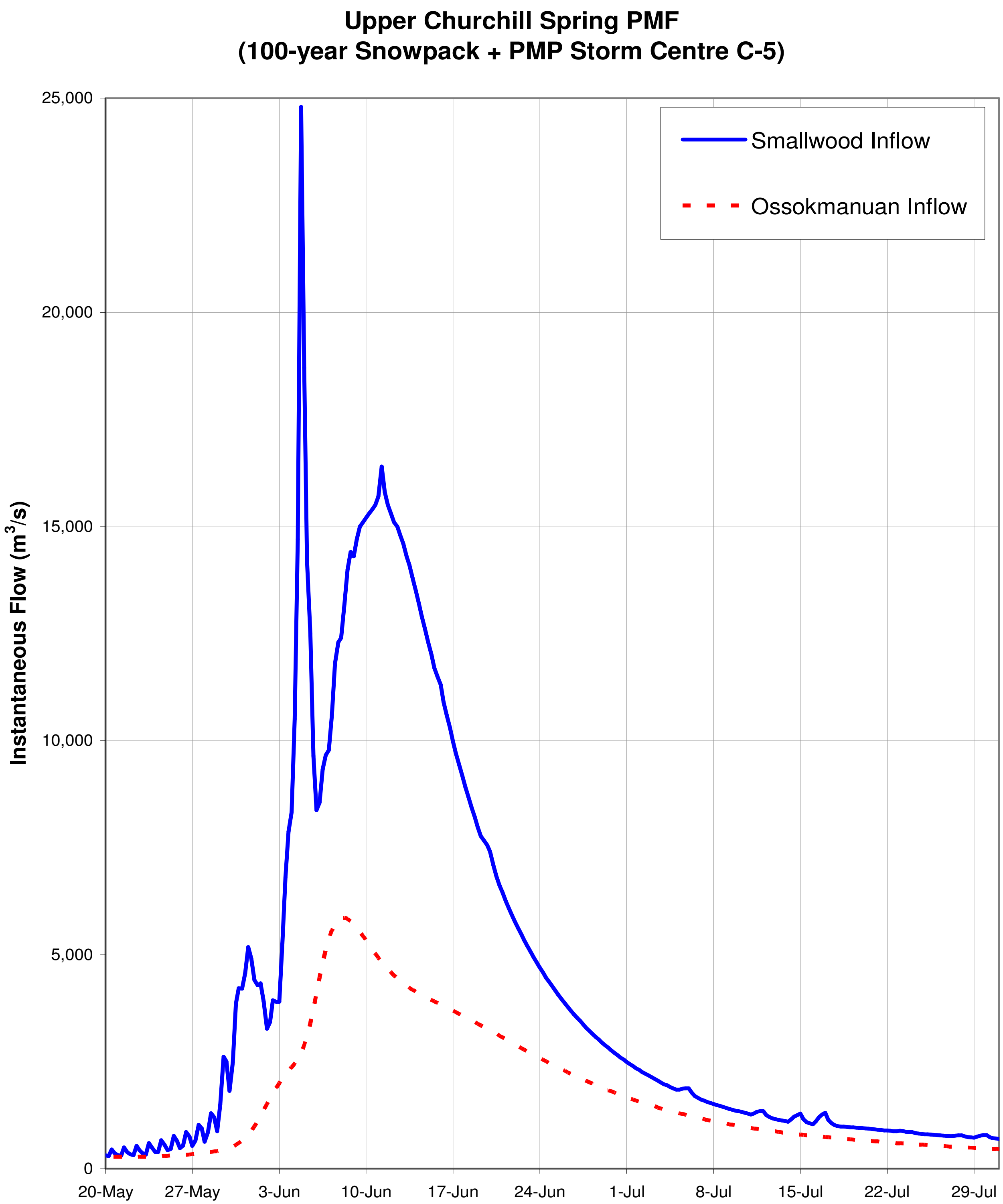

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Figure 2.3
Upper Churchill Spring PMF Inflow Hydrographs
Nalcor Energy - Lower Churchill Project
GI1141 - Upper Churchill PMF and Flood Handling Procedures Update

3. Churchill Falls Flood Routing

The flood handling operation of the Churchill Falls Project employs decision-based procedures defined in the Flood Handling Study undertaken by Acres in 1989. In the SSARR hydrological modelling of the PMF scenarios and storm centre comparisons, these flood handling procedures were represented by effective stage-discharge rating relationships. However, review of flood handling procedures for the critical PMF/storm centre scenario requires routing through the Churchill Falls complex using the decision-based ARSP operational model. This also provides the most accurate estimate of the Upper Basin contribution to the Lower Basin PMF.

3.1 Upper Basin Operational Model

The model used to define the flood handling operation of the Churchill Falls Project in 1989 was the Acres Reservoir Simulation Program (ARSP). ARSP is a general multipurpose, multi-reservoir simulation program that represents the water resource system as a capacitated flow network. Operating policies and priorities are defined through a penalty structure associated with each element of the flow network, and optimal operating decisions can be made given the initial state of the system and estimates of net inflows to the system.

The 1989 ARSP model for Churchill Falls was recompiled for the Lower Churchill PMF study (GI1140), and revised for the present study using PMF inflows to Smallwood Reservoir and Ossokmanuan/Gabbro Lake from the integrated basin-wide SSARR model. Figure 3.1 shows a schematic of the ARSP model and Table 3.1 provides a description of the numbered components of the model.

3.2 Comparison of PMF Inflow Estimates

Whereas the SSARR model generates inflows at six hour intervals, ARSP operates on a daily time step. Therefore the SSARR inflows were converted to daily inflows for use in the ARSP model.

Table 3.2 compares the maximum daily inflows for the 1969 and 2009 PMF estimates. The 1969 PMF was presented in the 1989 Acres study as one daily hydrograph for the entire Upper Basin, having a maximum daily inflow of 30,764 m^3/s. To enable a comparison, this has been broken down by the reservoir drainage areas used for the present study.

Figure 3.2 shows the inflow hydrographs for both the 1969 and 2009 PMF estimates. The maximum daily inflow of the 2009 PMF estimate occurs earlier than that of the 1969 estimate, for both Smallwood Reservoir and Ossokmanuan/Gabbro Lake. The 1969 Smallwood PMF hydrograph has a maximum daily inflow of 20,035 m^3/s, occurring on June 18. The 2009 Smallwood PMF hydrograph is represented as a two-peak event. The initial peak on June 4 has a daily inflow of 16,540 m^3/s due to direct rainfall (plus snowmelt) on the reservoir surface. This is followed by a second peak on June 11 with a daily inflow of 15,170 m^3/s caused by runoff from the full drainage area that feeds the reservoir. For Ossokmanuan/Gabbro Lake, the maximum daily inflows for the 1969 and 2009 PMF estimates are 9,965 m^3/s on June 18 and 5,798 m^3/s on June 8, respectively.

3.3 Existing Flood Handling Procedures

3.3.1 Description of Existing Procedures

The existing flood handling procedures for the Churchill Falls Project are based on the Flood Handling Study prepared by Acres in 1989. The 1989 procedures were based on the 1969 PMF estimate. Key aspects of the flood handling procedures are summarized below.

- A pre-spill procedure is used by CF(L)Co to determine the extent to which the Smallwood Reservoir must be drawn down during the late winter to provide flood handling capacity for the spring freshet.
- The pre-spill procedure predicts the amount of reservoir inflow that can be expected in the coming freshet. This takes into consideration various factors such as the accumulated snowpack on the ground. Based on the predicted inflow, the desired May 1 target level to ensure safe handling of the expected inflow is calculated.
- If the predicted inflow is potentially the PMF, the May 1 target level is set at 469.68 m. (However, the PMF being an extremely remote event, the May 1 target level is normally much higher, e.g., 472.26 m for mean annual snowpack.)
- In any case, if Smallwood Reservoir is above the May 1 target level, it must be drawn down in advance of May 1 by turbining water through the powerhouse. (In most years, the Smallwood level on May 1 has been below the PMF target.)
- The May 1 target level defines the initial point on the reservoir rule curve (the track of desired reservoir level over time) before the freshet. During the spring runoff period, the rule curve is set equal to the May 1 target level for several weeks following May 1. The rule curve then rises to FSL by the end of the spring runoff period.
- As long as Smallwood is below its rule curve, releases are made from Ossokmanuan/Gabbro into Smallwood. If Smallwood rises above its rule curve, Gabbro Control Structure is closed, eliminating further inflow to the Smallwood Reservoir from Ossokmanuan/Gabbro. This action effectively divides the Churchill system into two components (Smallwood and Ossokmanuan/Gabbro) which are then managed independently for the rest of the flood period.
- In managing the Smallwood level, water is discharged through Lobstick Control Structure and then through the power plant and Jacopie Spillway in order to maintain the reservoir at rule curve.
- In an extreme flood event, additional discharge capacity from the system would be provided through the Forebay Spillway (via the Lobstick and Whitefish Control Structures), upon Smallwood Reservoir attaining a defined trigger level (473.20 m). Note: use of the Forebay Spillway is restricted due to the elevated plant tailwater level that would result from debris being carried from the spillway channel into the Churchill River below the power plant tailrace. However, the flood handling procedures, as they currently exist, are to use the Forebay Spillway in flood events of extremely remote frequency (including the PMF).

- In managing the Ossokmanuan/Gabbro level, after Gabbro Control Structure is closed, Ossokmanuan Control Structure is opened. In an extreme flood event, controlled dike breaching is required upon Ossokmanuan/Gabbro attaining a defined trigger level.
- During the PMF, power plant discharge is assumed to be zero due to interruption of generation, possibly from transmission system failure which might not be restored during the flood event. (However, even if a power flow is assumed, there is no change in the simulated maximum levels or total Upper Basin discharge; the power flow is simply diverted from the spill flow already going through Jacopie.)

3.3.2 Simulation of Existing Procedures

As discussed in Chapter 1, detailed PMF modelling following the current CDA Guidelines has shown that the 1969 PMF estimate is too conservative, and as a result the existing flood handling procedures for the PMF are also too conservative. This is shown by routing the 2009 PMF estimate (i.e., storm centre C-5) in the ARSP model using the existing flood handling procedures, and comparing it to the routing of the 1969 estimate as follows.

Figures 3.3 and 3.4 compare the simulated water level in Smallwood and Ossokmanuan/Gabbro Reservoirs for the 1969 and 2009 PMF estimates.

For the 1969 PMF estimate, in Smallwood Reservoir, the May 1 target level (469.68 m) and rule curve result in a Maximum Flood Level (MFL) of 473.66 m. The water level starts to rise above the rule curve (triggering closure of the Gabbro Control Structure and hydrologically separating Smallwood from Ossokmanuan). Spill is continuously discharged through the Lobstick Control Structure to the Jacopie Spillway, but water begins to store in the reservoir on June 2 when the inflow exceeds the spill capacity at Lobstick. The water level continues to rise past 473.20 m which triggers opening of the Whitefish Control Structure to pass Smallwood spill through the Forebay Spillway on June 21. The peak water level of 473.66 m (MFL) occurs on June 30, and the water level subsequently returns to the Full Supply Level (FSL) of 472.74 m.

The rising water level in Ossokmanuan/Gabbro Lake triggers spill through the Ossokmanuan Control Structure on June 3. Controlled breaches of Julian Dykes 3, 4 and 7 are initiated on June 9. The peak water level of 480.06 m occurs on June 16.

For the 2009 PMF estimate, in Smallwood Reservoir, the water level starts to rise above the rule curve (triggering closure of the Gabbro Control Structure and hydrologically separating Smallwood from Ossokmanuan). Spill is continuously discharged through the Lobstick Control Structure to the Jacopie Spillway, but water begins to store in the reservoir on June 3 when the inflow exceeds the spill capacity at Lobstick. The water level rises to a peak level of 471.77 m on June 22. The water level then decreases until it encounters the rule curve on June 30, when the reservoir resumes filling as normal, and eventually reaches FSL.

The rising water level in Ossokmanuan/Gabbro Lake triggers spill through the Ossokmanuan Control Structure on June 6. Controlled breaches of Julian Dykes 3, 4 and 7 are initiated on June 13 just as the peak water level of 479.32 m occurs.

It is evident that the 1969 PMF estimate is more conservative than the 2009 PMF estimate, as it results in a water level in Smallwood Reservoir almost 2 m higher when the same rules are followed. It should also be noted that for the 2009 PMF estimate, when using the existing May 1 target level/rule curve, it is no longer necessary to pass spill from Smallwood through the Whitefish Control Structure and the Forebay Spillway.

Tables 3.3 and 3.4 outline the simulated flows in the ARSP model for the 1969 and 2009 PMF estimates, respectively.

3.4 Modified Flood Handling Procedures

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Table 3.1
ARSP Schematic Description

Schematic No.	Description
1	Ossokmanuan/Gabbro Lake Inflow (from SSARR)
2	Ossokmanuan Control Structure Outflow
3	Julian Dyke 7 Breach Outflow
4	Julian Dykes 3&4 Breach Outflow
7	Gabbro Control Structure Outflow
8	Gabbro Control Structure Overflow
9	Smallwood Reservoir Inflow (from SSARR)
10	Orma/Sail Dykes Outflow
11	Lobstick Control Structure Outflow
12	Lobstick Dyke Breach Outflow
13	West Forebay Inflow
14	Jacopie Spillway Outflow
15	Jacopie Dyke Breach Outflow
16	Whitefish Control Structure Outflow
17	East Forebay Inflow
18	East Forebay Spillway Outflow
19	Churchill Falls Power Flow
20	Churchill River Flow downstream of Jacopie Spillway
21	Total Ossokmanuan/Gabbro Lake Outflow to Lower Basin
22	Total Upper Churchill Outflow to Lower Basin (to HEC-RAS)

Table 3.2
PMF Maximum Daily Inflows

Reservoir	ARSP Drainage Area	PMF Maximum Daily Inflow (m^3/s)	
	(km^2)	1969 Estimate[1]	2009 Estimate
Smallwood	45,110	20,035	[redacted] [redacted]
Ossokmanuan/Gabbro	22,432	9,963	[redacted]
West Forebay	1,108	492	[redacted]
East Forebay	617	274	[redacted]

Notes:
1. Based on drainage areas used for 2009 study.
   Original 1969 estimate is reported as 30,764 m^3/s maximum daily inflow to total Upper Churchill Basin.
2. First peak due to direct rainfall (plus snowmelt) on reservoir surface
3. Second peak due to runoff from the full drainage area to the reservoir

Table 3.3
ARSP Model 1969 PMF Routing through Upper Churchill Project
(Flows in m³/s)

Schematic No.	1	2	3	4	7	9	11	13	14	16	17	18	21	22
Date	**Ossok/Gabbro Inflow**	**Ossok CS**	**Julian Dyke 7 Breach**	**Julian Dykes 3&4 Breach**	**Gabbro CS**	**Smallwood Inflow**	**Lobstick CS**	**West Forebay Inflow**	**Jacopie Spillway**	**Whitefish CS**	**East Forebay Inflow**	**East Forebay Spillway**	**Total Ossok Outflow to Lower Basin**	**Total Upper Churchill Outflow**
26-May	229	0	0	0	585	461	1,928	11	1,965	0	6	0	0	1,965
27-May	318	0	0	0	646	640	2,277	16	2,322	0	9	0	0	2,322
28-May	334	0	0	0	653	671	2,667	16	2,723	0	9	0	0	2,723
29-May	437	0	0	0	666	879	3,083	22	3,149	0	12	0	0	3,149
30-May	564	0	0	0	686	1,135	3,659	28	3,741	0	16	0	0	3,741
31-May	719	0	0	0	713	1,446	4,358	36	4,458	0	20	0	0	4,458
1-Jun	857	0	0	0	0	1,723	4,509	42	4,593	0	24	0	0	4,593
2-Jun	1,014	0	0	0	0	2,039	4,717	50	4,673	0	28	39	0	4,712
3-Jun	1,208	536	0	0	0	2,429	4,730	60	4,774	0	33	81	536	5,391
4-Jun	1,472	1,196	0	0	0	2,959	4,755	73	4,854	0	40	101	1,196	6,151
5-Jun	1,807	1,424	0	0	0	3,634	4,795	89	4,930	0	50	121	1,424	6,475
6-Jun	2,219	1,836	0	0	0	4,462	4,848	110	5,010	0	61	141	1,836	6,987
7-Jun	2,707	2,251	0	0	0	5,444	4,915	134	5,102	0	74	161	2,251	7,514
8-Jun	3,304	2,630	0	0	0	6,645	4,891	163	5,182	0	91	181	2,630	7,993
9-Jun	4,054	2,726	2,753	311	0	8,152	4,746	200	5,221	0	112	201	5,790	11,212
10-Jun	4,878	2,708	2,732	295	0	9,809	4,706	241	5,221	0	134	218	5,735	11,174
11-Jun	5,748	2,863	2,965	454	0	11,560	4,670	284	5,221	0	158	234	6,282	11,737
12-Jun	6,657	3,024	3,204	668	0	13,386	4,649	329	5,221	0	183	243	6,896	12,360
13-Jun	7,495	3,146	3,373	908	0	15,072	4,643	370	5,221	0	206	245	7,427	12,893
14-Jun	8,231	3,230	3,520	1,075	0	16,551	4,647	407	5,221	0	226	244	7,825	13,290
15-Jun	8,927	3,286	3,630	1,173	0	17,952	4,661	441	5,221	0	246	238	8,089	13,548
16-Jun	9,507	3,308	3,673	1,212	0	19,117	4,685	470	5,221	0	261	227	8,193	13,641
17-Jun	9,893	3,300	3,657	1,198	0	19,895	4,712	489	5,221	0	272	216	8,155	13,592
18-Jun	9,963	3,273	3,602	1,149	0	20,035	4,739	492	5,221	0	274	204	8,024	13,449
19-Jun	9,907	3,231	3,516	1,072	0	19,922	4,766	489	5,221	0	272	193	7,819	13,233
20-Jun	9,623	3,175	3,413	964	0	19,352	4,792	475	5,221	0	265	181	7,552	12,954
21-Jun	9,272	3,110	3,323	820	0	18,645	6,711	458	5,221	1,892	255	2,062	7,253	14,536
22-Jun	8,777	3,040	3,224	683	0	17,651	6,788	434	5,221	1,942	241	2,100	6,947	14,268
23-Jun	8,315	2,964	3,111	582	0	16,721	6,854	411	5,221	1,985	229	2,133	6,657	14,011
24-Jun	7,827	2,885	2,993	479	0	15,740	6,909	387	5,221	2,018	215	2,156	6,357	13,734
25-Jun	7,323	2,804	2,872	378	0	14,727	6,955	362	5,221	2,040	201	2,168	6,054	13,443
26-Jun	6,833	2,715	2,739	302	0	13,741	6,991	338	5,221	2,053	188	2,171	5,756	13,148
27-Jun	6,409	2,625	2,603	230	0	12,888	7,019	317	5,221	2,063	176	2,174	5,458	12,853
28-Jun	5,964	2,540	2,477	165	0	11,993	7,039	295	5,221	2,066	164	2,169	5,182	12,572
29-Jun	5,625	2,462	2,360	107	0	11,312	7,053	278	5,221	2,062	155	2,157	4,929	12,307
30-Jun	5,140	2,381	2,239	47	0	10,337	7,060	254	5,221	2,051	141	2,139	4,667	12,027

Table 3.4
ARSP Model 2009 Upper Churchill PMF Routing through Upper Churchill Project
(Flows in m^3/s)

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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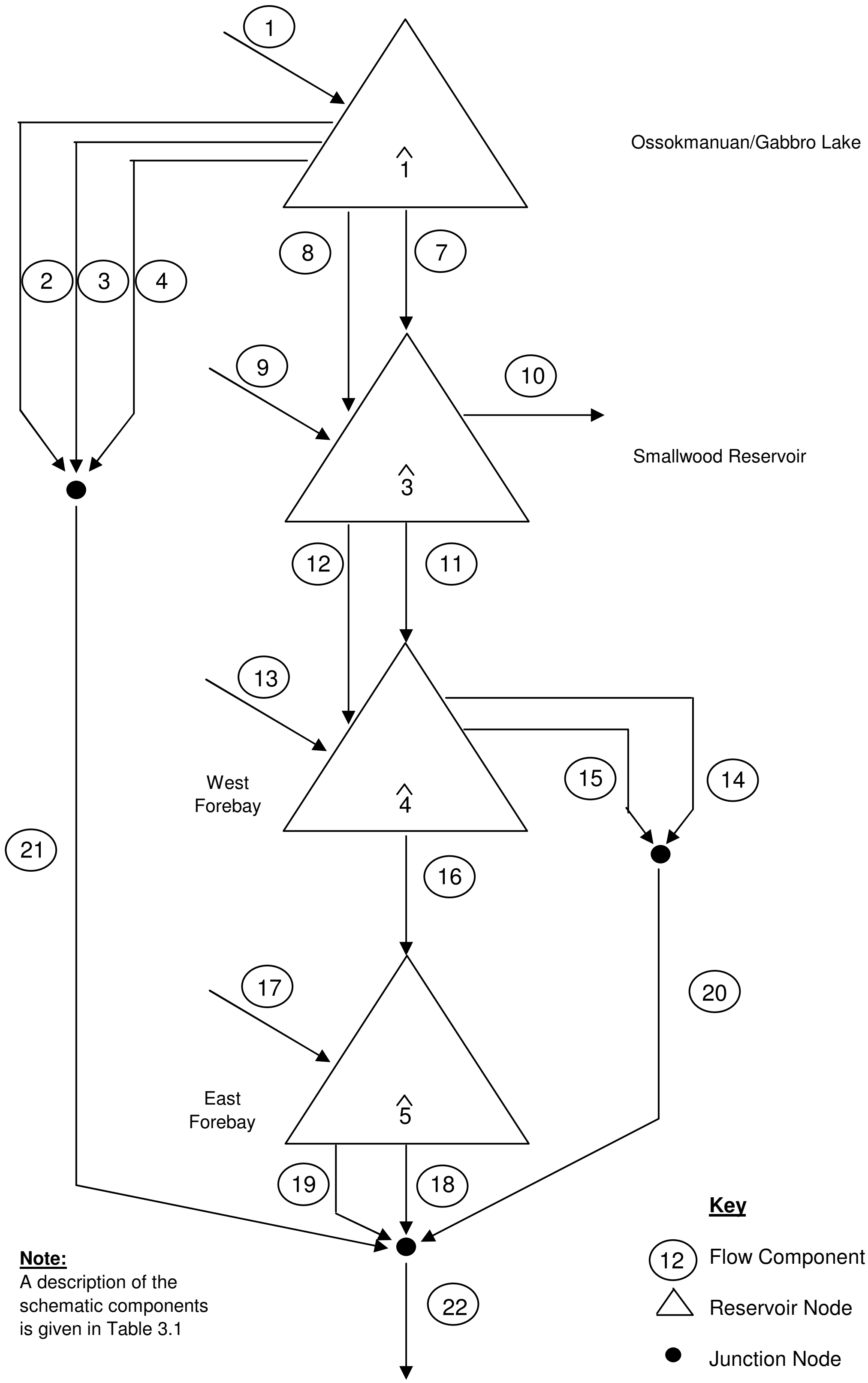

Note:
A description of the schematic components is given in Table 3.1

Figure 3.1
ARSP Model Schematic
Nalcor Energy - Lower Churchill Project
GI1141 - Upper Churchill PMF and Flood Handling Procedures Update

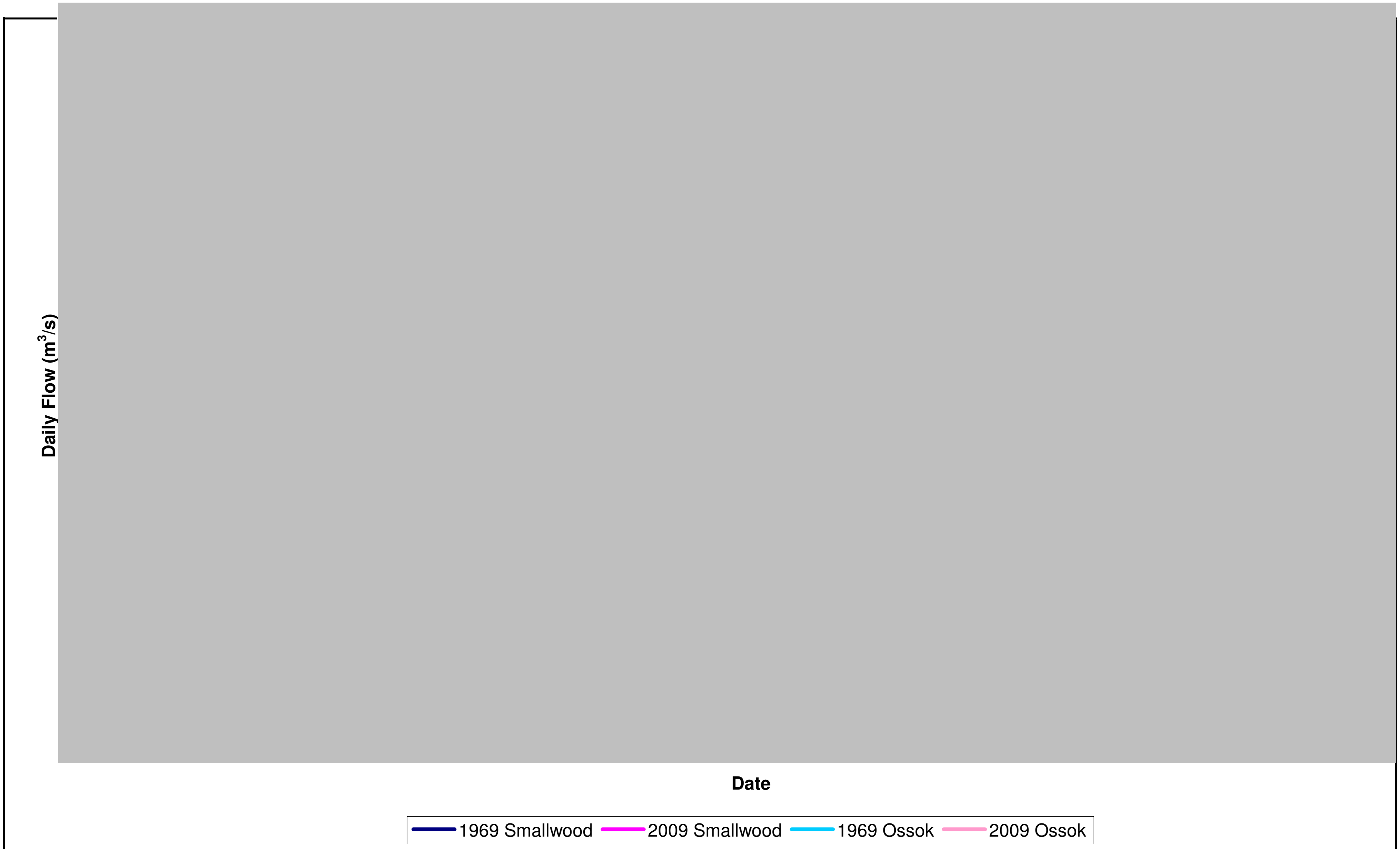

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Figure 3.2
Comparison of PMF Estimates: Daily Inflow Hydrographs
Nalcor Energy - Lower Churchill Project
GI1141 - Upper Churchill PMF and Flood Handling Procedures Update

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Figure 3.3
Comparison of PMF Estimates: Smallwood Reservoir Level
Nalcor Energy - Lower Churchill Project
GI1141 - Upper Churchill PMF and Flood Handling Procedures Update

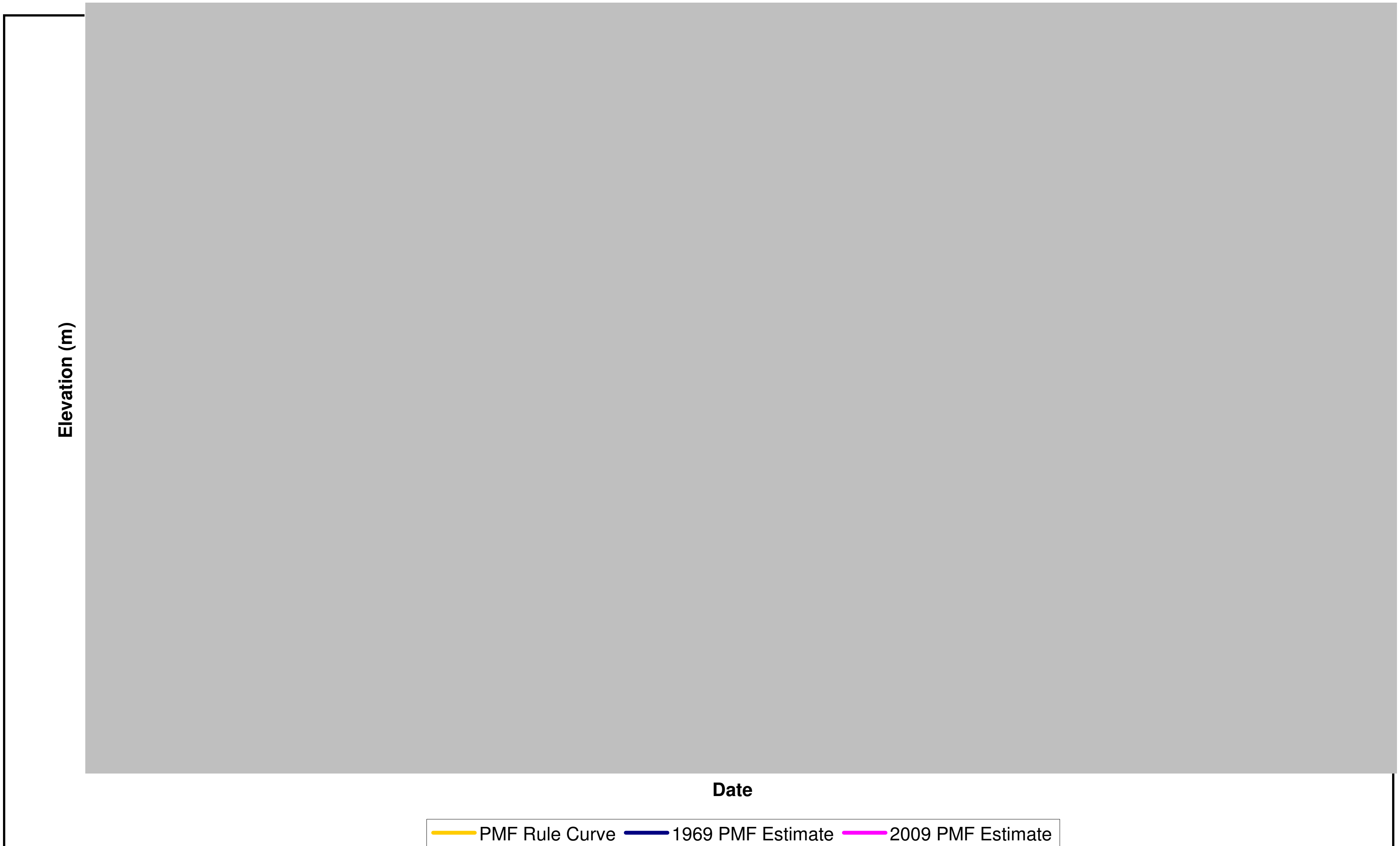

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Figure 3.4
Comparison of PMF Estimates: Ossokmanuan/Gabbro Lake Level
Nalcor Energy - Lower Churchill Project
GI1141 - Upper Churchill PMF and Flood Handling Procedures Update

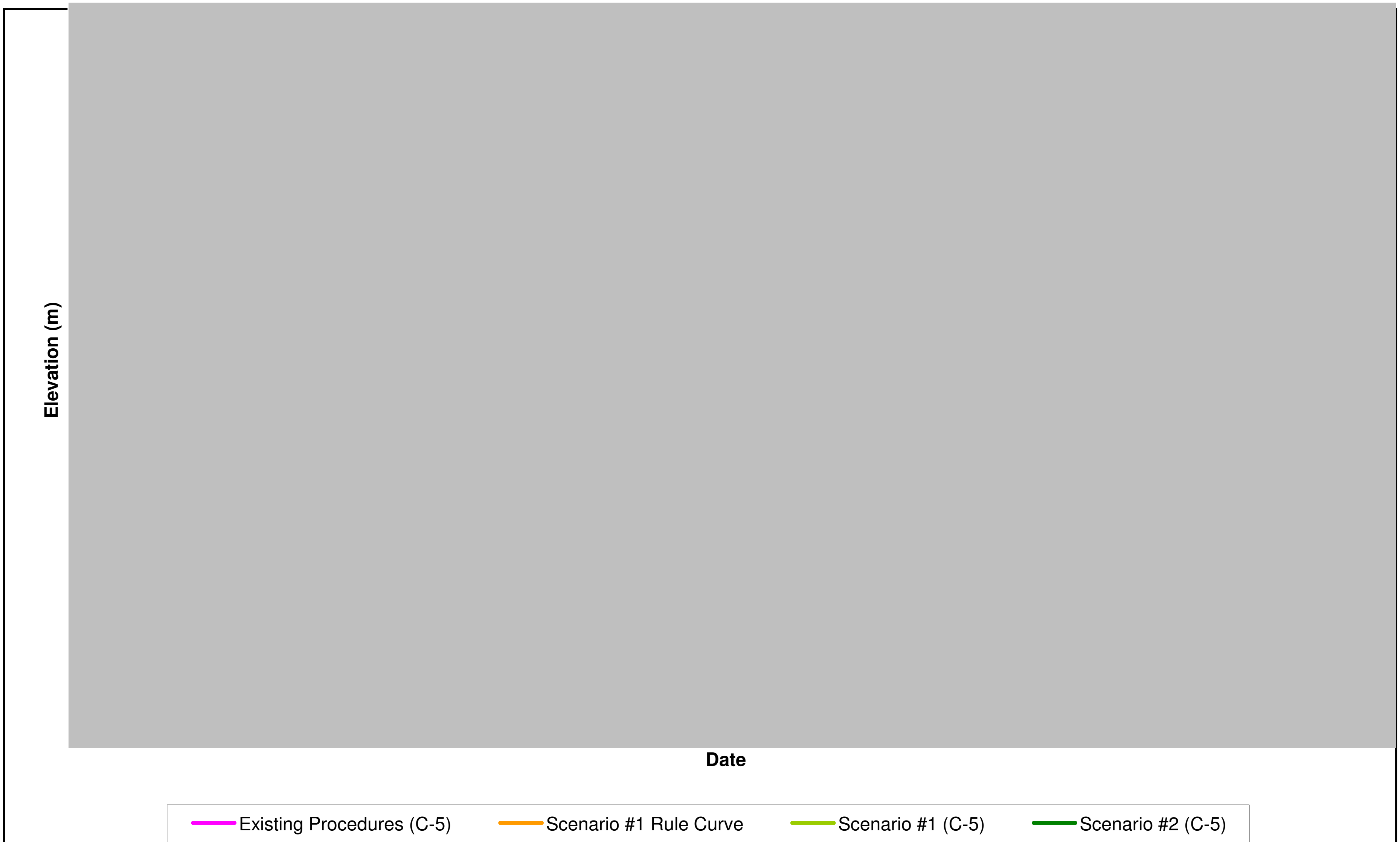

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Figure 3.5

Flood Handling Scenarios for Upper Churchill PMF: Smallwood Reservoir Level

Nalcor Energy - Lower Churchill Project

GI1141 - Upper Churchill PMF and Flood Handling Procedures Update

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Figure 3.6
Flood Handling Scenarios for Upper Churchill PMF: Ossokmanuan/Gabbro Lake Level
Nalcor Energy - Lower Churchill Project
GI1141 - Upper Churchill PMF and Flood Handling Procedures Update

Figure 3.7

Flood Handling Scenarios for Lower Churchill PMF: Smallwood Reservoir Level

Nalcor Energy - Lower Churchill Project

GI1141 - Upper Churchill PMF and Flood Handling Procedures Update

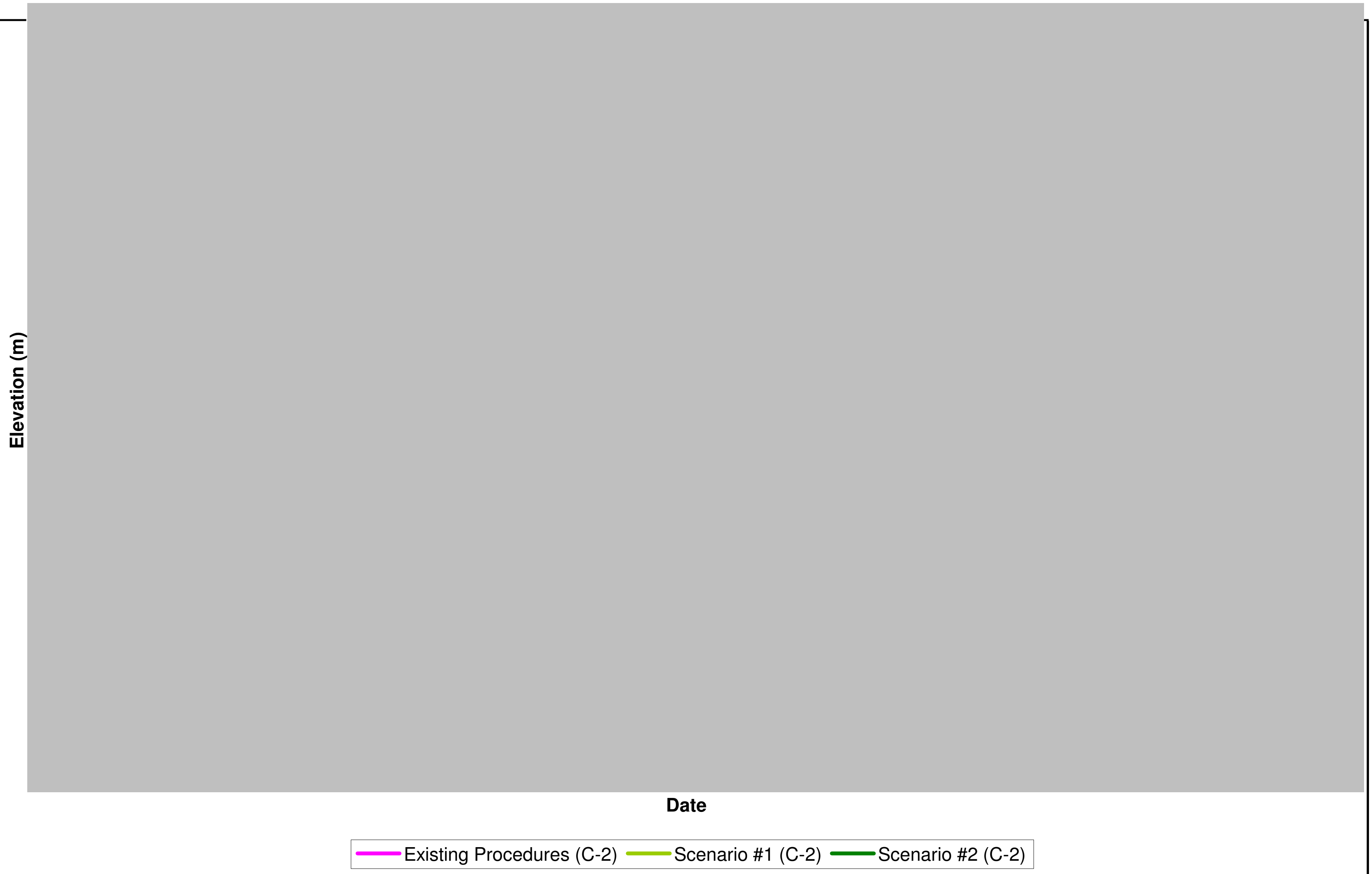

Figure 3.8
Flood Handling Scenarios for Lower Churchill PMF: Ossokmanuan/Gabbro Lake Level
Nalcor Energy - Lower Churchill Project
GI1141 - Upper Churchill PMF and Flood Handling Procedures Update

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Figure 3.9

Flood Handling Scenarios for Lower Churchill PMF: Upper Basin Total Outflow Hydrograph

Nalcor Energy - Lower Churchill Project

GI1141 - Upper Churchill PMF and Flood Handling Procedures Update

4. Lower Churchill River Dynamic Modelling

The Lower Churchill River is a long, deeply inscribed channel that receives flood inflow peaks from its tributaries at approximately the same time along its length. Thus, the time of travel and the flood peak attenuation along the Lower Churchill River have a significant and critical impact on the Lower Basin PMF peaks at Gull Island and Muskrat Falls. To assess these effects, the simulated tributary inflows and Upper Basin inflows were routed using a dynamic hydraulic model (HEC-RAS). Dynamic hydraulic models are based on the physical characteristics of the river channel and solution of the Saint-Venant equations of unsteady flow and are not subject to the uncertainties of extrapolation applicable to hydrological routing approaches.

4.1 HEC-RAS Model

The HEC-RAS dynamic hydraulic model of the Lower Churchill River was used to route the outflows from the Upper Basin (from the ARSP model) and lateral inflow hydrographs to the Churchill River (from the SSARR model) to determine the peak flows at the Gull Island and Muskrat Falls developments.

The event simulated in the HEC-RAS model is the Lower Churchill PMF (storm centre C-2), which was previously determined in GI1140. This is a completely separate event from the Upper Churchill PMF (storm centre C-5) which is presented in Chapter 2. Both storms impact the Upper and Lower Basins. However, only the Upper Churchill PMF runoff estimate has been reduced in severity (current estimate vs. previous estimate from 1969). There has been no change in the estimated runoff associated with the Lower Churchill PMF event; however, there is potential for changes in Upper Basin flood handling procedures to affect the peak discharge at Gull Island and Muskrat Falls during the Lower Churchill PMF event, hence the purpose of the HEC-RAS simulations.

4.1.1 Model Development

Development of the HEC-RAS model is detailed in the GI1110 Hydraulic Modeling of River report. The GI1110 report covers surveys, cross section extraction, model set up and calibration of the model from Churchill Falls tailrace to Goose Bay. Figure 4.1 shows the post-project river profile for the HEC-RAS model from the GI1110 report.

The post-project model was subsequently modified for use in the Lower Churchill Dam Break Study (GI1190). A number of interpolated cross sections were added to make the model more robust and increase stability for the dam break simulations. For the present study, the model was modified further by updating the inline structures at Gull Island and Muskrat Falls as per the following.

- **Gull Island Dam Layout and Spillway Rating Curves** – "Lower Churchill Project – Pre-FEED Engineering Study, Gull Island GI1061 – Review of Structure Layouts and Interfaces, 5 x 450 MW" SNC Lavalin Inc.; July 2008.
- **Muskrat Falls Dam Layout and Rating Curves** – "Lower Churchill Project – Pre-FEED Engineering Study, Muskrat Falls MF1050 – Spillway Design Review" SNC Lavalin Inc.; December 2007.

The updated dam layout and spillway rating curves are shown as Figures 4.2 to 4.6.

4.1.2 Spillway Gate and Turbine Operations

In the model, the water level at each dam is maintained at Full Supply Level by opening gates until the gate capacity is exceeded, when the reservoirs are allowed to surcharge to pass the increasing inflow, and (in the case of Muskrat Falls) emergency spillway facilities come into play. The Full Supply Levels used in the model are 125 m and 39 m, for Gull Island and Muskrat Falls, respectively.

As in the 1989 study base case, turbine flow was assumed to be zero for this analysis. During a PMF event, it is conservative to assume zero turbine flow as this produces the worst case flood handling scenario. Also, during a PMF storm event, it is possible for transmission lines to become compromised which would require that the powerhouse cease operation.

4.2 Simulations

HEC-RAS simulations were completed to route the Upper Basin outflows in the Lower Churchill PMF, for the three flood handling scenarios presented in Chapter 3:

- Existing flood handling procedures.
- [redacted]

Resulting peak discharges at Gull Island and Muskrat Falls are shown in Table 4.1.

Table 4.1
Lower Churchill PMF Peak Flow Estimates

Dam	Existing Procedures	Scenario 1	Scenario 2
Gull Island	21,760 m^3/s	[redacted]	[redacted]
Muskrat Falls	23,190 m^3/s	[redacted]	[redacted]

PMF hydrographs at Gull Island and Muskrat Falls are presented in Figures 4.7 and 4.8, respectively.

With the feasibility study project layouts in GI1140, the simulated peak flows with the existing flood handling procedures were 20,800 m^3/s at Gull Island, and 22,420 m^3/s at Muskrat Falls. The increase in the simulated values to 21,760 and 23,190 m^3/s are a consequence of the increased discharge capacity of the revised configurations, which result in less storage attenuation and higher outflows at lower stages. An iterative reservoir routing approach is generally required in spillway design to determine the relationship between the design discharge and the available storage attenuation; this should be carried out as part of the design finalization using the dynamic river model.

4.2.1 [redacted]

[redacted]

[redacted]

4.2.2 [redacted]

[redacted]

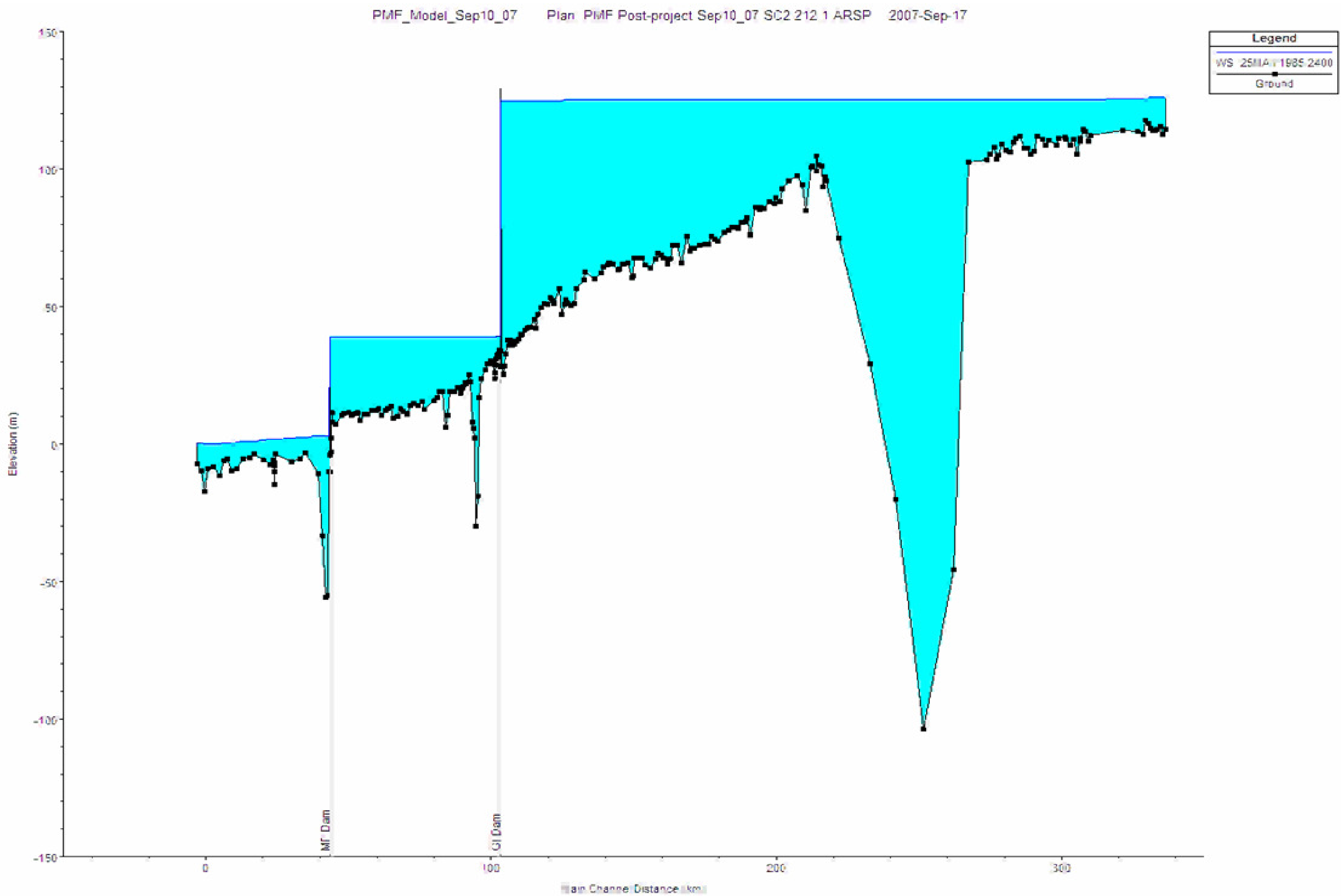


Figure 4.1
HEC-RAS Post-Project Profile
Nalcor Energy - Lower Churchill Project
GI1141 - Upper Churchill PMF and Flood Handling Procedures Update

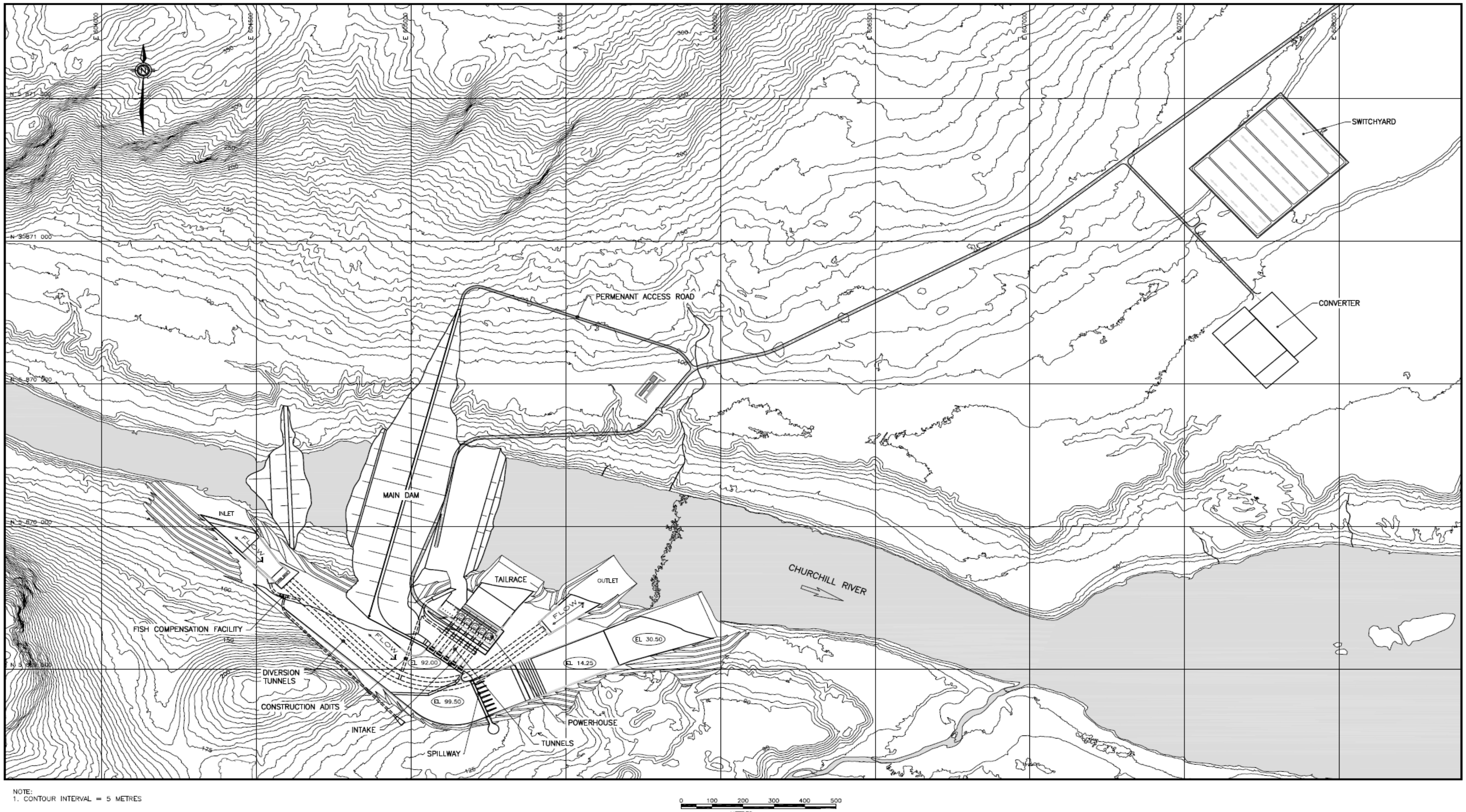


Figure 4.2
Gull Island Project General Arrangement - 4 x 450 MW
Nalcor Energy - Lower Churchill Project
GI1141 - Upper Churchill PMF and Flood Handling Procedures Update

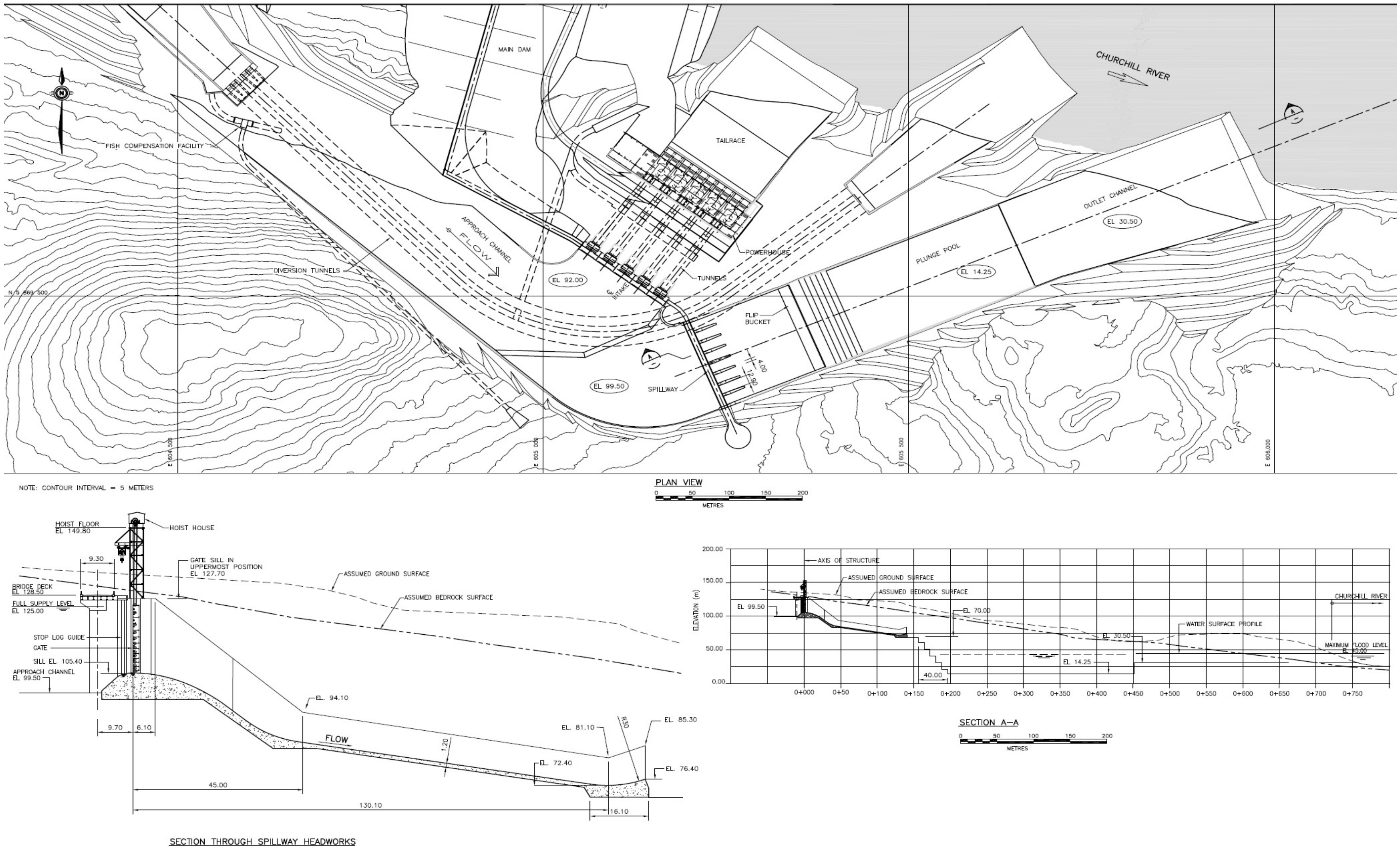


Figure 4.3
Gull Island Spillway - 4 x 450 MW
Nalcor Energy - Lower Churchill Project
GI1141 - Upper Churchill PMF and Flood Handling Procedures Update

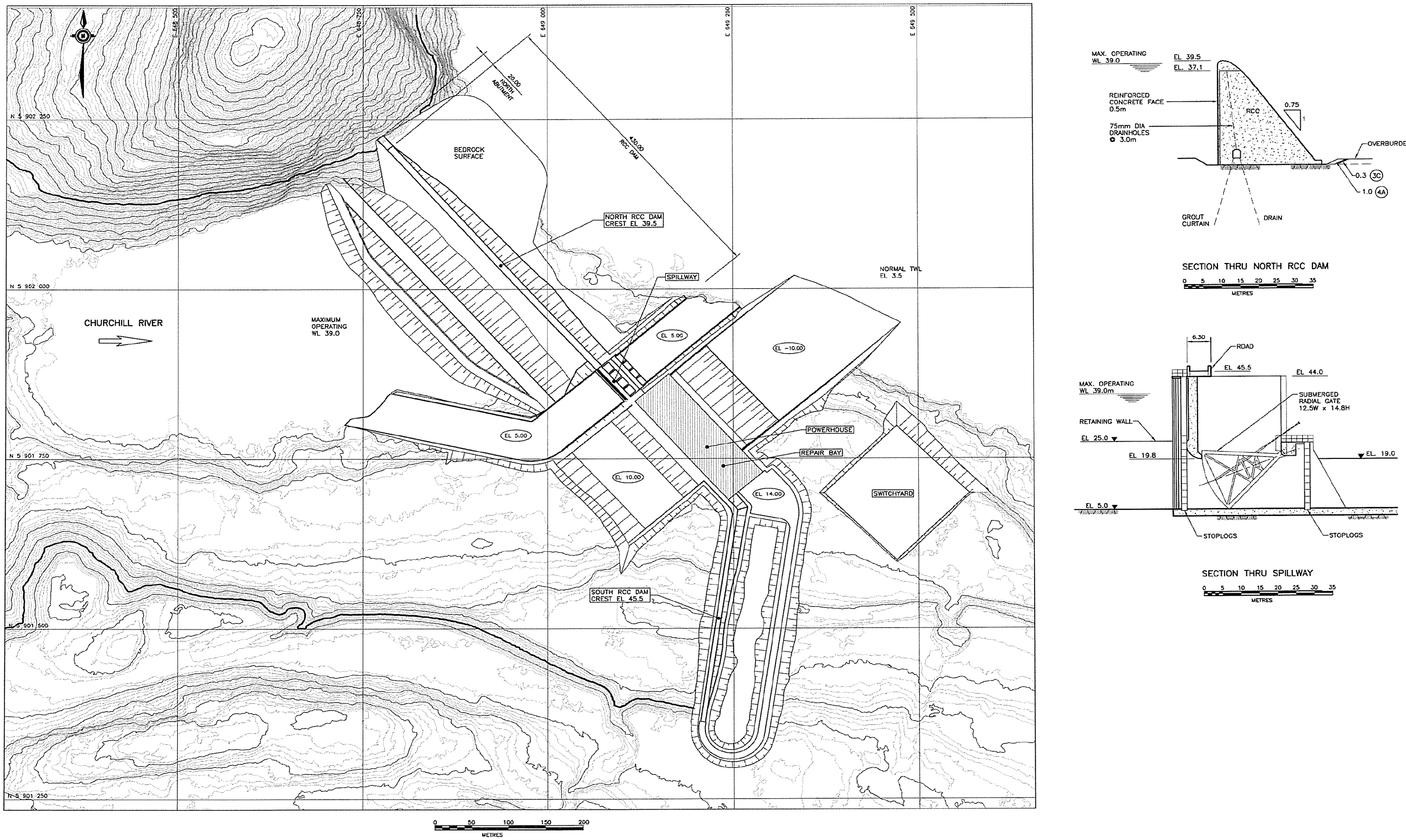
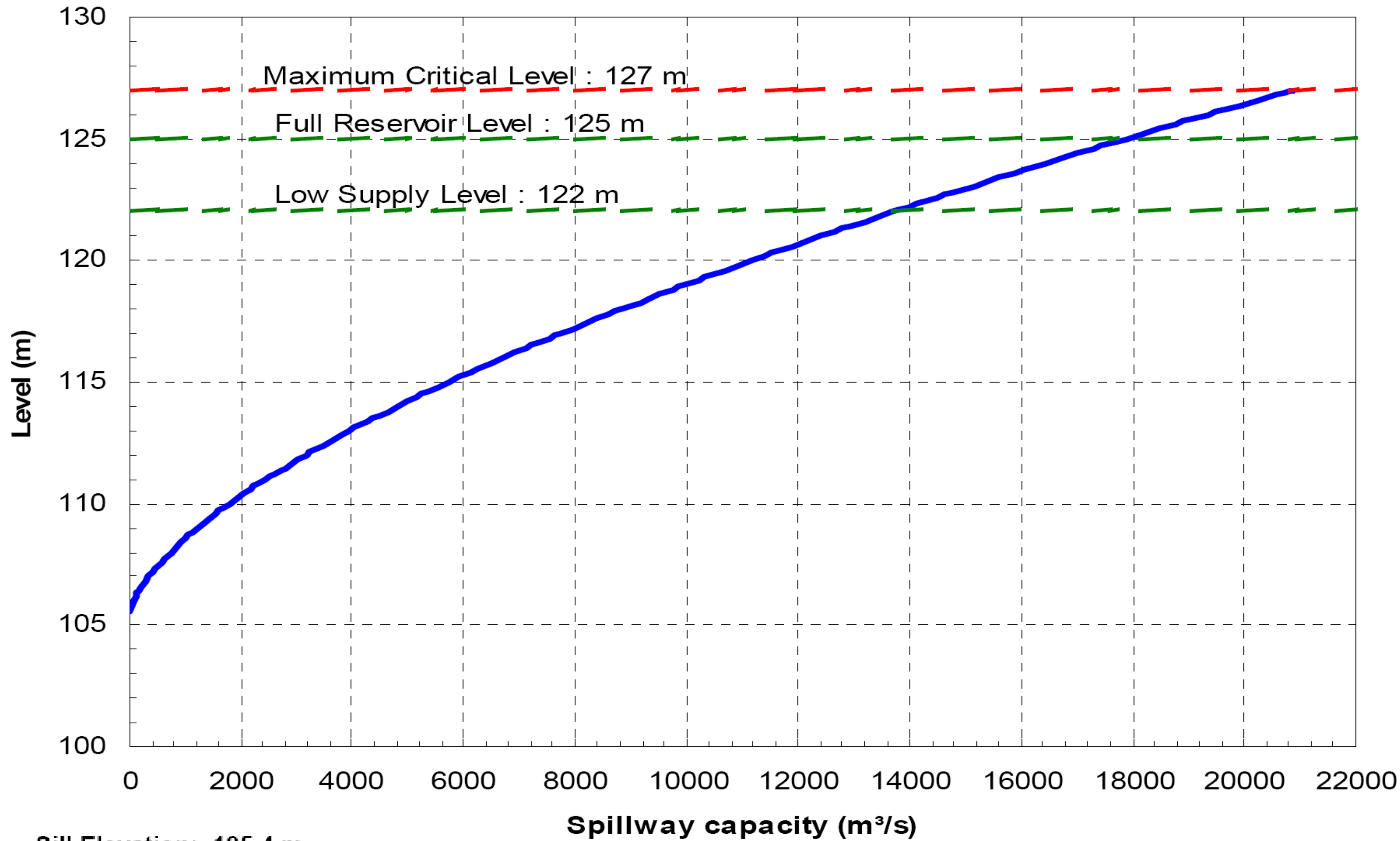


Figure 4.4
Muskrat Falls Arrangement - Variant 10 - Spillway Scheme 3B
Nalcor Energy - Lower Churchill Project
GI1141 - Upper Churchill PMF and Flood Handling Procedures Update



Sill Elevation: 105.4 m

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Figure 4.5
Gull Island Spillway Rating Curve - 8 Gates (12.9 m width)
Nalcor Energy - Lower Churchill Project
GI1141 - Upper Churchill PMF and Flood Handling Procedures Update

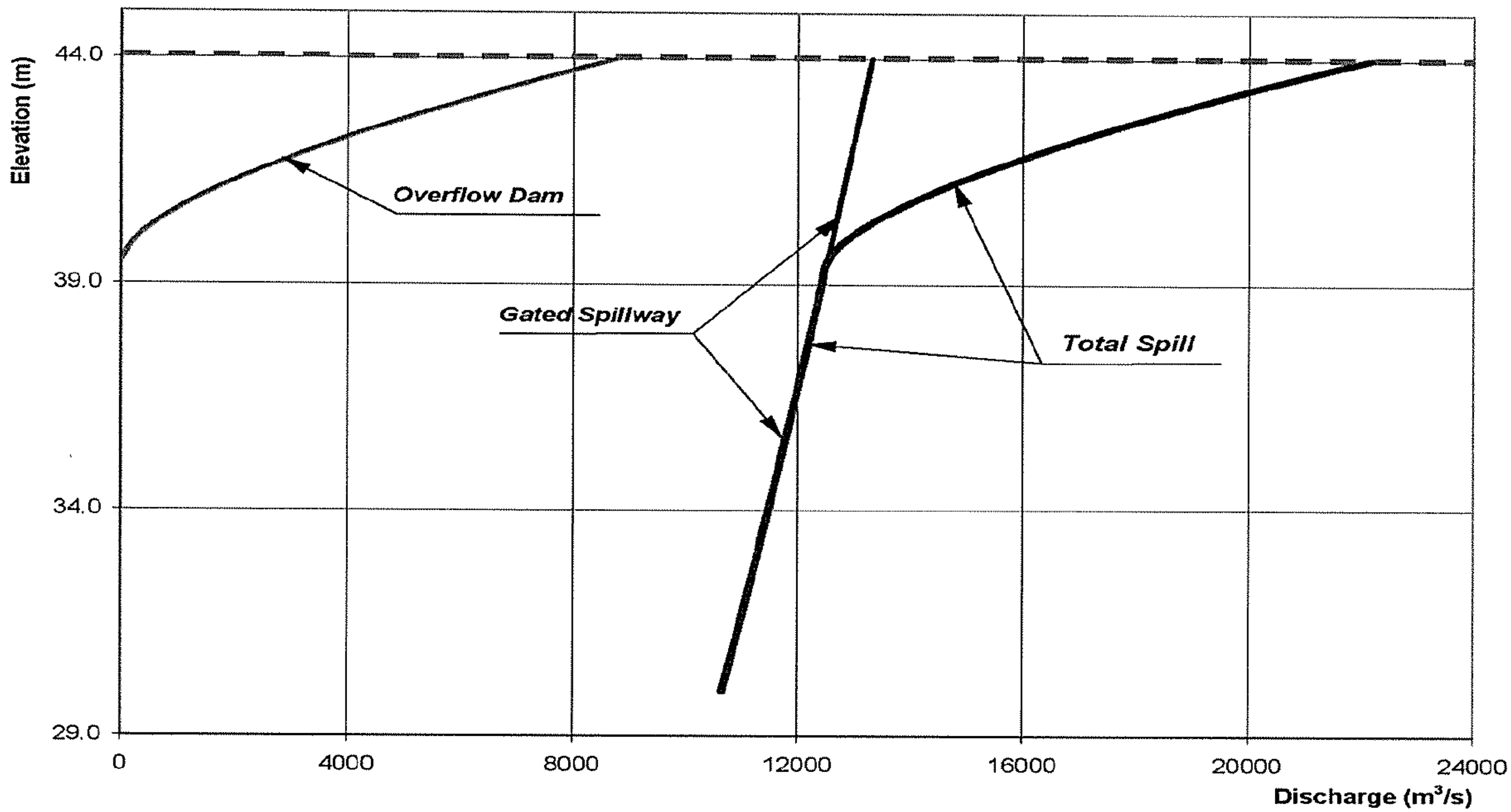

Figure 4.6
Muskrat Falls Total Spill Rating Curve - Scheme 3B
Nalcor Energy - Lower Churchill Project
GI1141 - Upper Churchill PMF and Flood Handling Procedures Update

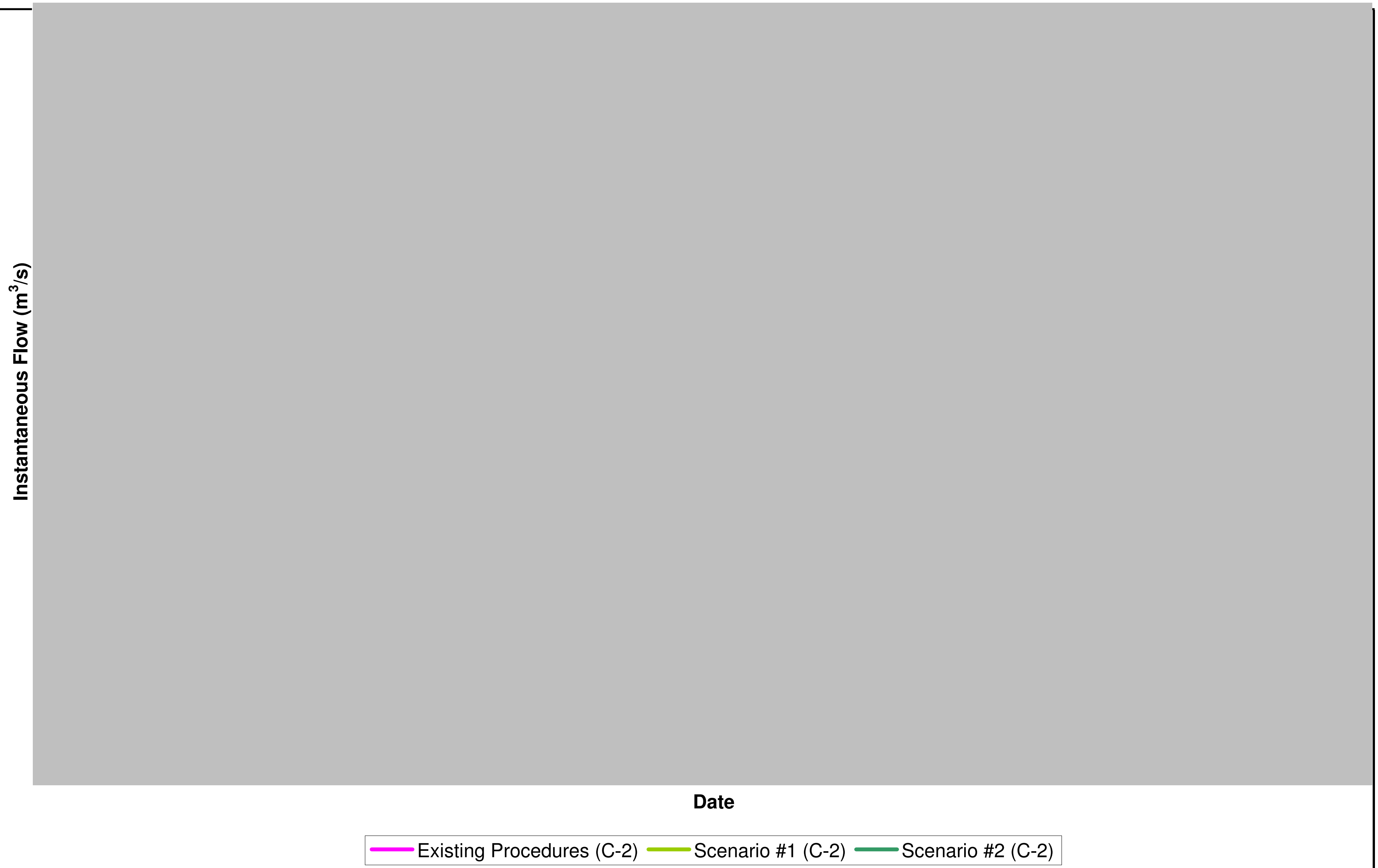

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Figure 4.7
Gull Island PMF Hydrograph - STA 102.5
Nalcor Energy - Lower Churchill Project
GI1141 - Upper Churchill PMF and Flood Handling Procedures Update

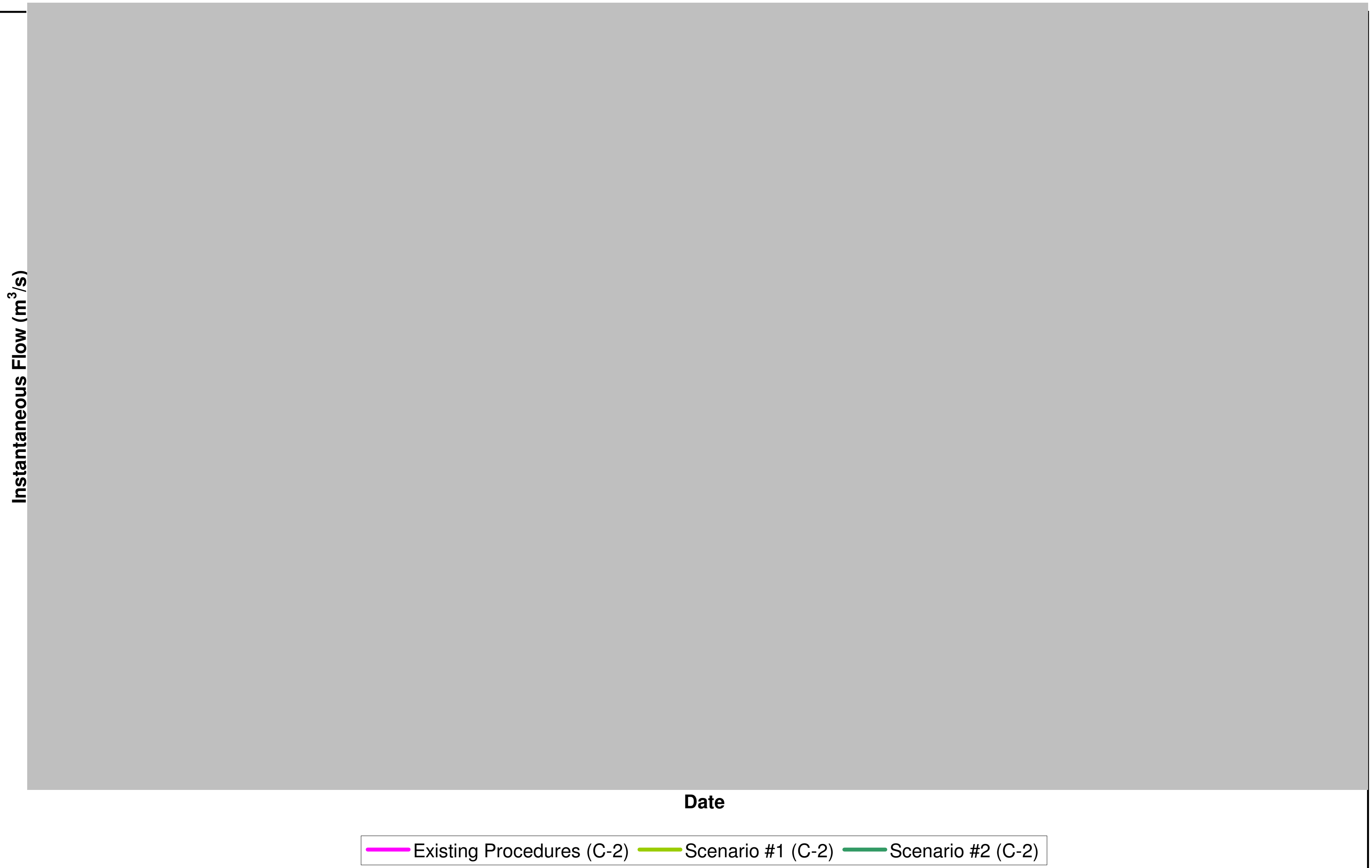

Figure 4.8
Muskrat Falls PMF Hydrograph - STA 43.1
Nalcor Energy - Lower Churchill Project
GI1141 - Upper Churchill PMF and Flood Handling Procedures Update

5. Discussion

5.1 Implications of Smaller PMF Estimate for Upper Basin

[redacted]

- [redacted]
- [redacted]
- [redacted]

[redacted]

[redacted]

5.2 Review of PMF Estimates for Lower Basin

A chronological summary of various PMF estimates for Gull Island and Muskrat Falls from recent studies is presented in Table 5.1 below.

Table 5.1
Summary of Recent Estimates of Lower Churchill PMF Peak Flows

PMF Estimates	Gull Island	Muskrat Falls
Feasibility Studies (1999)	19,700 m^3/s	22,100 m^3/s
Acres PMF Study (1999)	21,700 m^3/s	24,400 m^3/s
GI1140 PMF Study (2007)	20,800 m^3/s	22,420 m^3/s
GI1141 (Existing Procedures/ Revised Configurations)	21,760 m^3/s	23,190 m^3/s
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

Relative to the estimates from GI1140 (2007), the variation is plus or minus 5 percent at Gull Island, and minus 5 to plus 10 percent at Muskrat Falls. This range is considered to be within the expected accuracy of PMF studies generally.

To finalize the spillway sizing for Gull Island and Muskrat Falls, and in the interest of reducing the required spillway capacity, the following should be considered.

- Spillway capacity should be finalized by an iterative process of spillway sizing and storage routing using the dynamic river model.
- [redacted]
- It should be investigated whether there is potential for Gull Island and Muskrat Falls Reservoirs to attenuate the PMF (by drawing down reservoirs to Low Supply Level prior to the PMF).
- [redacted]

Figure 5.1

Potential Variation of Scenario #2 Results for Lower Churchill PMF: Smallwood Reservoir Level

Nalcor Energy - Lower Churchill Project

GI1141 - Upper Churchill PMF and Flood Handling Procedures Update

6. Conclusions and Recommendations

6.1 Conclusions

The Upper Churchill PMF and Flood Handling Procedures Update study has been completed with the following conclusions.

1. Current dam safety practice, as defined by the current CDA Dam Safety Guidelines, is to define the PMF as the largest flood that can reasonably be expected to occur, rather than the largest flood that could possibly be expected to occur. For the original Upper Churchill PMF estimate developed in 1969, the Probable Maximum Precipitation (PMP) was combined with a Probable Maximum Snowpack Accumulation (PMSA) and maximum snowmelt temperatures. Current PMF calculations would be based on a less severe combination of meteorological inputs. This in turn would be expected to produce a smaller PMF estimate.
2. Based on analysis according to the current CDA Dam Safety Guidelines, the Upper Churchill Basin Probable Maximum Flood would occur as the result of a warm front melting a 1/100 AEP snowpack, followed by a spring Probable Maximum Precipitation.
3. The 1/100 AEP Upper Basin average snowpack is 536 mm.
4. The maximum temperatures would be 24 °C during the melt period and 16 °C during the PMP.
5. The critical spring PMP would have a 66-hour rainfall depth of 286 mm over the central 10 km^2 and would be centred over the area draining directly into Smallwood Reservoir, oriented on a WNW to ESE axis. The PMP would have an average depth of 130 mm over the Upper Churchill Basin. It would commence four days after the start of the critical melt temperature sequence.
6. The SSARR PMF instantaneous peak inflows to Smallwood Reservoir from a 1/100 AEP snowpack and spring PMP are characterized by an instantaneous peak of 24,800 m^3/s (16,540 m^3/s maximum daily) resulting from direct rainfall and snowmelt on the reservoir surface, followed by a secondary instantaneous peak of 16,400 m^3/s (15,170 m^3/s maximum daily) from the runoff from the full drainage area to the reservoir. The estimated instantaneous peak at Ossokmanuan/Gabbro Lake is 5,860 m^3/s (5,798 m^3/s maximum daily).
7. [redacted]
8. [redacted]
9. [redacted]

10. [redacted]

11. [redacted]

12. [redacted]

13. A[redacted]

6.2 Recommendations

The recommendations of the study are as follows.

1. Nalcor and CF(L)Co should form a task force for a joint investigation to develop and optimize flood handling procedures in the Upper Basin.
2. If any changes are implemented to the Upper Churchill flood handling procedures, the available models should be used to confirm the ability of the Lower Churchill projects to pass the PMF.
3. The dynamic HEC-RAS model should be used to test any further variants to the Lower Churchill project configurations as part of finalization of the spillway designs.
4. It should be investigated whether there is potential for Gull Island and Muskrat Falls Reservoirs to attenuate the PMF (by drawing down the reservoirs to Low Supply Level prior to the PMF).

List of References

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Appendix A

SSARR Model 2009 PMF Inflow Hydrographs

not filed in public version