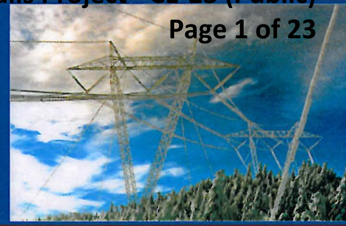
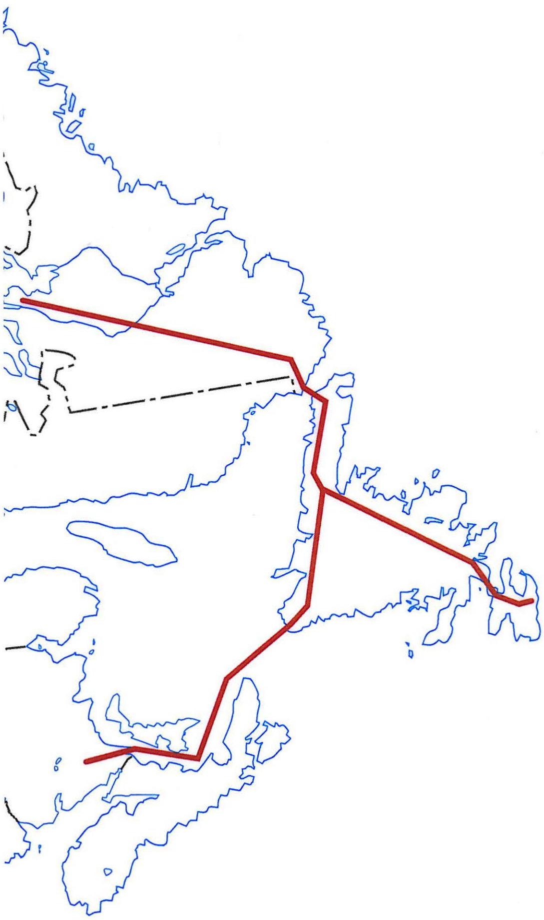
nalcor energy





THE Lower Churchill PROJECT

December 2010

MF1330 - Hydraulic Modeling and Studies 2010 Update

Report 2: Muskrat Falls PMF and Construction Design Flood Study

prepared by

HATCH™

nalcor energy

REGISTERED PROFESSIONAL ENGINEER
MICHAEL M. ROSALES
M. Rosales
SIGNATURE
Dec. 10, 2010
DATE
NEWFOUNDLAND & LABRADOR

THE Lower Churchill PROJECT

December 2010

PROVINCE OF NEWFOUNDLAND AND LABRADOR
PEG Newfoundland and Labrador
PERMIT HOLDER
This Permit Allows
HATCH LTD.
To practice Professional Engineering in Newfoundland and Labrador.
Permit No. as issued by PEG 00090
which is valid for the year 2010

MF1330 - Hydraulic Modeling and Studies 2010 Update

Report 2: Muskrat Falls PMF and Construction Design Flood Study

prepared by

HATCH™

Table of Contents

List of Tables

List of Figures

Executive Summary

Nalcor Energy – Lower Churchill Project (NE-LCP) 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 developed estimates of the Probable Maximum Flood (PMF) and Construction Design Flood (CDF) at the Muskrat Falls site. The estimates were originally prepared in 2007 under Work Task Order GI1140, and assumed that the Muskrat Falls hydroelectric facility would be constructed after the Gull Island hydroelectric facility. The objective of the present study was to revisit the PMF and CDF for Muskrat Falls, assuming the upstream Gull Island site has not yet been developed.

The approach for the present study was to simulate 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, to include the revised project layouts and enhancements of the HEC-GeoRAS model geometry.

Without the Gull Island facility, the simulated PMF peak outflow at Muskrat Falls was 25,060 m^3/s and the simulated peak water level was 44.78 m. With Gull Island, the simulated PMF peak outflow at Muskrat Falls was 23,270 m^3/s and the simulated peak water level was 44.29 m.

Statistical flood frequency analysis was done on a 30-year data set of annual maximum instantaneous flows for the Churchill River at Muskrat Falls hydrometric station (03OE001) to estimate the inflow with an annual exceedance probability (AEP) of 1/20. The 1/20 AEP flood has been chosen as the CDF for the Muskrat Falls diversion phase. The resulting simulated peak outflow at Muskrat Falls was 5,890 m^3/s and the simulated peak water level was 22.78 m. These values are similar to those determined in MF1130 – River Operation During Construction and Impounding, which were 5,800 m^3/s and 22.7 m, respectively.

1. Introduction

Nalcor Energy – Lower Churchill Project (NE-LCP) 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 231 km and 291 km downstream respectively from the Upper Churchill hydroelectric facility that was developed in the early 1970's. The total potential capacity at the two sites is 3,074 megawatts (MW); the Gull Island site being the larger at 2,250 MW and the Muskrat Falls site having a capacity of 824 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. In December 2007 Hatch issued the final report of GI1140 – PMF and Construction Design Flood Study to NE-LCP. The scope of work for that study included the determination of the Probable Maximum Flood (PMF) and routing of the corresponding PMF hydrograph through the Gull Island and Muskrat Falls reservoirs to estimate the spillway design capacity at each site. The study also determined the Construction Design Flood (CDF) for each site. The GI1140 study assumed that the construction of the Muskrat Falls hydroelectric facility would occur after the construction of the Gull Island facility. The objective of this study is to revisit the PMF and CDF for Muskrat Falls, assuming the upstream Gull Island site has not yet been developed.

2. Probable Maximum Flood

The approach for the present study was to simulate the dynamic hydraulic routing of the PMF inflows along the Lower Churchill River, using the HEC-GeoRAS model as updated in MF1330 - Hydraulic Modeling of River - 2010 Update. The present study did not require further hydrologic (i.e., precipitation-runoff) modeling of the PMF. The PMF runoff hydrographs are inputs for the HEC-GeoRAS model and were previously determined in GI1140 (Hatch 2007) from the ARSP operational model of Churchill Falls and the SSARR watershed model. The only changes since GI1140 that affect the simulated Lower Churchill flood routing are the updated project layouts, and enhancements of the HEC-GeoRAS model geometry, as detailed in MF1330 (Hatch 2010).

The following simulations were carried out.

- Pre-project PMF routing.
- Muskrat Falls PMF routing without Gull Island.
- Post-Project PMF routing.

2.1 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 2.1 and are compared to the pre-project peak flows from GI1140. As expected, the difference is negligible and confirms that the modifications to the model sections in MF1330 have preserved the overall conveyance. The simulated pre-project flow hydrograph is shown as Figure 2.1.

Table 2.1: 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

2.2 Muskrat Falls PMF Routing without Gull Island

The scenario for the Muskrat Falls facility alone, without the upstream Gull Island facility was then run. It was assumed that the water level at Muskrat Falls is maintained at Full Supply Level (FSL) 39.0 m by opening spillway gates until the gate capacity is exceeded, at which time the reservoir surcharges, and the north dam overflow comes into play. The plant discharge capacity was omitted from the simulation. The current MF1050 spillway design discharge is 22,100 m^3/s at a design maximum flood level (MFL) of 44.0 m (SNC-Lavalin 2007).

The resulting simulated peak outflow at Muskrat Falls was 25,060 m^3/s and the simulated peak water level was 44.78 m. Introduction of the dam resulted in an attenuation of 1,000 m^3/s, or 4 percent, of the pre-project peak flow.

2.3 Post-Project PMF Routing

The post-project scenario with Gull Island and Muskrat Falls was then run to determine the further attenuation that would result from the Gull Island reservoir. It was assumed that the water level at Gull Island is maintained at FSL 125.0 m by opening spillway gates until the gate capacity is exceeded, at which time the reservoir surcharges. The plant discharge capacities of both facilities was omitted from the simulation. The resulting simulated peak outflow at Muskrat Falls was 23,270 m^3/s and the simulated peak water level was 44.29 m. This represents a negligible change from the model result in GI1141 (Hatch 2009), which also represented the revised project layouts.

The simulated peak outflows and water levels at Muskrat Falls are summarized in Table 2.2 below. Without the Gull Island reservoir, the peak water level at Muskrat Falls is 0.49 m higher and the peak outflow is approximately 8 percent larger than with the Gull Island reservoir. Figure 2.2 shows the simulated outflow and water surface elevation hydrographs at Muskrat Falls.

Table 2.2: Muskrat Falls PMF

Scenario	Pre-Project	MF without GI	Post-Project (MF with GI)
Peak Outflow (m^3/s)	26,060	25,060	23,270
Peak WL (m)	-	44.78	44.29

2.4 Estimate of Required Spill Capacity

The estimated peak water level of 44.78 m (without Gull Island) is of concern, as it exceeds the design MFL of 44.0 m. Consequently, the model was run to estimate the required discharge to limit the peak water level at 44.0 m in the PMF without Gull Island. For modeling purposes, the approach was to iteratively increase the available gate capacity until the simulated peak water level did not exceed 44.0 m.

The final iteration assumed five gates with a design capacity of 3,200 m^3/s each, added to the overflow section design capacity of 8,800 m^3/s, for a total design capacity of 24,800 m^3/s at MFL 44.0 m. The simulated peak outflows and water levels at Muskrat Falls are summarized in Table 2.3 below. Figure 2.3 shows the simulated outflow and water surface elevation hydrographs at Muskrat Falls.

It was not within the present scope of work to undertake a detailed spillway design optimization. As recommended in GI1141 (Hatch 2009), the HEC-RAS model should be used to test variants in finalization of the spillway design.

Table 2.3: Muskrat Falls PMF with Increased Spill Capacity

Scenario	Pre-Project	MF without GI	Post-Project (MF with GI)
Peak Outflow (m^3/s)	26,060	24,770	23,080
Peak WL (m)	-	43.93	43.42

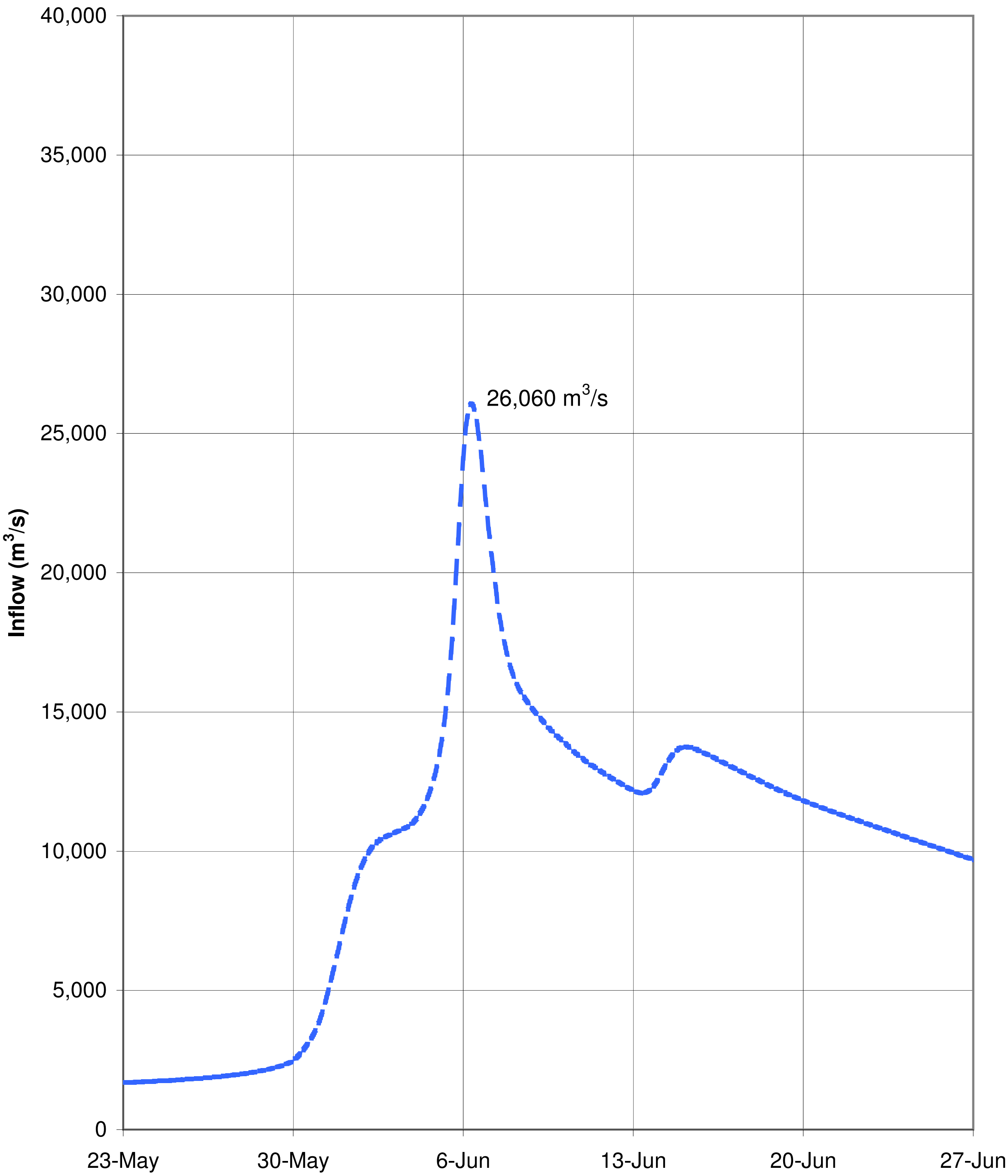


Figure 2.1
Muskrat Falls PMF Inflow Hydrograph (Pre-Project)
MF1330 - Muskrat Falls PMF and Construction Design Flood Study
Nalcor Energy - Lower Churchill Project

HATCH™

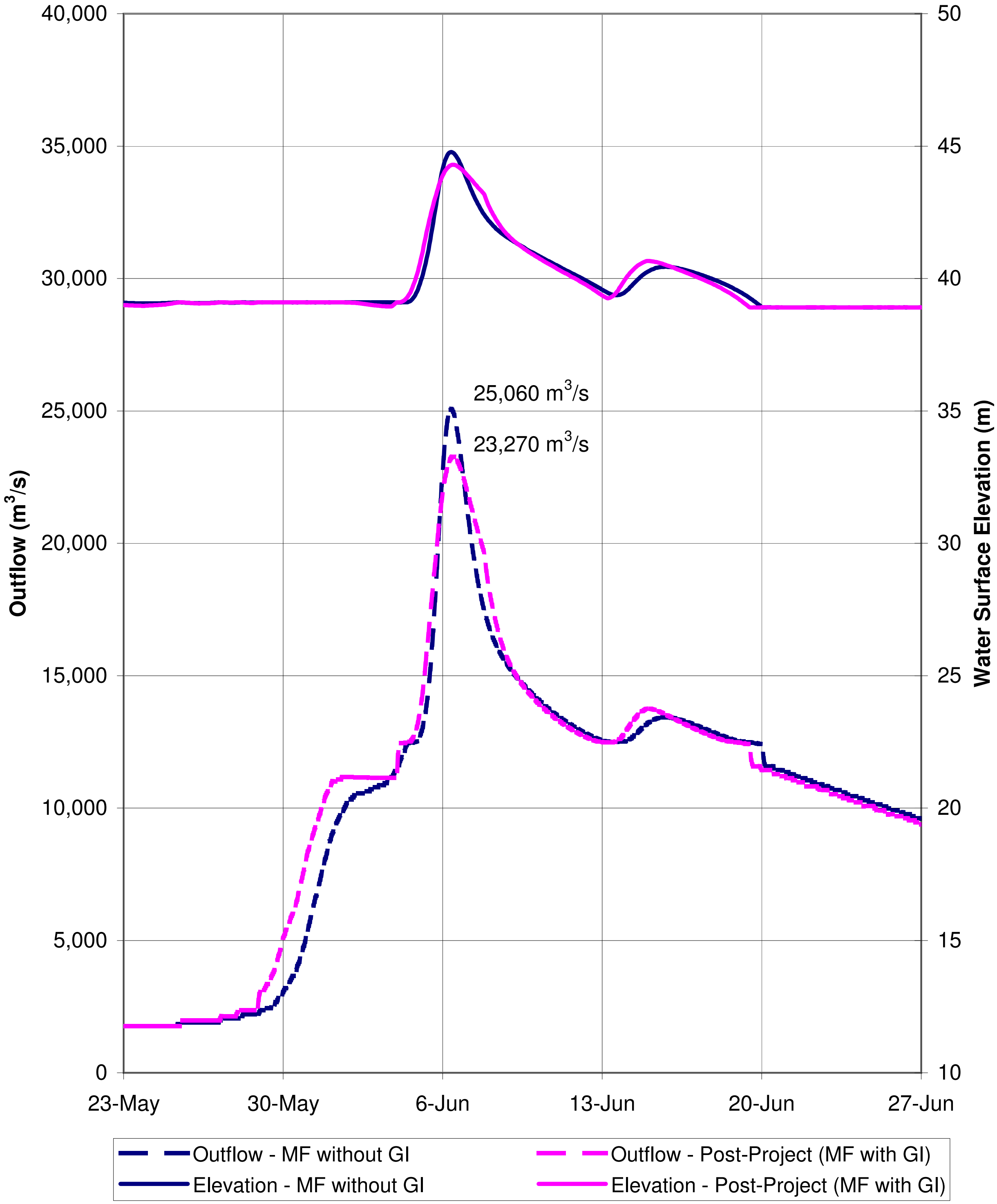


Figure 2.2
Muskrat Falls PMF Outflow and Elevation Hydrographs
MF1330 - Muskrat Falls PMF and Construction Design Flood Study
Nalcor Energy - Lower Churchill Project

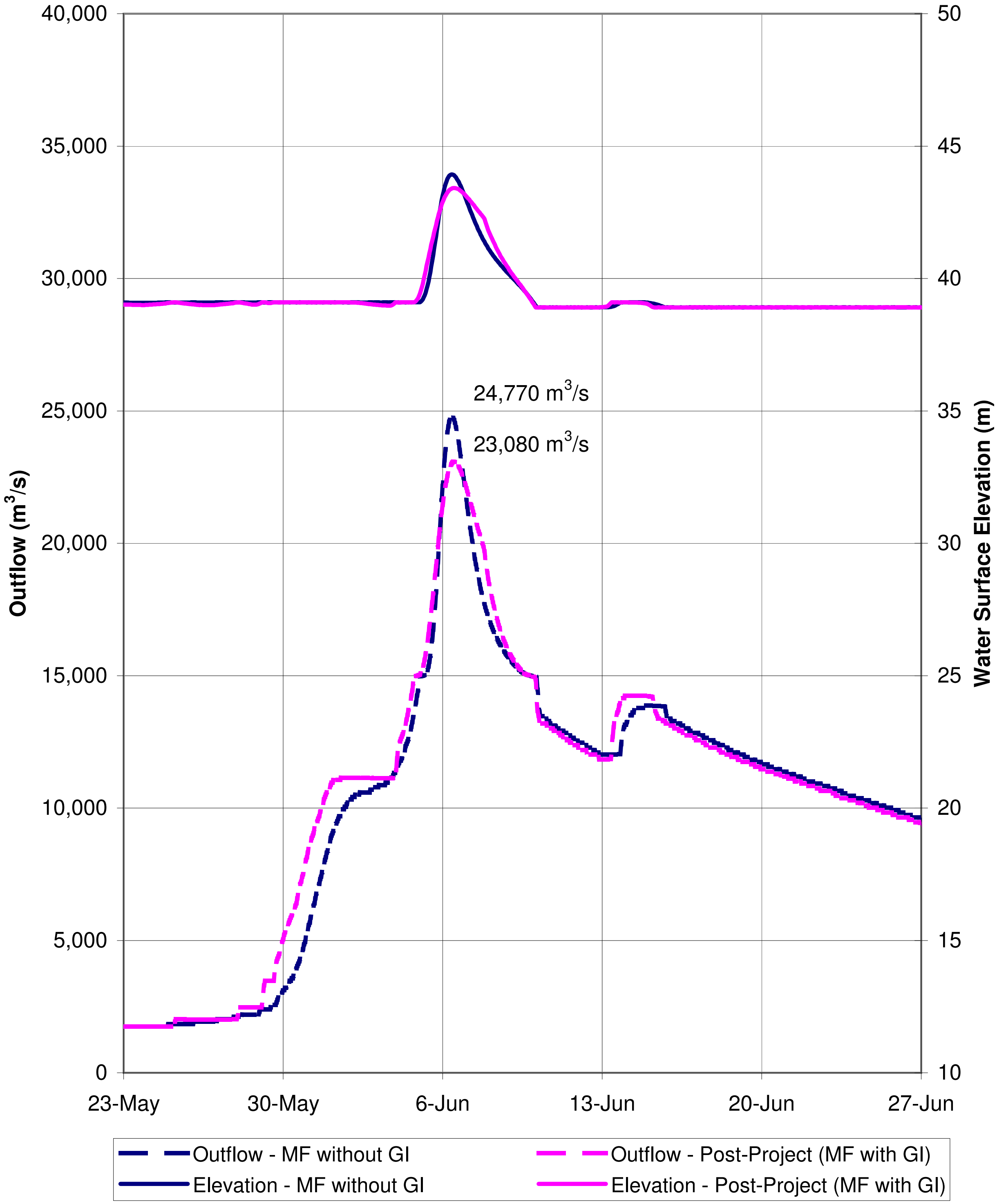


Figure 2.3

Muskrat Falls PMF Outflow and Elevation Hydrographs (Increased Spill Capacity)

HATCH™

MF1330 - Muskrat Falls PMF and Construction Design Flood Study

Nalcor Energy - Lower Churchill Project

3. Construction Design Flood

In GI1140 (Hatch 2007), the Muskrat Falls CDF was estimated using hydrologic techniques, i.e., statistical flood frequency analysis of recorded in-stream data from the Water Survey of Canada (WSC) hydrometric station 03OE001 at Muskrat Falls. Because the analysis used historical flow data, pre-project conditions are implicit in the peak flow estimate.

In MF1130 (Hatch 2008), the CDF inflow hydrograph was developed on the basis of the peak flow estimate, and the construction diversion was assessed using a level-pool storage routing model (ARSP). However, given the need for a detailed simulation of hydraulic conditions in the river during construction, the updated HEC-GeoRAS model was used in the present study to refine the estimate of peak diversion outflow and water level. Additionally, it was necessary to evaluate any change in the Muskrat Falls CDF assuming that the upstream Gull Island site has not yet been developed.

The process of analysis was as follows.

- Update the statistical flood frequency estimate of the CDF peak flow using the additional available years of record from the WSC station.
- Calibrate the HEC-GeoRAS lateral inflows to replicate the CDF inflow hydrograph at the Muskrat Falls site in the pre-project condition.
- Introduce the Muskrat Falls cofferdam and diversion geometry to simulate the dynamic routing effect through the river channel and diversion facilities during the CDF.
- Introduce the completed Gull Island dam geometry, with the Muskrat Falls cofferdam and diversion geometry, to quantify its effect on the Muskrat Falls CDF.

3.1 Flood Frequency Analysis

In GI1140 (Hatch 2007), the statistical flood frequency analysis was done on a 28-year data set of annual maximum instantaneous flows for the Churchill River at Muskrat Falls (03OE001) from 1978 to 2006 (1989 missing), representing the period in which the Churchill River has been regulated by the Churchill Falls development. Maximum flows for 2007 and 2008 have since been published by WSC and these values were appended to the data set for the present study, bringing the sample size to 30. The analysis was performed on this series, which incorporates discharges from the Churchill Falls development, and also on a series representing the local (Lower Churchill) inflows only, which was synthesized by subtracting the recorded flows from the Churchill Falls powerhouse (WSC record 03OD005).

Figures 3.1 and 3.2 show the results of the frequency analyses using the 3-Parameter Lognormal (3PLN) distribution, which was adopted for the data in GI1140. The points represent the data set, and the 3PLN frequency distribution curve is fit to the data using the Method of Moments in the HYFRAN statistical analysis package to estimate the floods for various return periods. The upper and lower bounds of the 95 percent confidence interval are also plotted. That is, the probability that the true value lies between the upper and lower curves is 95 percent. The additional data from 2007 and 2008 do not represent extreme events and have not appreciably altered the frequency curves as compared to the analysis in

GI1140. The estimated 1/20, 1/40 and 1/60 AEP flood peaks at Muskrat Falls are shown in Table 3.1 below.

Table 3.1: Muskrat Falls Flood Frequency Estimates

Peak Inflow (Pre-Project)	1/20 AEP (m^3/s)	1/40 AEP (m^3/s)	1/60 AEP (m^3/s)
Local	4,520	4,830	5,000
Total	5,910	6,250	6,430

Estimates for the 1/20 and 1/40 AEP are within half a percent of the previous GI1140 estimates. (1/60 AEP estimates were not prepared in GI1140.) The difference between the local and total peaks is consistent, at approximately 1,400 m^3/s, which is representative of the normal outflow from the Churchill Falls powerhouse during the spring flood season.

The CDF that has been adopted for the Muskrat Falls diversion is the 1/20 AEP flood, which is associated with a 5 percent probability of being equaled or exceeded in any one year.

3.2 CDF Inflow Hydrograph

In MF1130 (Hatch 2008), the CDF inflow hydrograph was developed from the historic flood hydrograph of 1998 (peak 5,640 m^3/s, occurred May 16, 1998). Of all the flood events in the 30-year series, it had the third-highest peak flow, but was the largest on the basis of 31-day volume, and therefore its hydrograph shape would be expected to produce the most conservative water elevations during the routing simulation. The CDF inflow hydrograph was developed for the present study by factoring up the 1998 hydrograph to match the 1/20 AEP peak flow estimate of 5,910 m^3/s. The resulting CDF inflow hydrograph is shown as Figure 3.3.

The CDF hydrograph portrays the river flow at the Muskrat Falls site in the pre-project condition. By definition, it is the result of the upstream and lateral watershed inflows, transformed by the natural channel routing process up to that point in the river. In simulating the CDF in HEC-GeoRAS, the hydrograph cannot itself be used as the flow input to the model, or else the channel routing effect will be doubly represented. Instead, it was necessary to synthesize the lateral watershed inflows so that the model output correctly replicates the CDF pre-project hydrograph at the Muskrat Falls site, before proceeding to introduce the diversion geometry.

The upstream inflow from the Churchill Falls development was assumed to be a constant 1,400 m^3/s. Subtracting this flow from the CDF hydrograph leaves the local portion contributed by the Lower Churchill watershed. Instead of revisiting the SSARR watershed model, it was determined that the contribution from each of the Lower Churchill subbasins could be adequately approximated by prorating the local hydrograph according to the subbasin drainage area, and adjusting the peak and timing of the subbasin inflow hydrograph to produce a calibrated model result at the Muskrat Falls site. Once this was completed, the diversion geometry was introduced.

3.3 Muskrat Falls CDF Routing without Gull Island

The scenario for the Muskrat Falls diversion without the upstream Gull Island facility was run. It was assumed that the river flow passes through the open sluiceway and the water level upstream of the cofferdam varies freely with the inflow. The diversion was designed to discharge 5,300 m^3/s at elevation 21.7 m (MF1050, SNC-Lavalin 2007).

The resulting simulated peak outflow at Muskrat Falls was 5,890 m^3/s and the simulated peak water level was 22.78 m. This represents a negligible change from the previous results from MF1130 (Hatch 2008), which were 5,800 m^3/s and 22.7 m, respectively.

3.4 Muskrat Falls CDF Routing with Gull Island

The scenario for the Muskrat Falls diversion with the upstream Gull Island facility was run. It was assumed that the water level at Gull Island is maintained at FSL 125.0 m by increasing the plant flow until the turbine capacity is exceeded, at which time the spillway gates come into play. With this assumption, there will be no surcharge above FSL at Gull Island, as the plant and spillway gates have ample combined capacity to pass the flow while maintaining the level at FSL.

The resulting simulated peak outflow at Muskrat Falls was 6,020 m^3/s and the simulated peak water level was 23.04 m. These were increases in flow and level of 130 m^3/s and 0.26 m respectively, compared to the scenario without Gull Island. Though the increases are small, the reason is the assumed form of operation for the Gull Island reservoir. By rigidly maintaining the level at FSL, there is no attenuation; water is discharged from the Gull Island reservoir at the same rate that it enters. Whereas in the case without Gull Island, there is a small amount of natural channel attenuation present in the reach upstream of the Gull Island site. In order to match this attenuation, some storage would have to be permitted.

The flow and stage hydrographs for both alternatives are shown as Figure 3.4.

The feasibility of using the storage in the Gull Island reservoir to attenuate the Muskrat Falls CDF was not investigated in detail. It is expected that such a scheme would require an adequate system of flood forecasting, to enable such a decision with the knowledge that the flood is not an extreme flood and can be passed without encroaching on the design maximum flood level at Gull Island.

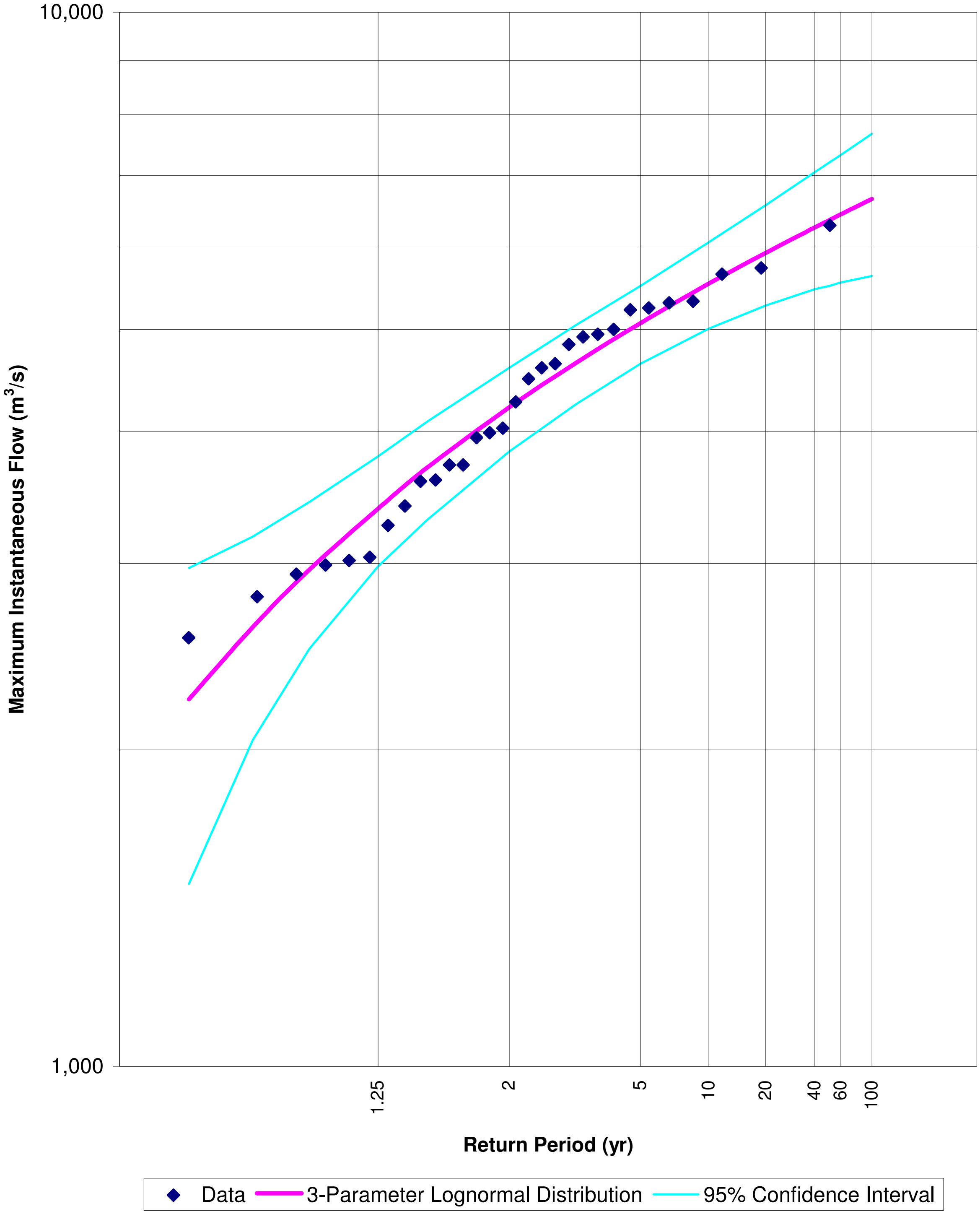


Figure 3.1
Muskrat Falls - Total Flood Frequency Distribution
(Includes Churchill Falls Powerhouse Flows)

HATCH™

MF1330 - Muskrat Falls PMF and Construction Design Flood Study
Nalcor Energy - Lower Churchill Project

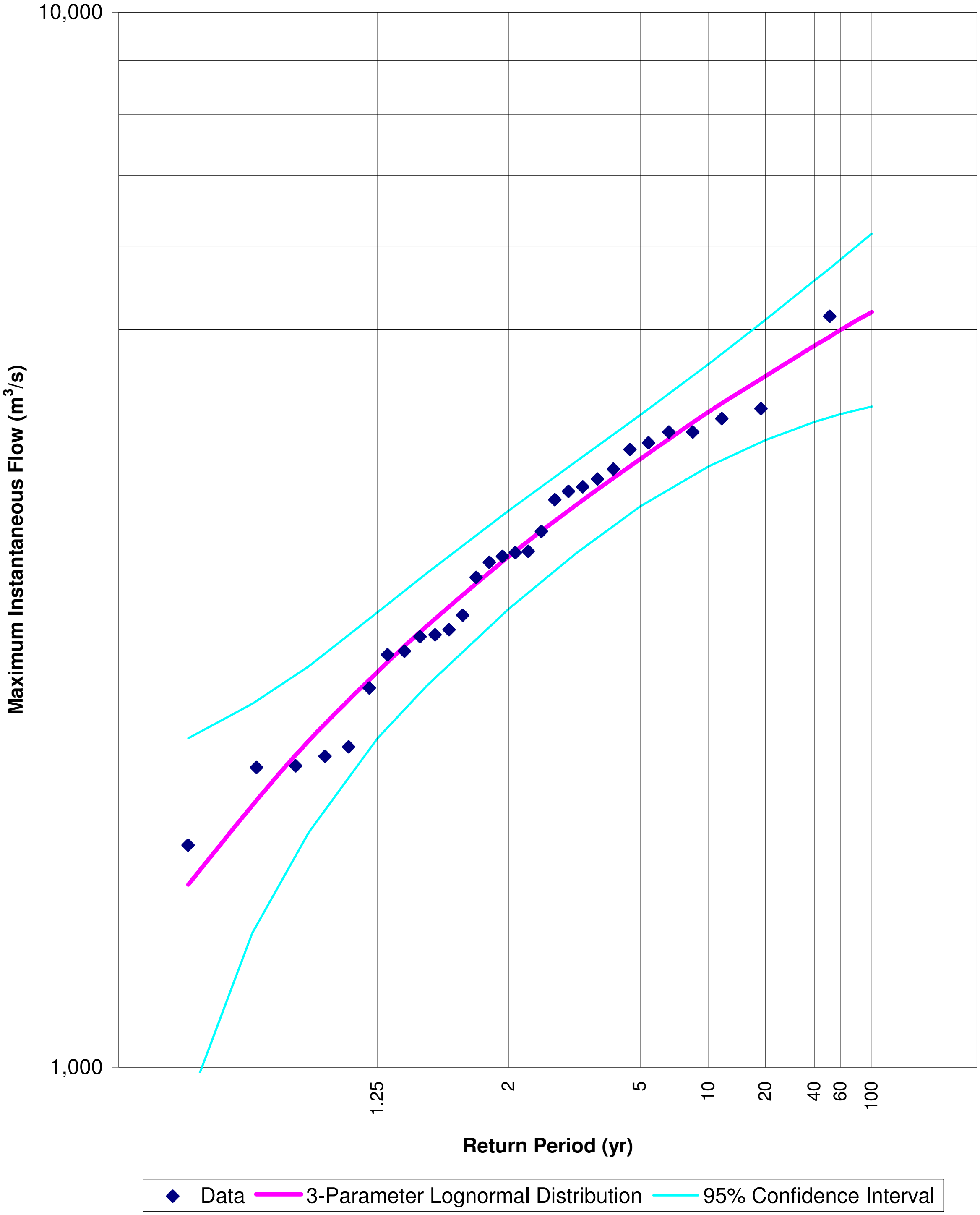


Figure 3.2
Muskrat Falls - Local Flood Frequency Distribution
(Excludes Churchill Falls Powerhouse Flows)
MF1330 - Muskrat Falls PMF and Construction Design Flood Study
Nalcor Energy - Lower Churchill Project

HATCH™

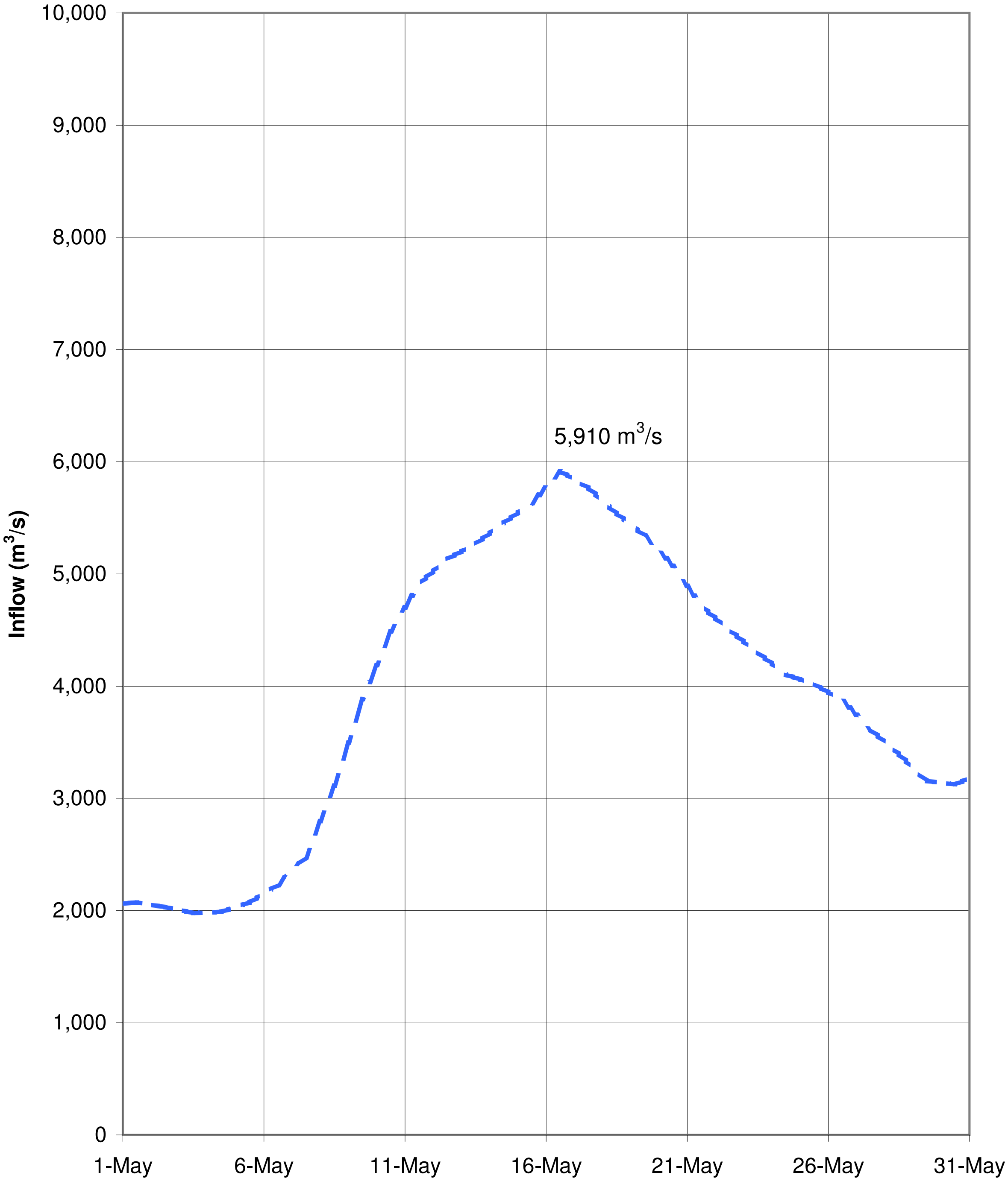


Figure 3.3
Muskrat Falls 1/20 AEP Inflow Hydrograph
MF1330 - Muskrat Falls PMF and Construction Design Flood Study
Nalcor Energy - Lower Churchill Project

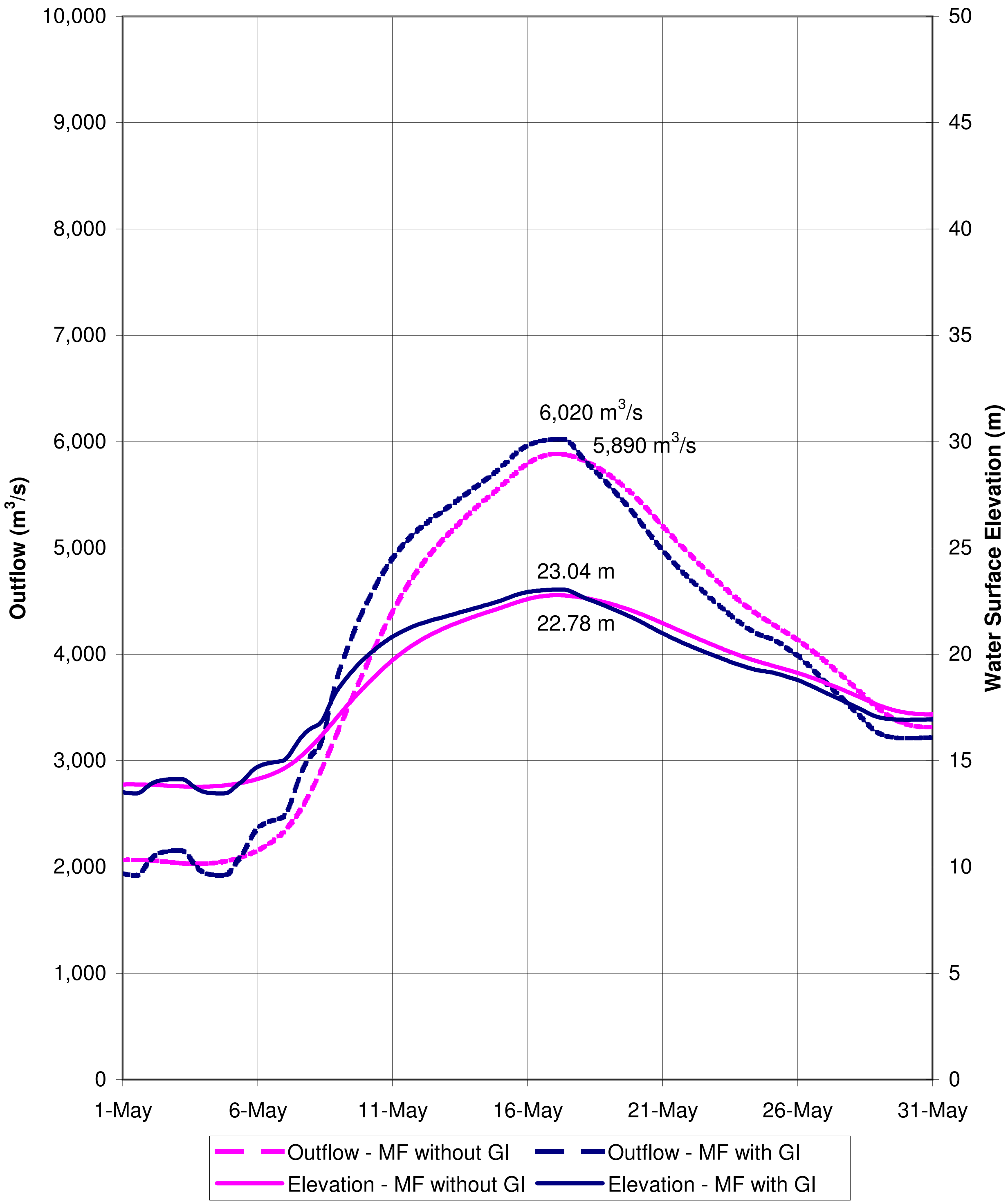


Figure 3.4

Muskrat Falls CDF Outflow and Elevation Hydrographs

MF1330 - Muskrat Falls PMF and Construction Design Flood Study

Nalcor Energy - Lower Churchill Project

HATCH™

4. Conclusions

The conclusions of the study are as follows.

1. The simulated pre-project PMF peak inflow at the Muskrat Falls site is 26,060 m^3/s.
2. 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.
3. 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 is approximately 8 percent larger than with the Gull Island reservoir.
4. To limit the peak water level at Muskrat Falls in the PMF (without Gull Island) to 44.0 m, the estimated spillway design discharge capacity is 24,800 m^3/s at MFL 44.0 m. It was not within the present scope of work to undertake a detailed spillway design optimization. As recommended in GI1141 (Hatch 2009), the HEC-RAS model should be used to test variants in finalization of the spillway design.
5. The estimated CDF (1/20 AEP peak inflow) at the Muskrat Falls site is 5,910 m^3/s.
6. 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.

List of References

Hatch Ltd. GI1140 – PMF and Construction Design Flood Study. Prepared for Newfoundland and Labrador Hydro – Lower Churchill Project, December 2007.

Hatch Ltd. GI1141 – Upper Churchill PMF and Flood Handling Procedures Update. Prepared for Nalcor Energy – Lower Churchill Project, August 2009.

Hatch Ltd. MF1130 – River Operation During Construction and Impounding. Prepared for Newfoundland and Labrador Hydro – Lower Churchill Project, January 2008.

Hatch Ltd. MF1330 – Hydraulic Modeling of the River - 2010 Update. Prepared for Nalcor Energy - Lower Churchill Project, September 2010.

SNC-Lavalin Inc. MF1050 – Spillway Design Review. Prepared for Newfoundland and Labrador Hydro – Lower Churchill Project, December 2007.