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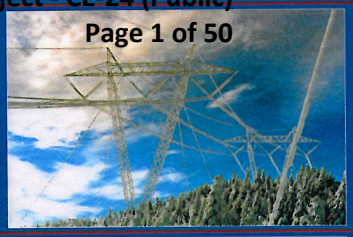

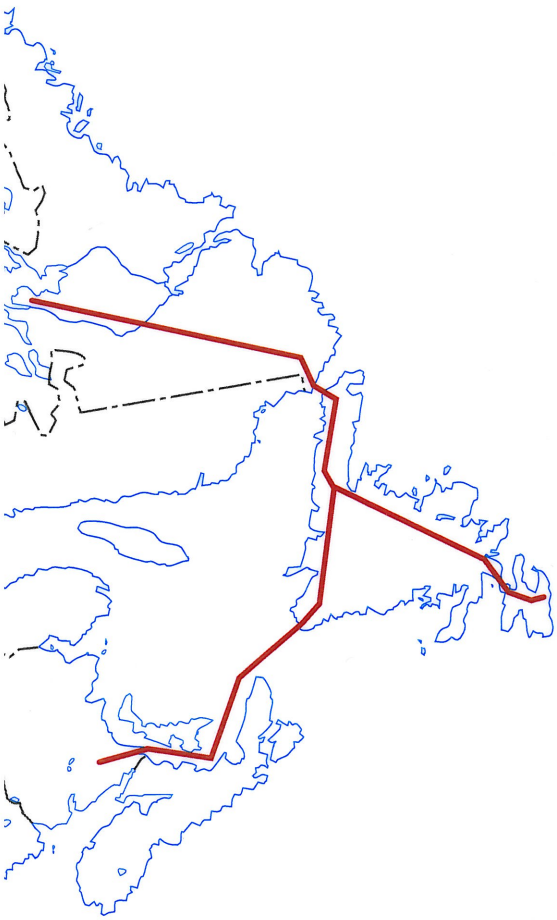

THE Lower Churchill PROJECT

December 2010

MF1330 - Hydraulic Modeling and Studies 2010 Update

Report 3: Muskrat Falls Dam Break Study

prepared by

HATCH™

nalcor energy

REGISTERED PROFESSIONAL ENGINEER
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THE Lower Churchill PROJECT

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Executive Summary

Nalcor Energy – Lower Churchill Project (NE-LCP) is undertaking preliminary engineering studies for the development of the hydroelectric potential of the Lower Churchill River at Gull Island and Muskrat Falls. In 2008 Hatch issued GI1190 - Dam Break Study to NE-LCP which analysed several dam breach scenarios, included inundation mapping for the potentially flooded areas. It also presented an assessment of potential loss of life and economic impacts on downstream property and inhabitants. In that study several scenarios were considered assuming that Gull Island would be constructed prior to Muskrat Falls. The objective of the current work was to complete a dam break analysis, inundation mapping, and consequence assessment for the Muskrat Falls Dam, assuming the upstream Gull Island development was not yet constructed. Updates to project layout and spillway capacity that have been made since the GI1190 study were included in the current study.

The HEC-GeoRAS hydraulic model, updated as part of MF1330, was used to simulate the dam breach floodwave downstream of the Muskrat Falls Dam. Two Muskrat Falls dam breach scenarios were simulated: one under "Fair Weather" conditions, and the second under Inflow Design Flood (Probable Maximum Flood - PMF) conditions. PMF conditions were simulated with and without failure of the Muskrat Falls Dam so that the incremental consequence of dam failure could be assessed. PMF inflow hydrographs used in the current study were developed under the Muskrat Falls PMF and CDF Update Study (completed as part of MF1330). Results of that study indicate a PMF peak flow at Muskrat Falls of 23,270 m^3/s with Gull Island reservoir upstream and 25,060 m^3/s without Gull Island reservoir upstream. This is a difference of 1,790 m^3/s, or an increase of approximately 7.7 percent without the Gull Island reservoir upstream.

For both dam breach scenarios, the North Overflow Roller Compacted Concrete (RCC) Dam was assumed to fail monolithically by overturning or sliding. This is the same assumption used in the original GI1190 Dam Break Study but the breach parameters were updated to correspond to the updated project layout. This led to an increase in the average width of the breach, from 260 m used in GI1190 to 430 m. All other breach parameters including time of formation, final breach bottom elevation, and breach side slope remained unchanged.

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

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 April 2008 Hatch issued the final report of GI1190 – Dam Break Study to NE-LCP. The scope of work for that study included the simulation of various dam breach scenarios, the preparation of inundation mapping of potentially flooded areas, and the assessment of the potential incremental consequences of failure for both Gull Island and Muskrat Falls. For that study it was assumed that the Gull Island development would be constructed prior to the Muskrat Falls development. While similar in scope to GI1190, the current study assumes that the upstream Gull Island development has not been constructed prior to Muskrat Falls.

Dam failures during the predetermined Inflow Design Flood (Probable Maximum Flood – PMF) as well as during "Fair Weather" conditions were considered in the current study, as specified by the 2007 Canadian Dam Association Dam Safety Guidelines (CDA Guidelines). The PMF inflow hydrograph for Muskrat Falls was determined in the PMF and Construction Design Flood Study (GI1140) issued to Nalcor in December 2007. The same inflow hydrology has been used in the current study.

2. Model Updates and Breach Parameter Selection

A description of the selection and setup of the original HEC-GeoRAS dam break model is provided in the GI1190 Final Report (Hatch, 2008). This original model was updated as an earlier part of MF1330 to include additional bathymetry and updated project layouts (further detail is provided in MF1330 Report 1: Hydraulic Modeling of the River). This section summarizes the updated dam layout and the breach scenario selection for the current study.

2.1 Dam Layout

The updated Muskrat Falls Dam configuration (Variant 10, Scheme 3b) is comprised of the following structures as outlined in the MF1050 report.

- 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 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 MFL of 44.0 m.
- Four (4) unit powerhouse capable of passing 2,667 m^3/s at full load.

Figure 2.1 illustrates the arrangement of the above structures. Figure 2.2 presents the discharge rating curve which was input to the hydraulic model to represent the discharge capacity.

2.2 Breach Scenario and Parameter Selection

The dam breach scenario used in GI1190 was reviewed in light of the new project configuration described above. Because the dam structures are constructed using RCC (similar to the previous project layout), erosion type failures were not considered for the Muskrat Falls Dam. For such structures it is much more likely that the mode of failure would be monolithically by overturning or sliding.

The assumption for worst case downstream flooding involves failure of the North RCC Overflow Dam, which is 430 m long and has a bottom elevation of 4.0 m. This breach width is significantly greater than the 260 m breach width assumed in GI1190 which represented the overflow portion of the North RCC Dam (i.e. not including the rubber dam section). Although the increase in breach width is large, there is little effect on the peak outflow and peak water levels downstream. This is because most of the volume is released before the breach is fully formed.

Due to the relatively rapid nature of the failure mechanism, the breach was assumed to be fully formed within 1 hour of breach initiation. The side slopes of the breach were assumed to be vertical (0H:1V).

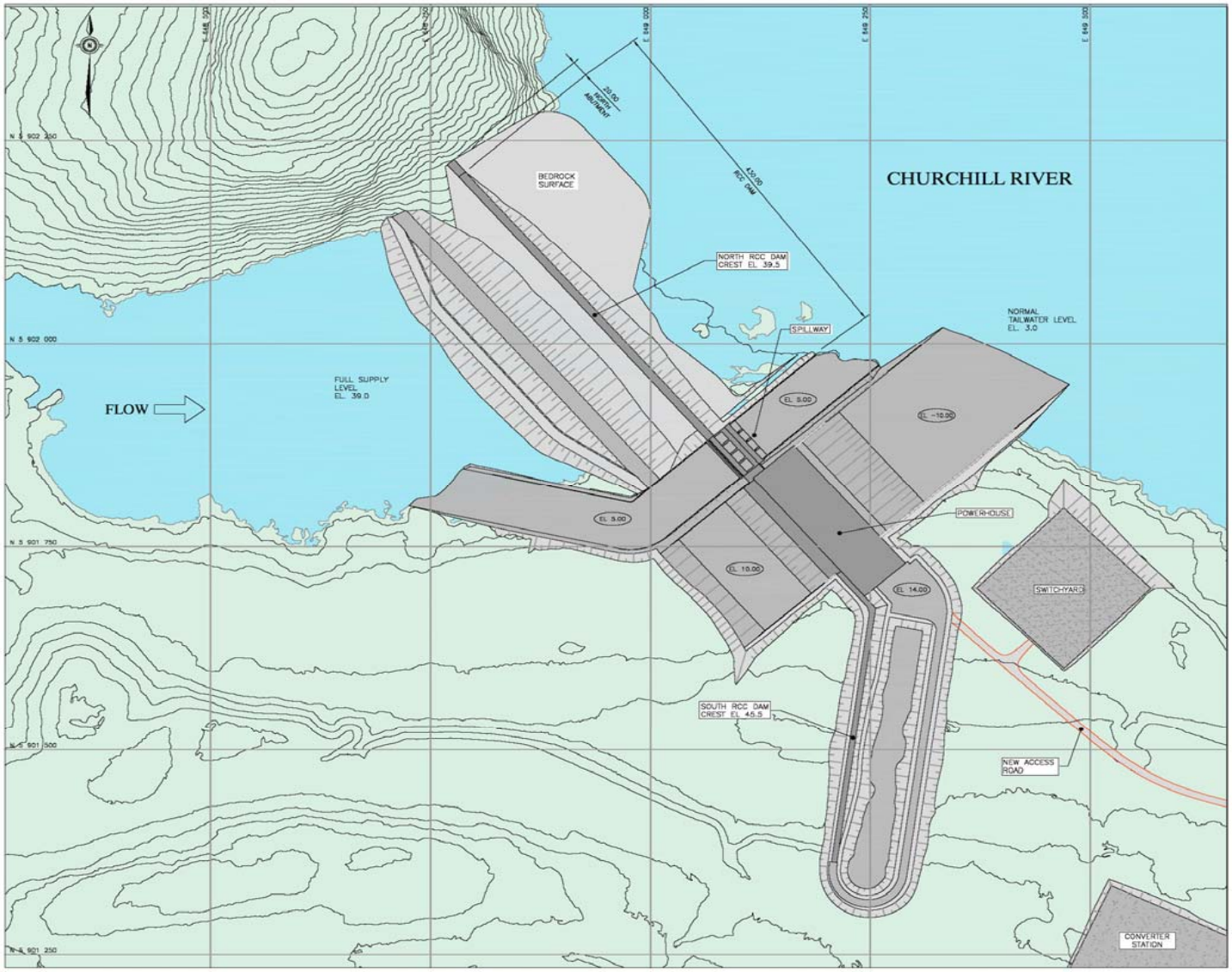

Figure 2.1
Muskrat Falls Project Layout (Variant 10, Scheme 3b)
Muskrat Falls Dam Break Study - 2010 Update
Nalcor Energy - Lower Churchill Project

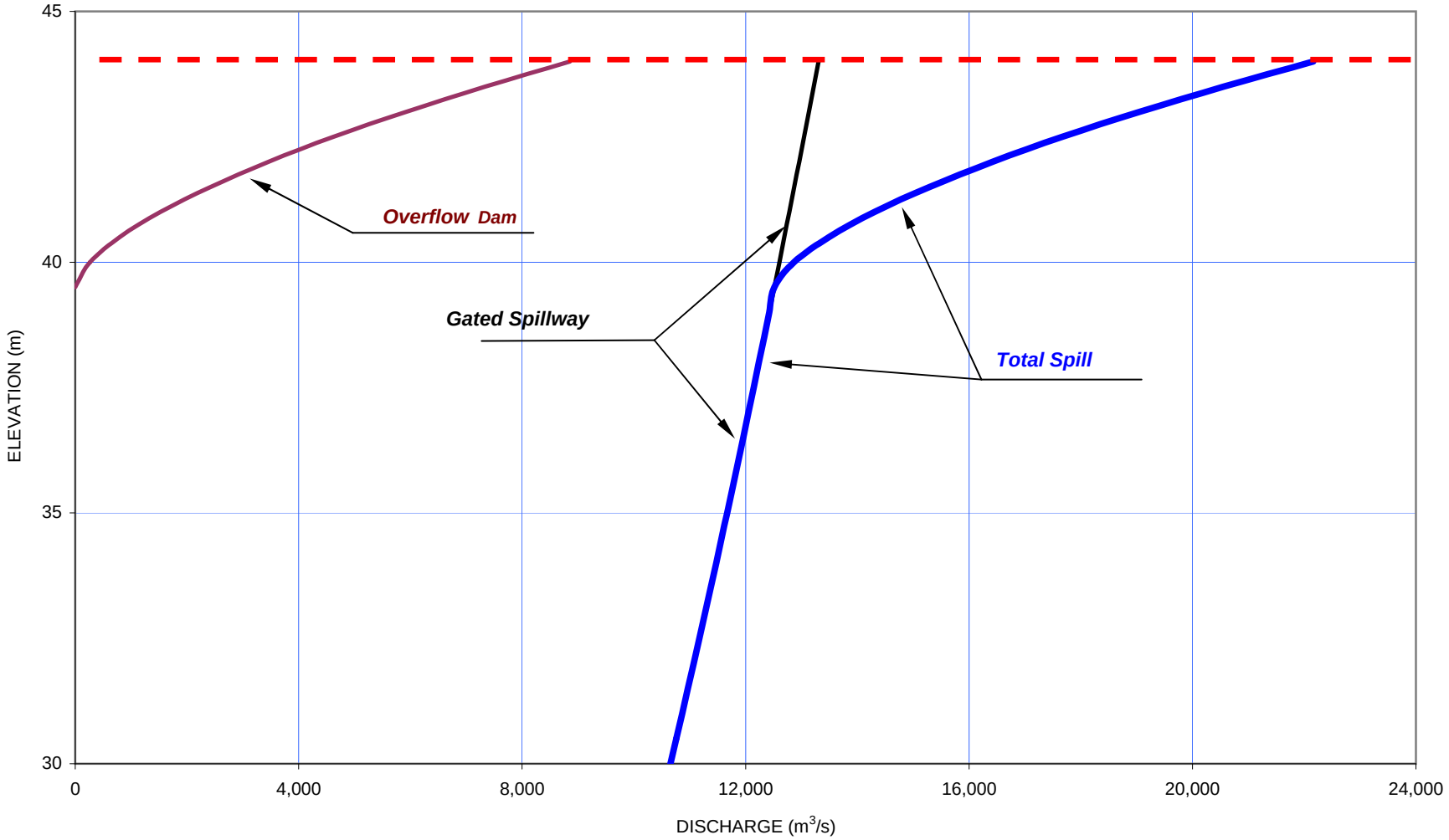

Figure 2.2
Muskrat Falls Discharge Rating Curve
Muskrat Falls Dam Break Study - 2010 Update
Nalcor Energy - Lower Churchill Project

3. HEC-GeoRAS Analysis Results

3.1 "Fair Weather" Conditions Breach Results

Simulations were undertaken to estimate the impacts of a breach at Muskrat Falls on downstream water levels during "Fair Weather" conditions. Inundation mapping corresponding to this scenario is provided in Appendices A and B. Figure 3.1 presents the maximum water surface profile in the reach downstream of Muskrat Falls, and Figures 3.2 to 3.6 include stage and flow hydrographs for key locations in this reach. Table 3.1 below summarizes the results for a number of key downstream locations.

Table 3.1: HEC-GeoRAS Results – "Fair Weather" Conditions, Muskrat Falls Dam Breach

Distance Downstream of MF Dam (km)	Cross Section Description	Maximum Water Level without Breach (m)	Breach Flood Summary				
			Breach Flood Arrival Time (hr)	Peak Water Level (m)	Incremental Depth of Flooding (m)	Maximum Discharge (m^3/s)	Time to Peak Water Level (hr)
1.5	D/S Muskrat Falls Dam	2.6	0	15.4	12.8	62,200	3.4
18.7	U/S Blackrock Bridge	1.6	0.6	11.7	10.1	42,000	3.8
33.6	Happy Valley - Goose Bay	0.7	1.4	6.4	5.7	38,200	6.8
40.0	Mud Lake	0.5	1.7	5.2	4.7	35,200	7.3

General observations from this simulation follow.

- The initial flow of 1,800 m^3/s would be passing through the powerhouse at the time of the breach. This represents average flow conditions in the river.
- A breach at Muskrat Falls 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.
- Incremental water level increases would range from approximately 12.8 m downstream of Muskrat Falls to approximately 4.7 m near Mud Lake.
- There would be approximately 1.4 to 1.7 hours of warning time available between the initiation of the breach and the flood wave reaching the populated areas of the downstream reach (Happy Valley - Goose Bay, Mud Lake).

3.2 PMF Conditions Breach Results

Simulations were undertaken to estimate the impacts of a breach at Muskrat Falls on downstream water levels during PMF conditions. Inundation mapping corresponding to this simulation is provided in Appendices C and D. Figure 3.7 presents the maximum water surface profile in the reach downstream of Muskrat Falls, and Figures 3.8 to 3.12 include stage and flow hydrographs for key locations in this reach. Table 3.2 below summarizes the results for a number of key downstream locations.

Table 3.2: HEC-GeoRAS Results – PMF Conditions, Muskrat Falls Dam Breach

Distance Downstream of MF Dam (km)	Cross Section Description	Maximum Water Level without Breach (m)	Breach Flood Summary				
			Breach Flood Arrival Time (hr)	Peak Water Level (m)	Incremental Depth of Flooding (m)	Maximum Discharge (m^3/s)	Time to Peak Water Level (hr)
1.5	D/S Muskrat Falls Dam	11.4	0	21.1	9.7	101,600	3.2
18.7	U/S Blackrock Bridge	8.2	0.3	17.3	9.1	66,900	3.4
33.6	Happy Valley - Goose Bay	5.4	0.8	8.8	3.4	62,700	5.9
40.0	Mud Lake	4.2	1.2	7.5	3.3	60,900	6.3

General observations from this simulation follow.

- After the forebay surcharges above the Full Supply Level (FSL), a speed-no-load discharge of 405 m^3/s was assumed to be passed through the powerhouse with the remainder of the flow being passed through the spillway gates and overtop of the North RCC Dam.
- A breach at Muskrat Falls would increase the outflow (immediately downstream of the dam) from an initial flow of approximately 25,100 m^3/s to a peak flow of approximately 110,900 m^3/s.
- Incremental water level increases would range from approximately 9.7 m downstream of Muskrat Falls to approximately 3.3 m near Mud Lake.
- There would be approximately 0.8 to 1.2 hours of warning time available between the initiation of the breach and the flood wave reaching the populated areas of the downstream reach (Happy Valley-Goose Bay, Mud Lake).

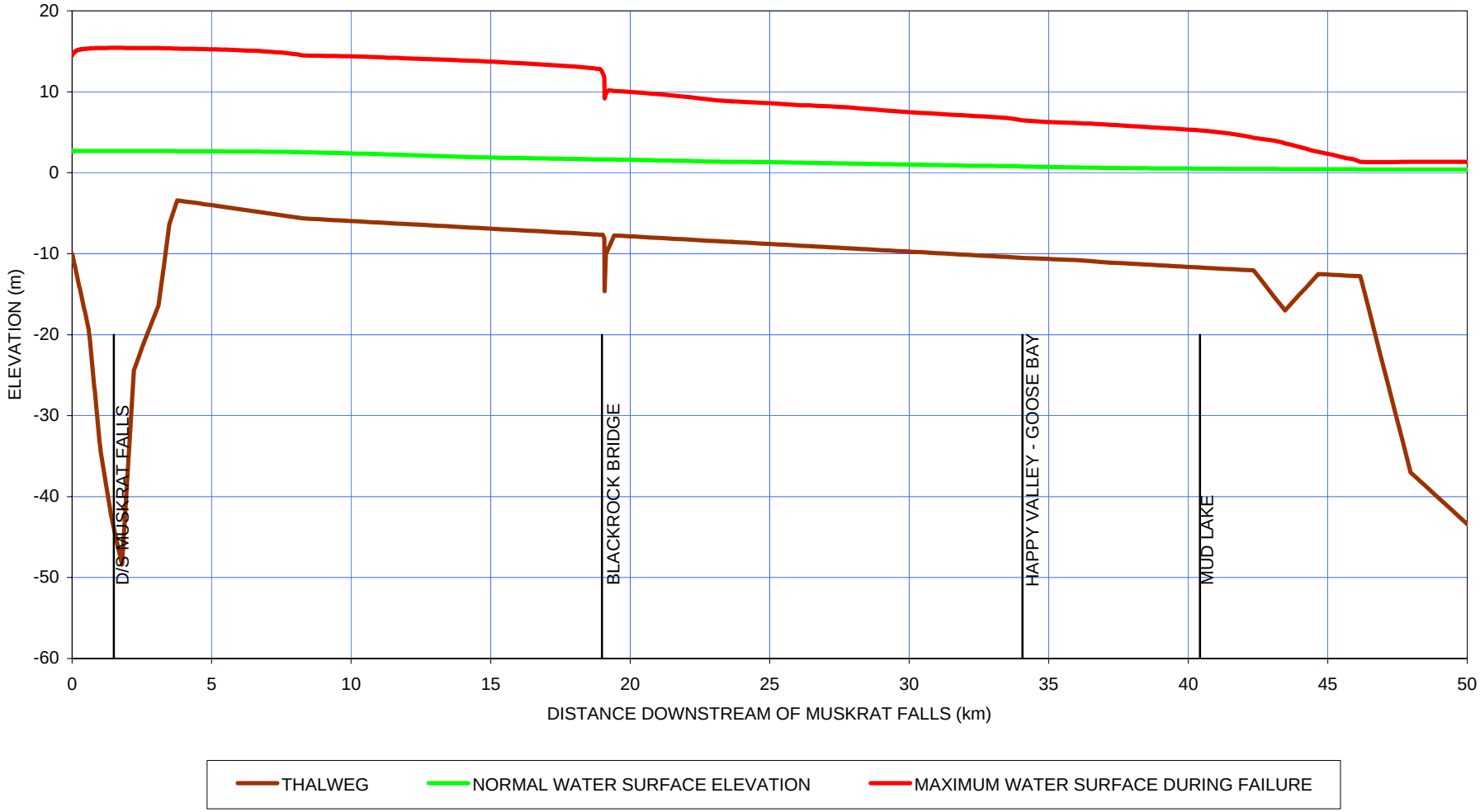

Figure 3.1
Fair Weather Conditions
Maximum Water Surface Elevation Profiles
Muskrat Falls Dam Break Study - 2010 Update
Nalcor Energy - Lower Churchill Project

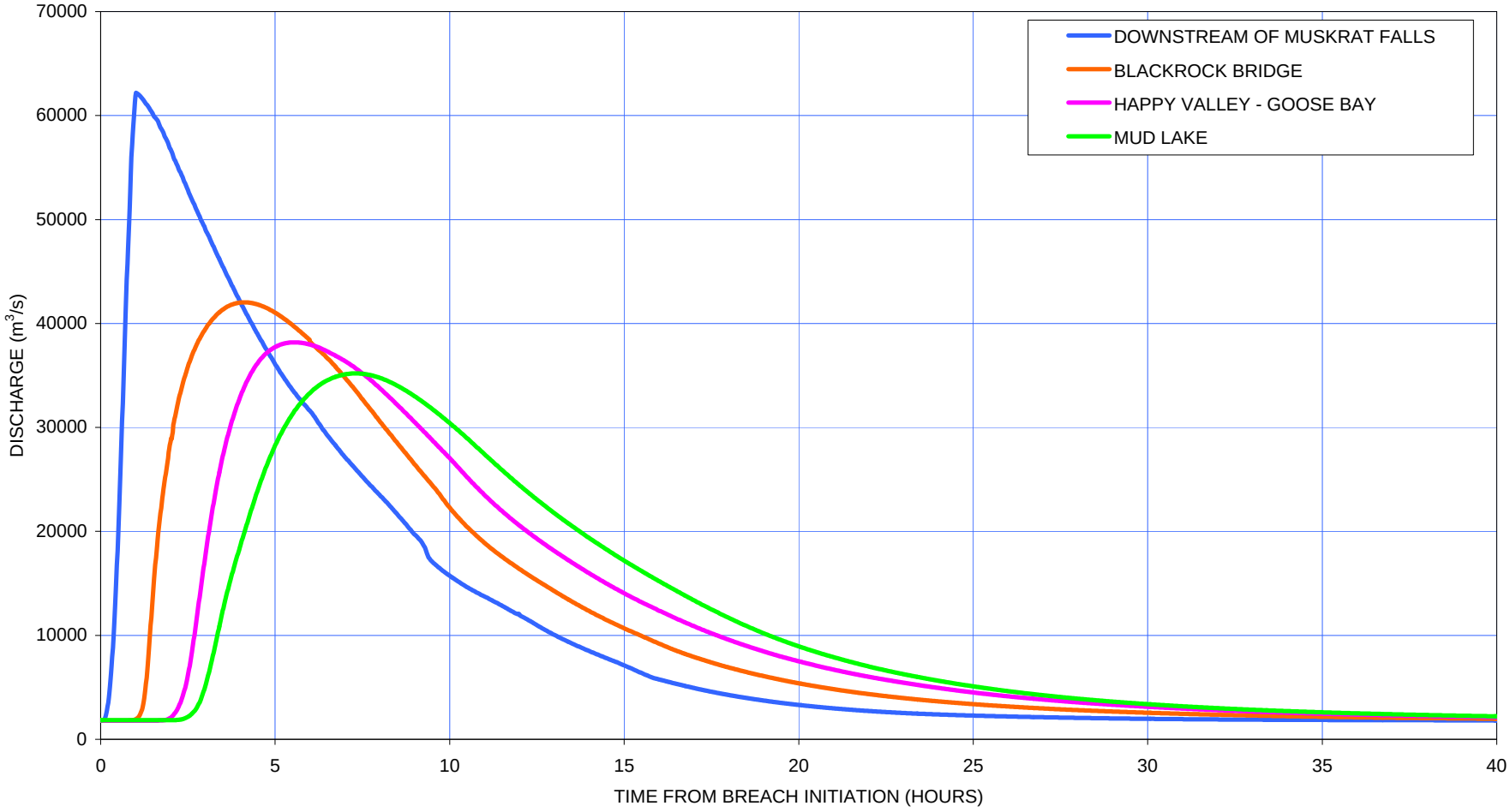

Figure 3.2
Fair Weather Conditions
Discharge Hydrographs at Key Locations
Muskrat Falls Dam Break Study - 2010 Update
Nalcor Energy - Lower Churchill Project

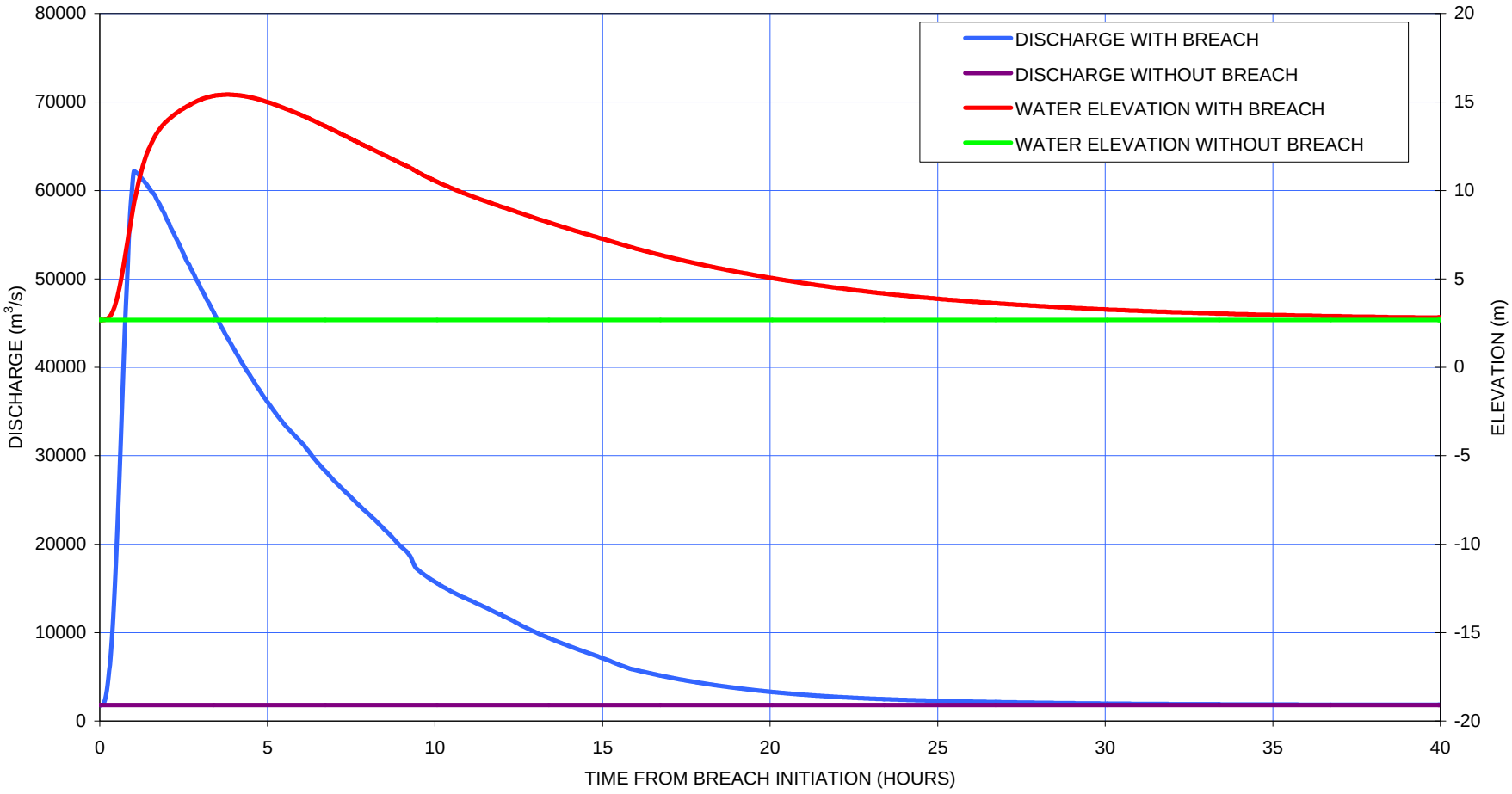

Figure 3.3
Fair Weather Conditions
Stage and Discharge Hydrographs 1.5 km d/s of Muskrat Falls Dam
Muskrat Falls Dam Break Study - 2010 Update
Nalcor Energy - Lower Churchill Project

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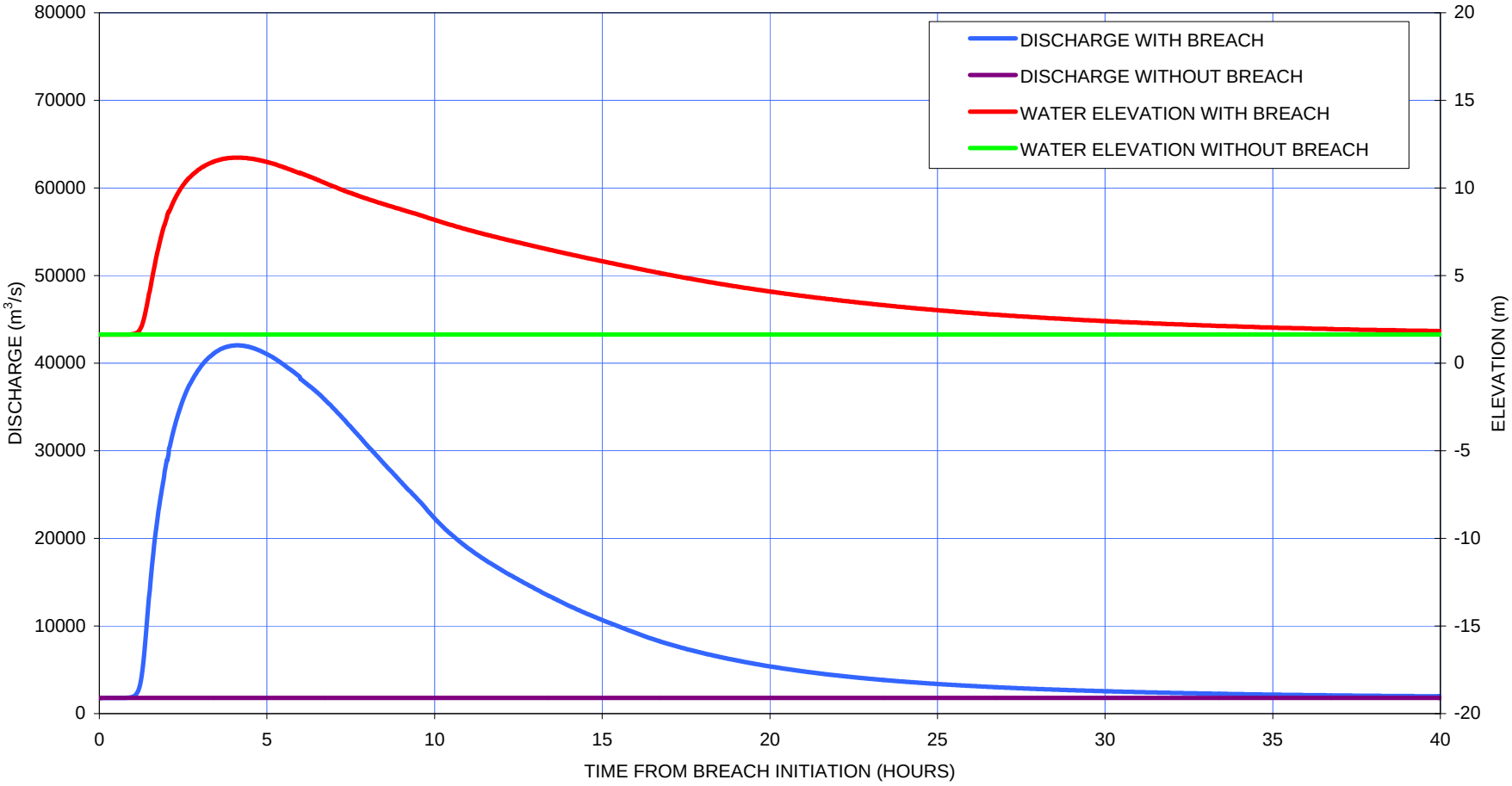

Figure 3.4
Fair Weather Conditions
Stage and Discharge Hydrographs at Blackrock Bridge
Muskrat Falls Dam Break Study - 2010 Update
Nalcor Energy - Lower Churchill Project

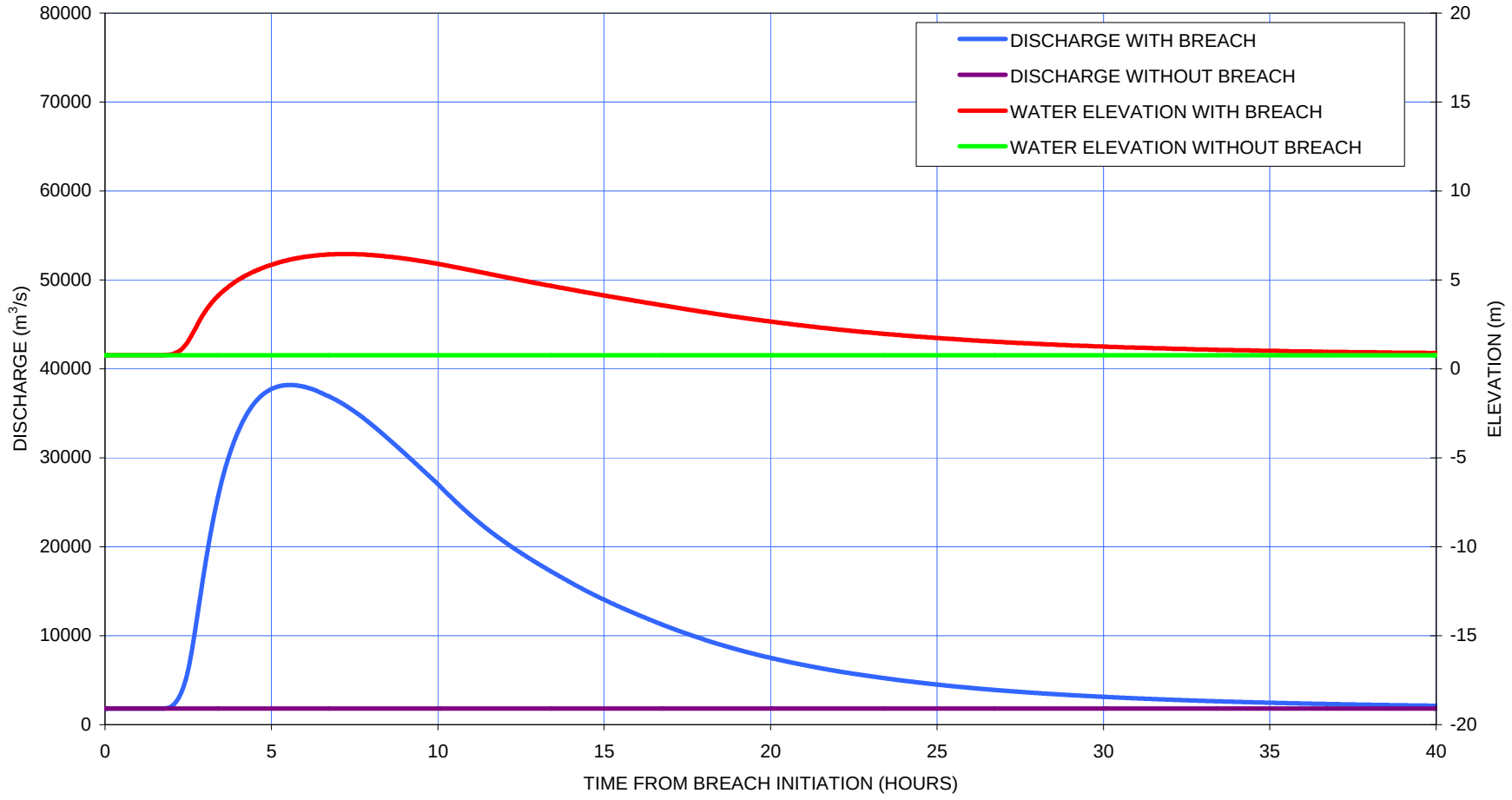

Figure 3.5
Fair Weather Conditions
Stage and Discharge Hydrographs at Happy Valley - Goose Bay
Muskrat Falls Dam Break Study - 2010 Update
Nalcor Energy - Lower Churchill Project

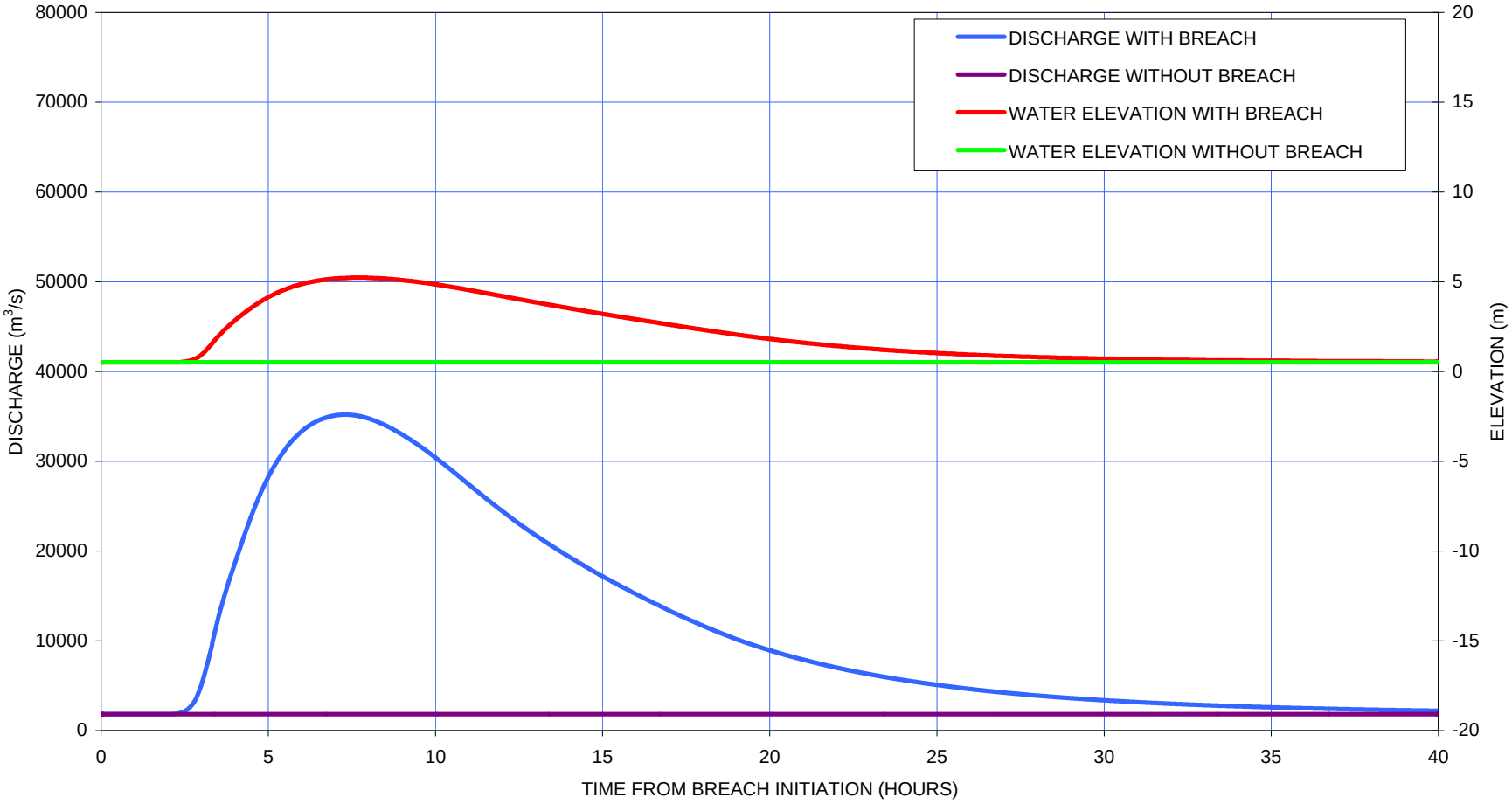

Figure 3.6
Fair Weather Conditions
Stage and Discharge Hydrographs at Mud Lake
Muskrat Falls Dam Break Study - 2010 Update
Nalcor Energy - Lower Churchill Project

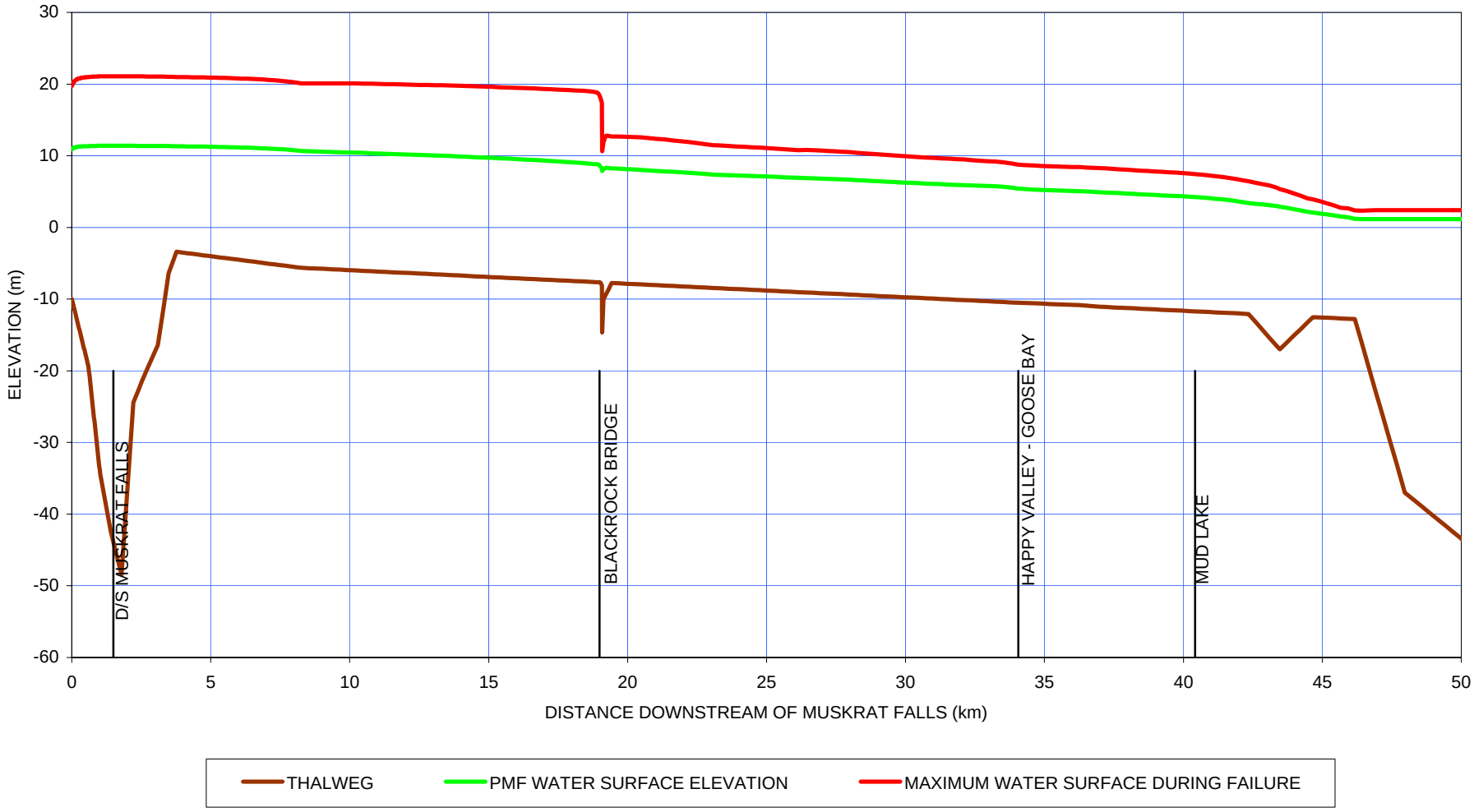

Figure 3.7
PMF Conditions
Maximum Water Surface Elevation Profiles
Muskrat Falls Dam Break Study - 2010 Update
Nalcor Energy - Lower Churchill Project

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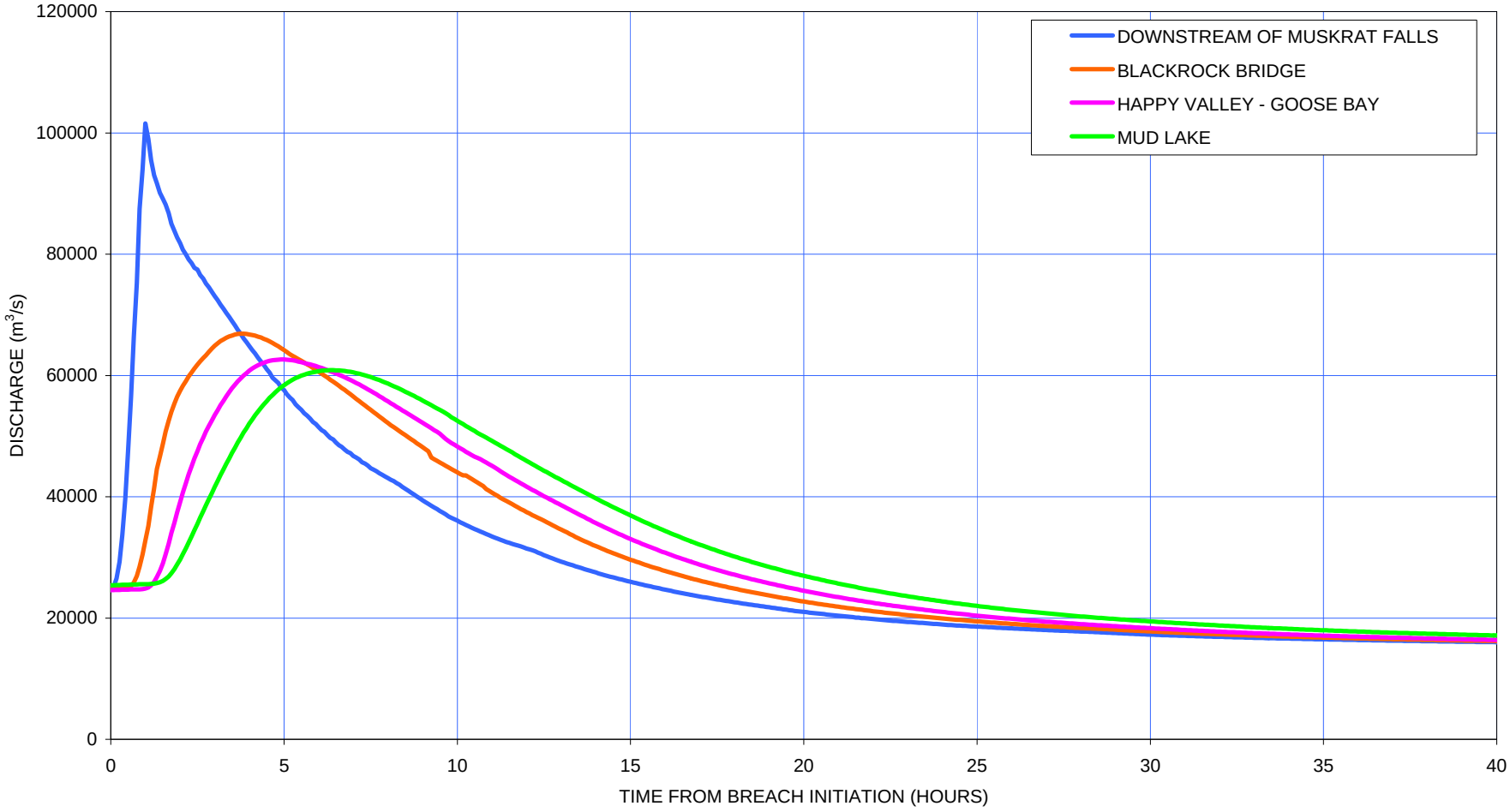


Figure 3.8
PMF Conditions
Discharge Hydrographs at Key Locations
Muskrat Falls Dam Break Study - 2010 Update
Nalcor Energy - Lower Churchill Project

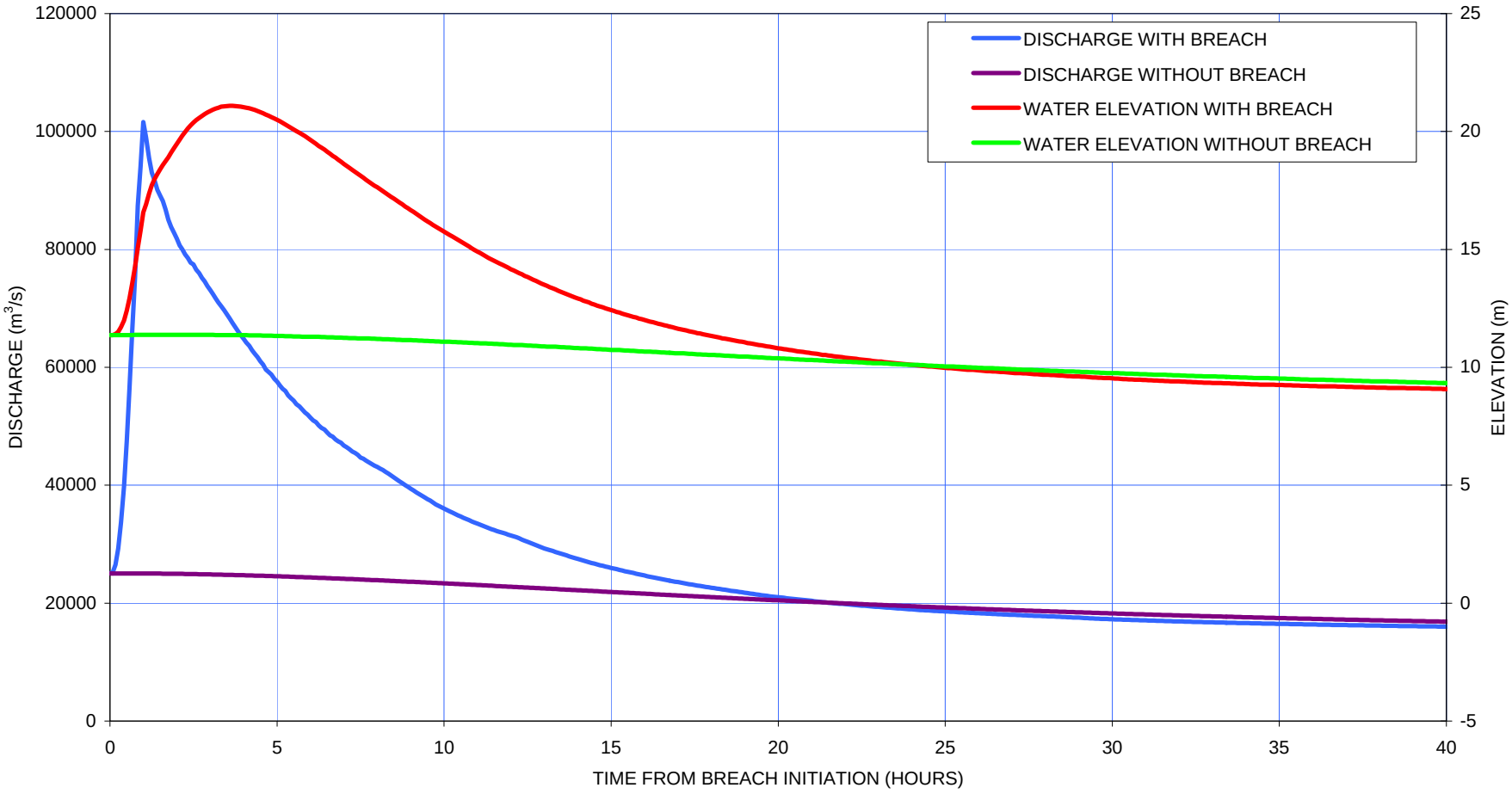


Figure 3.9
PMF Conditions
Stage and Discharge Hydrographs 1.5 km d/s of Muskrat Falls Dam
Muskrat Falls Dam Break Study - 2010 Update
Nalcor Energy - Lower Churchill Project

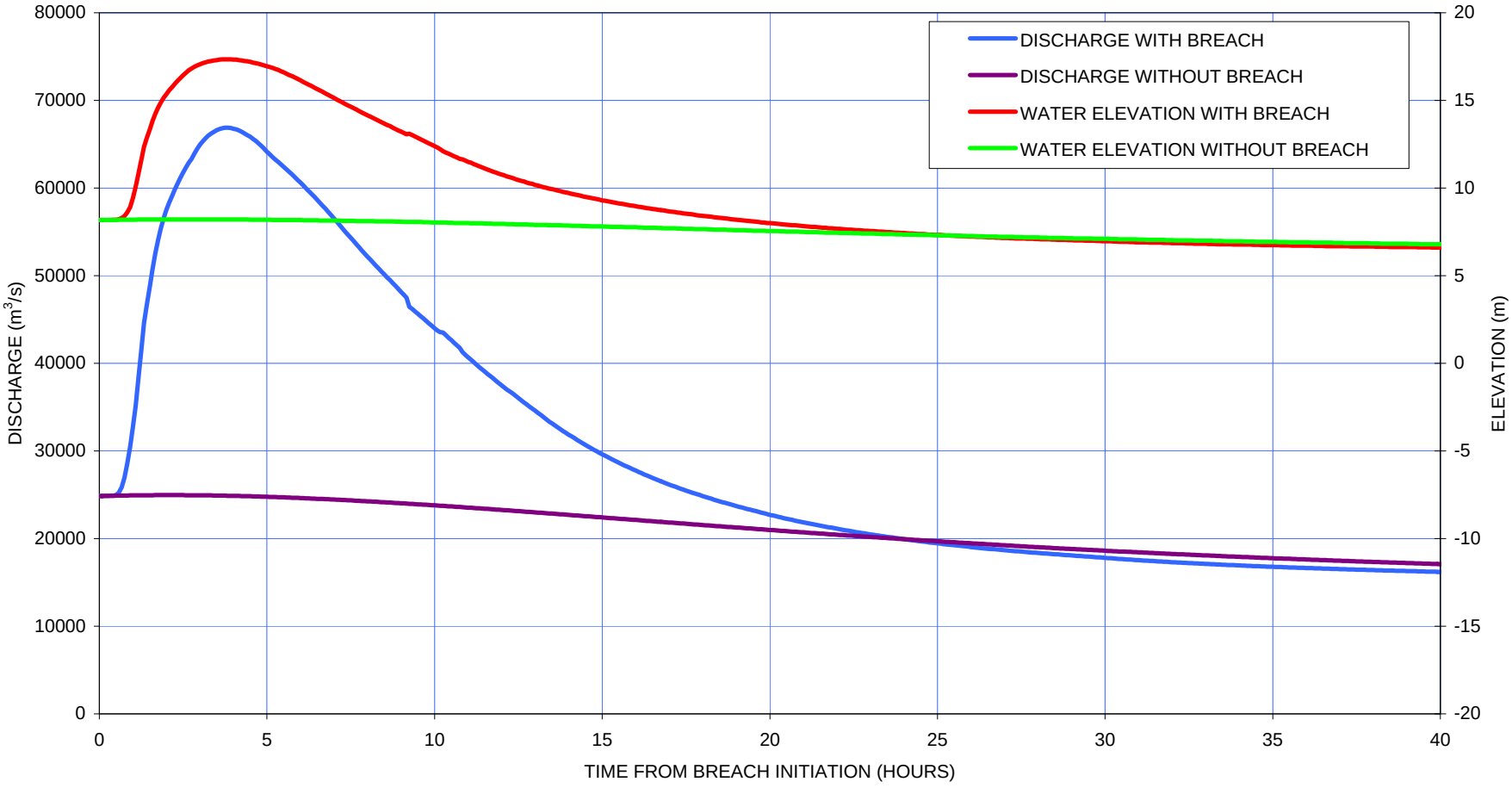


Figure 3.10
PMF Conditions
Stage and Discharge Hydrographs at Blackrock Bridge
Muskrat Falls Dam Break Study - 2010 Update
Nalcor Energy - Lower Churchill Project

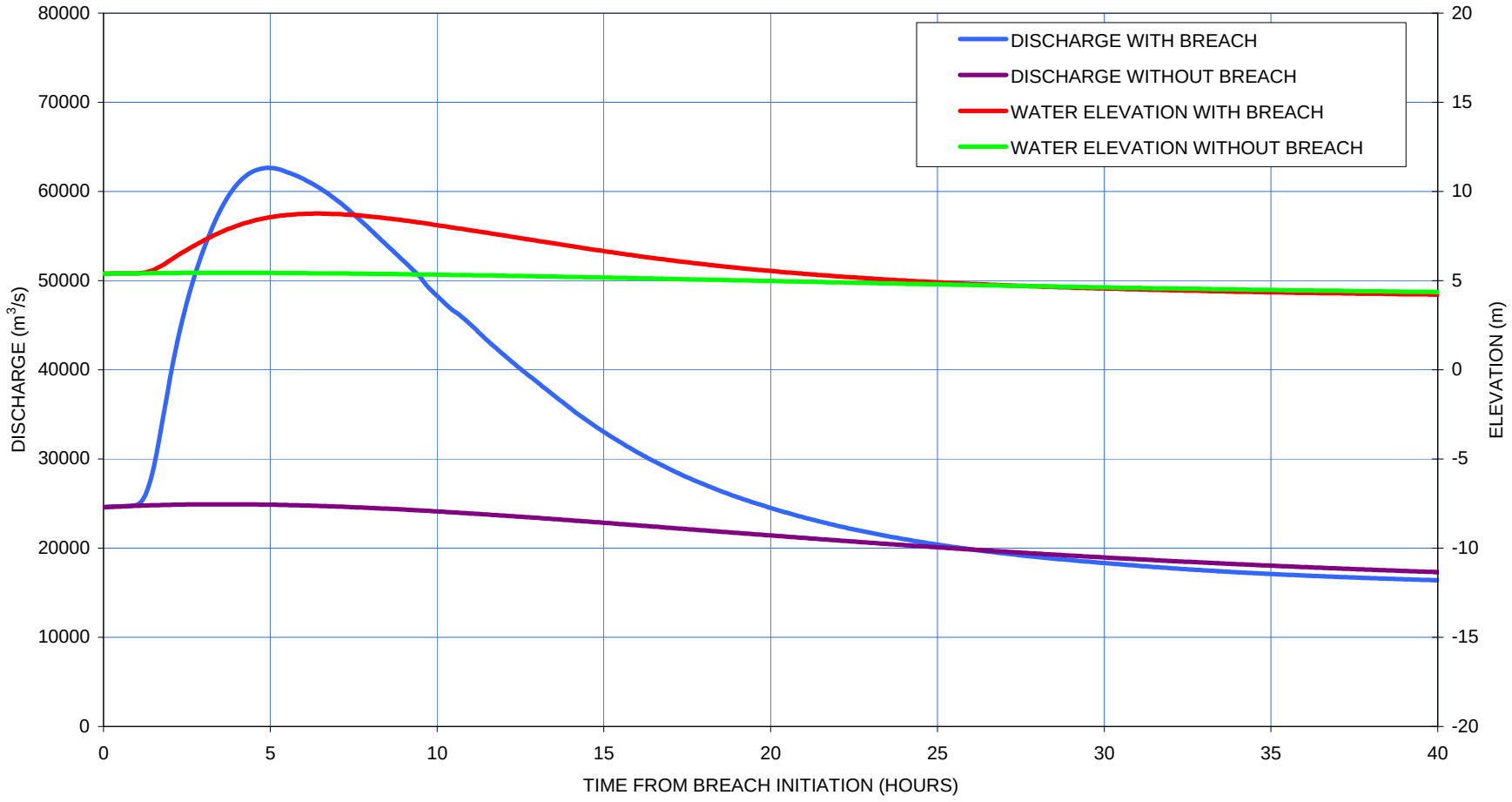


Figure 3.11
PMF Conditions
Stage and Discharge Hydrographs at Happy Valley - Goose Bay
Muskrat Falls Dam Break Study - 2010 Update
Nalcor Energy - Lower Churchill Project

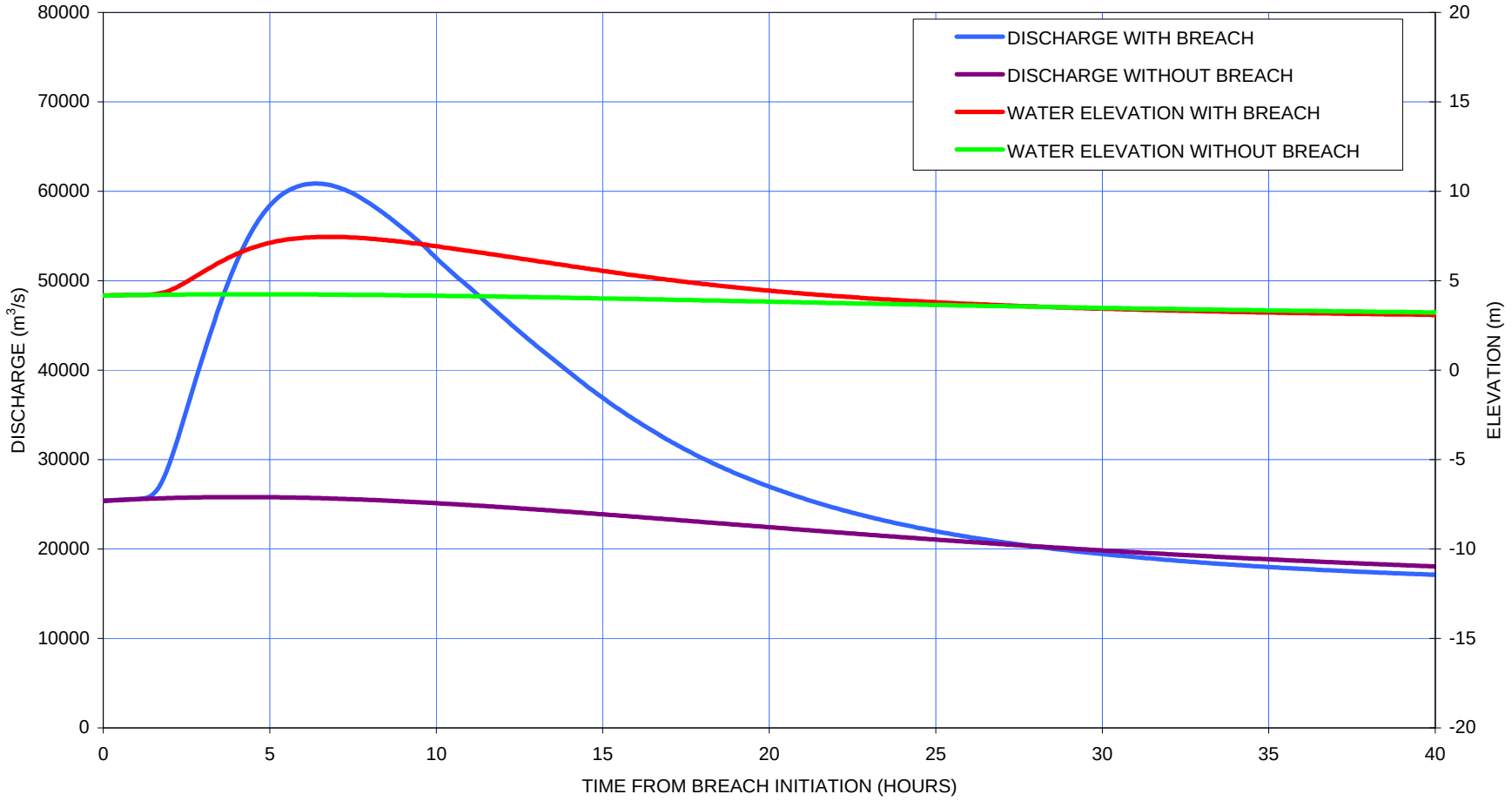


Figure 3.12
PMF Conditions
Stage and Discharge Hydrographs at Mud Lake
Muskrat Falls Dam Break Study - 2010 Update
Nalcor Energy - Lower Churchill Project

4. Inundation Mapping

Following the completion of each simulation, the maximum water surface profile from the HEC-GeoRAS model was exported into a Geographic Information System (ArcGIS) to prepare the inundation mapping along the river valley. Inundation mapping for the "Fair Weather" and PMF simulations are included in Appendices A through D.

Inundation maps for the area between Muskrat Falls and Lake Melville were prepared using 1:50,000 scale NTS topographic maps. The reach between Muskrat Falls and Mud Lake is shown on three maps at a 1:50,000 scale; a map of Goose Bay and Lake Melville including the communities of North West River and Sheshatshiu is shown at a 1:140,000 scale. The contours shown on these maps were prepared based on the LiDAR topographical survey data within the river valley, and 1:50,000 scale digital elevation data outside the river valley. Information boxes are provided on the maps providing specific information related to the dam breach flood wave at various locations. Information provided includes the following.

- Distance Downstream of Muskrat Falls Dam (km)
- Fair Weather Water Surface or Peak Flood Elevation (m)
- Peak Breach Elevation (m)
- Incremental Depth of Flooding (m)
- Breach Flood Wave Arrival Time (hrs)
- Time to Peak Water Elevation (hrs)

Figure 4.1 illustrates typical flood and dam breach hydrographs, and the derivation of the above values.

For the communities of Happy Valley - Goose Bay and Mud Lake, the only communities in which there is a population at risk within the inundated area, additional mapping was prepared at a larger scale (1:10,000 scale) to better define flood inundation lines. These maps were produced using high resolution aerial photography as a back drop to better illustrate the inundated areas. This aerial photography was taken for NE-LCP by TerraPoint during the LiDAR survey in 2006. Inundation mapping using aerial photography for "Fair Weather" and PMF simulations are included in Appendix B and D, respectively.

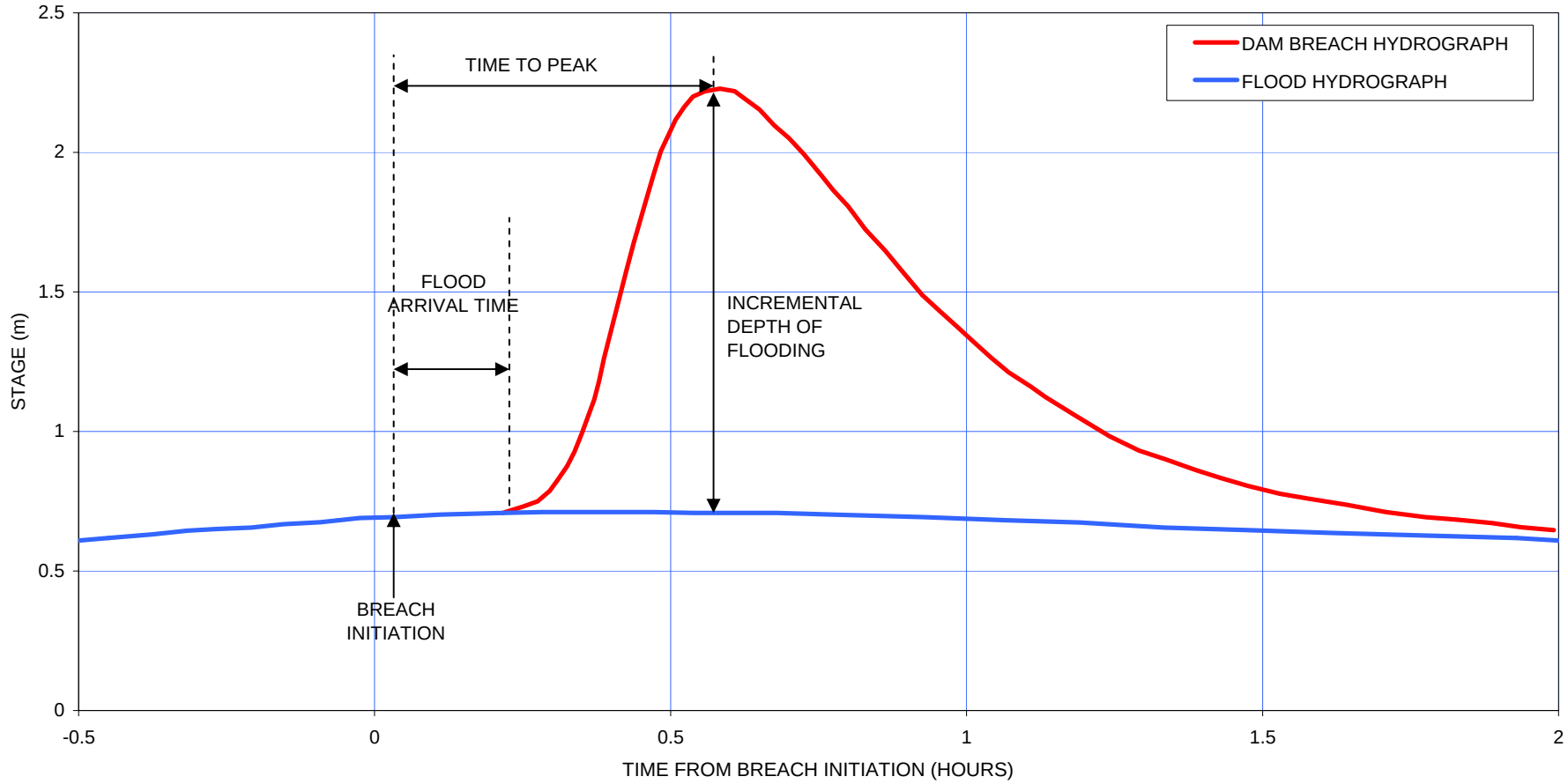


Figure 4.1
Typical Dam Breach and Flood Hydrographs
Muskrat Falls Dam Break Study - 2010 Update
Nalcor Energy - Lower Churchill Project

5. Consequences of Failure

The inundation maps presented in Appendices B and D were reviewed to determine the incremental consequences of failure, or the consequences of failure in the inundated area between the estimated water levels that would occur with and without failure of the dam.

5.1 Potential Loss of Life Assessment

The Population at Risk (PAR) in the incrementally inundated area provides an indication of the number of people exposed to the hazard. Consistent estimates of expected loss of life are very difficult to develop and the potential for Loss of Life (LOL) depends on many highly uncertain and variable factors, such as depth of flow, velocity, time of day, advance warning, topography, distance from the dam, transportation routes, and mobility of the population. Although no simple, reliable methodology is available, the quantitative approach for assessing the potential LOL for this study is based on the publication presented by DeKay and McClelland, "Predicting Loss of Life in Cases of Dam Failure and Flash Flood", 1991.

The DeKay/McClelland publication derived from historical data an expression of LOL in terms of the available Warning Time (WT), the size of the PAR, and the forcefulness of the floodwaters. WT is taken as the difference in time between the first initiation of dam breach occurring to the time it takes the initial flood wave to reach the PAR. The estimated PAR for a dam breach study such as this, reflects the population located within the incrementally inundated zone. The forcefulness of the floodwave generated by a breach of the Muskrat Falls Dam was categorized as high force (HF), which corresponds to deep fast flowing flood waters. The equation for LOL based on high force floodwaters is presented as follows:

$$LOL_{HF} = PAR / (1 + 13.277 * (PAR^{0.44}) * e^{[2.982*(WT)-3.790]})$$

PAR was determined by counting the number of homes/ structures in the incrementally inundated area (including the communities of Happy Valley – Goose Bay and Mud Lake) and multiplying by the average number of residents per household in Happy Valley - Goose Bay (2.8 persons/household based on the 2006 Statistics Canada Community Profiles). Table 5.1 provides the assessment of potential incremental LOL for both PMF and "Fair Weather" conditions.

Table 5.1: Potential Loss of Life Assessment

Scenario	# of Incrementally Inundated Buildings	PAR in Incrementally Inundated Area	WT (hours)	Incremental 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

The DeKay and McClelland publication notes that if WT is more than an hour or two, neither population would be in great danger. However, this assumes that evacuation orders are provided immediately after the time of dam breach initiation and that the PAR has coordinated emergency preparedness plans and

evacuation takes place. To assess the sensitivity of LOL to WT, the potential LOL was determined in the above tables assuming the PAR had no warning time. As can be seen from the above table, LOL is highly sensitive to WT. This illustrates the importance of having effective and current emergency preparedness and evacuation plans in order to be able to evacuate the potentially inundated areas prior to, or as quickly as possible after a dam breach.

5.2 Potential Economic Loss Assessment

For the purposes of this assessment, the inundation maps were reviewed to determine areas downstream of Muskrat Falls that would be within the incrementally inundated flood area and could therefore be negatively impacted by a dam breach. For the economic evaluation, a minimum assessment of economic damage was calculated by multiplying the number of buildings incrementally inundated by the average value of dwellings in Happy Valley - Goose Bay (~$135,000/ home based on the Statistics Canada 2006 Community Profiles). This represents a minimum assessment, since there would be economic damages associated with loss of energy, rebuilding generating stations, and rebuilding community infrastructure.

5.2.1 PMF Conditions

- Economic damages associated with loss of homes (~40) = $5,400,000.
- Approximate area of incremental flooding = 45 km^2.
- Overtopping of Blackrock Bridge.
- Loss of access and transportation routes in and around Happy Valley - Goose Bay.
- Loss of transmission line infrastructure in and around Happy Valley - Goose Bay.
- Loss of Muskrat Falls Hydroelectric Station and energy.

5.2.2 "Fair Weather" Conditions

- Economic damages associated with loss of homes (~350) = $47,250,000.
- Approximate area of incremental flooding = 120 km^2.
- Overtopping of Blackrock Bridge.
- Loss of access and transportation routes in and around Happy Valley - Goose Bay.
- Loss of transmission line infrastructure in and around Happy Valley - Goose Bay.
- Loss of Muskrat Falls Hydroelectric Station and energy.

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

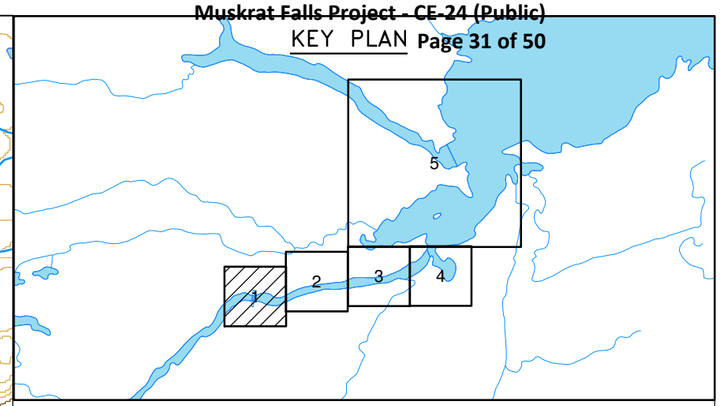
Appendix A

"Fair Weather" Inundation Mapping

DISTANCE DOWNSTREAM OF MUSKRAT FALLS DAM:	1.5 km
FAIR WEATHER WATER SURFACE ELEVATION:	2.6 m
PEAK BREACH ELEVATION:	15.4 m
INCREMENTAL DEPTH OF FLOODING:	12.8 m
BREACH FLOODWAVE ARRIVAL TIME:	0 hr
TIME TO PEAK WATER ELEVATION:	3.4 hr

Churchill River
Muskrat Falls
Churchill River
Lower Brook
MacKenzie River

KEY PLAN



– INDICATES AREA COVERED BY THIS SHEET.

LEGEND

- BUILDING
- TANK
- TOWER
- WATER BODY
- WETLAND
- BREACH INUNDATION
- ROAD
- RIVER
- HYDRAULIC MODEL CROSS SECTIONS
- TRANSMISSION LINE
- CONTOUR (20 m)
- INDEX CONTOUR (100 m)

NOTES:

1. ALL CONTOURS SHOWN ARE IN METRES.
2. COORDINATES ARE BASED ON THE UNIVERSAL TRANSVERSE MERCATOR PROJECTION, ZONE 20 NORTH, NORTH AMERICAN DATUM 1983.
3. THE SURFACE FEATURES WERE PRODUCED FROM 1:50000 NATIONAL TOPOGRAPHIC SYSTEM (NTS) MAPS.
4. LIDAR DATA OBTAINED IN 2006 WAS USED TO CREATE THE TOPOGRAPHIC CONTOURS WITHIN THE RIVER VALLEY AND OUTSIDE THE LIDAR EXTENTS, CONTOURS WERE PRODUCED FROM 1:50000 DIGITAL ELEVATION DATA

SCALE 1:50000
1000 500 0 1000 2000 3000
METRES

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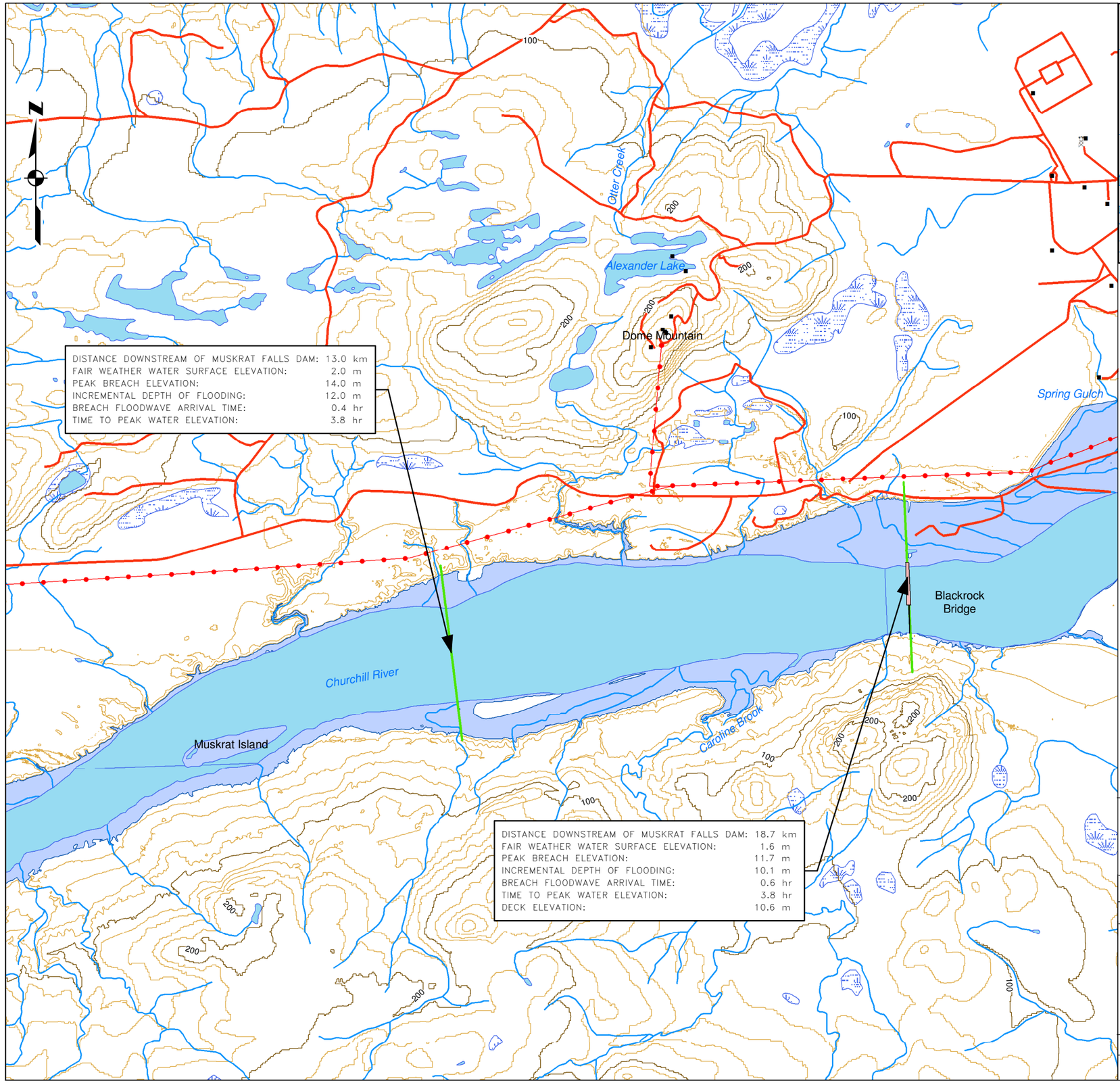
NALCOR ENERGY

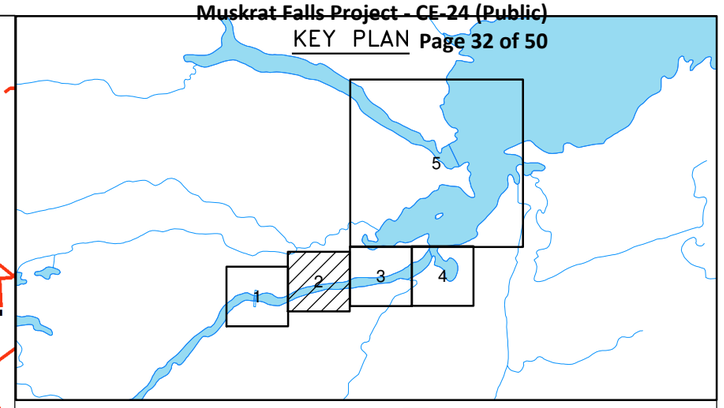
LOWER CHURCHILL PROJECT

FAIR WEATHER CONDITIONS
POST MUSKRAT FALLS
FAILURE OF MUSKRAT FALLS NORTH RCC DAM

SCALE	DRAWING NO.
1:50000	FIGURE A–1
HATCH PROJECT No. H–335459 MF1330	



KEY PLAN



▨ – INDICATES AREA COVERED BY THIS SHEET.

LEGEND

- BUILDING
- TANK
- TOWER
- WATER BODY
- WETLAND
- BREACH INUNDATION
- ROAD
- RIVER
- HYDRAULIC MODEL CROSS SECTIONS
- TRANSMISSION LINE
- CONTOUR (20 m)
- INDEX CONTOUR (100 m)

NOTES:

1. ALL CONTOURS SHOWN ARE IN METRES.
2. COORDINATES ARE BASED ON THE UNIVERSAL TRANSVERSE MERCATOR PROJECTION, ZONE 20 NORTH, NORTH AMERICAN DATUM 1983.
3. THE SURFACE FEATURES WERE PRODUCED FROM 1:50000 NATIONAL TOPOGRAPHIC SYSTEM (NTS) MAPS.
4. LIDAR DATA OBTAINED IN 2006 WAS USED TO CREATE THE TOPOGRAPHIC CONTOURS WITHIN THE RIVER VALLEY AND OUTSIDE THE LIDAR EXTENTS, CONTOURS WERE PRODUCED FROM 1:50000 DIGITAL ELEVATION DATA

1000 500 0 1000 2000 3000
SCALE 1:50000 METRES

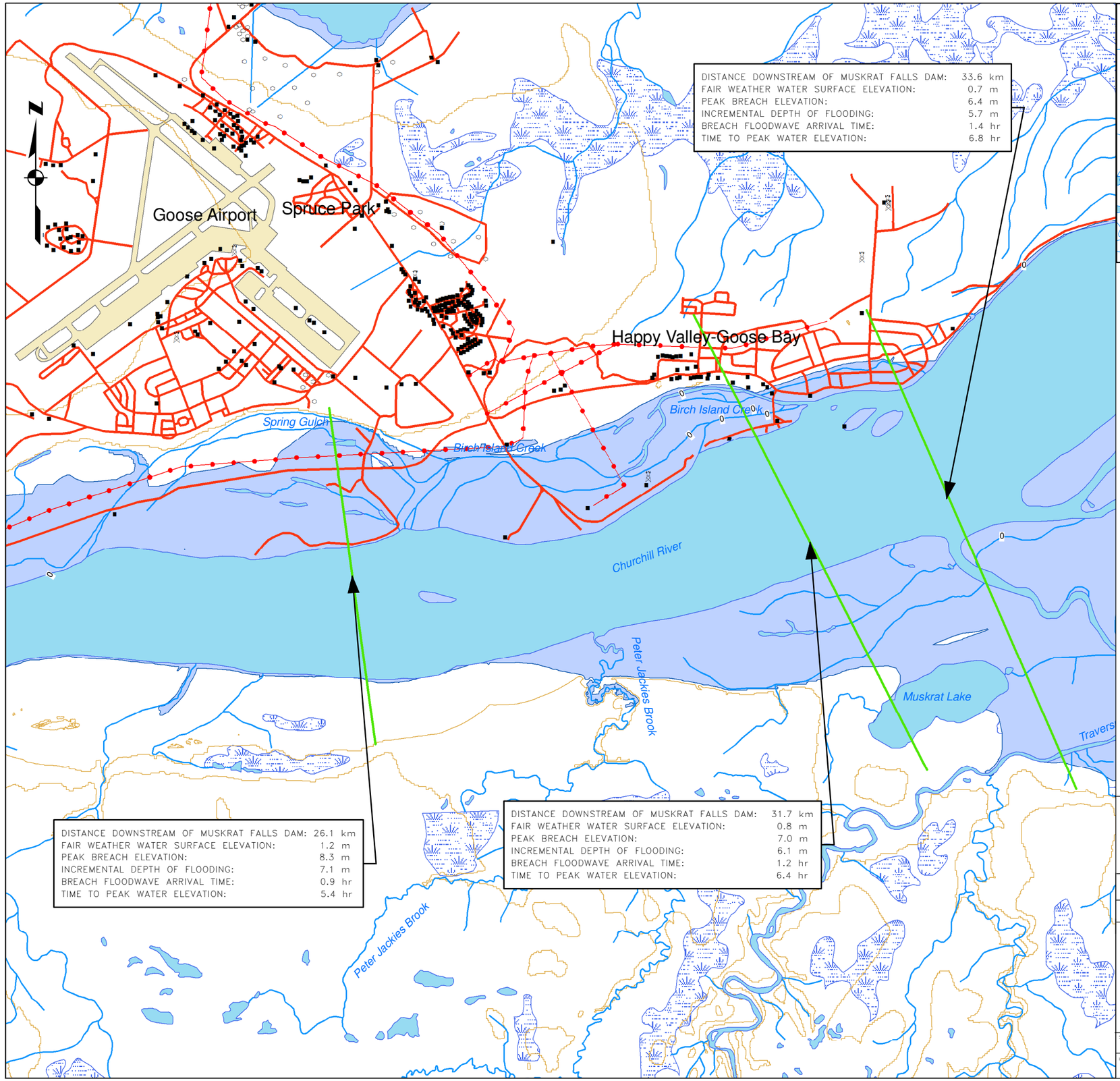
HATCH™ nalcor energy LOWER CHURCHILL PROJECT

NALCOR ENERGY

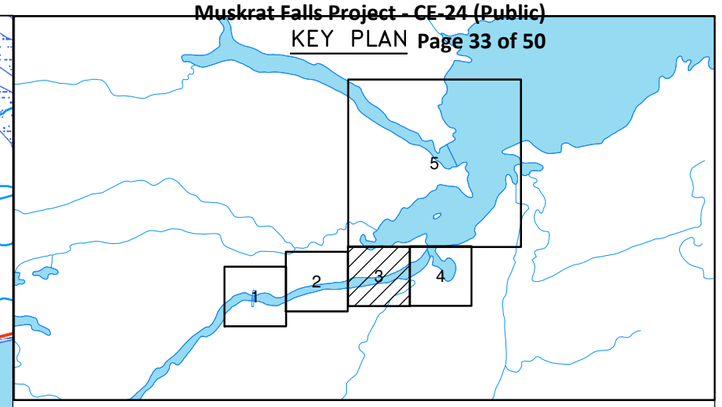
LOWER CHURCHILL PROJECT

FAIR WEATHER CONDITIONS
POST MUSKRAT FALLS
FAILURE OF MUSKRAT FALLS NORTH RCC DAM

SCALE	DRAWING NO.
1:50000	FIGURE A–2
HATCH PROJECT No. H–335459 MF1330	



KEY PLAN



– INDICATES AREA COVERED BY THIS SHEET.

LEGEND

- BUILDING
- TANK
- TOWER
- WATER BODY
- WETLAND
- BREACH INUNDATION
- ROAD
- RIVER
- HYDRAULIC MODEL CROSS SECTIONS
- TRANSMISSION LINE
- CONTOUR (20 m)
- INDEX CONTOUR (100 m)

NOTES:

1. ALL CONTOURS SHOWN ARE IN METRES.
2. COORDINATES ARE BASED ON THE UNIVERSAL TRANSVERSE MERCATOR PROJECTION, ZONE 20 NORTH, NORTH AMERICAN DATUM 1983.
3. THE SURFACE FEATURES WERE PRODUCED FROM 1:50000 NATIONAL TOPOGRAPHIC SYSTEM (NTS) MAPS.
4. LIDAR DATA OBTAINED IN 2006 WAS USED TO CREATE THE TOPOGRAPHIC CONTOURS WITHIN THE RIVER VALLEY AND OUTSIDE THE LIDAR EXTENTS, CONTOURS WERE PRODUCED FROM 1:50000 DIGITAL ELEVATION DATA

1000 500 0 1000 2000 3000
SCALE 1:50000 METRES

HATCH™ nalcor energy LOWER CHURCHILL PROJECT

NALCOR ENERGY

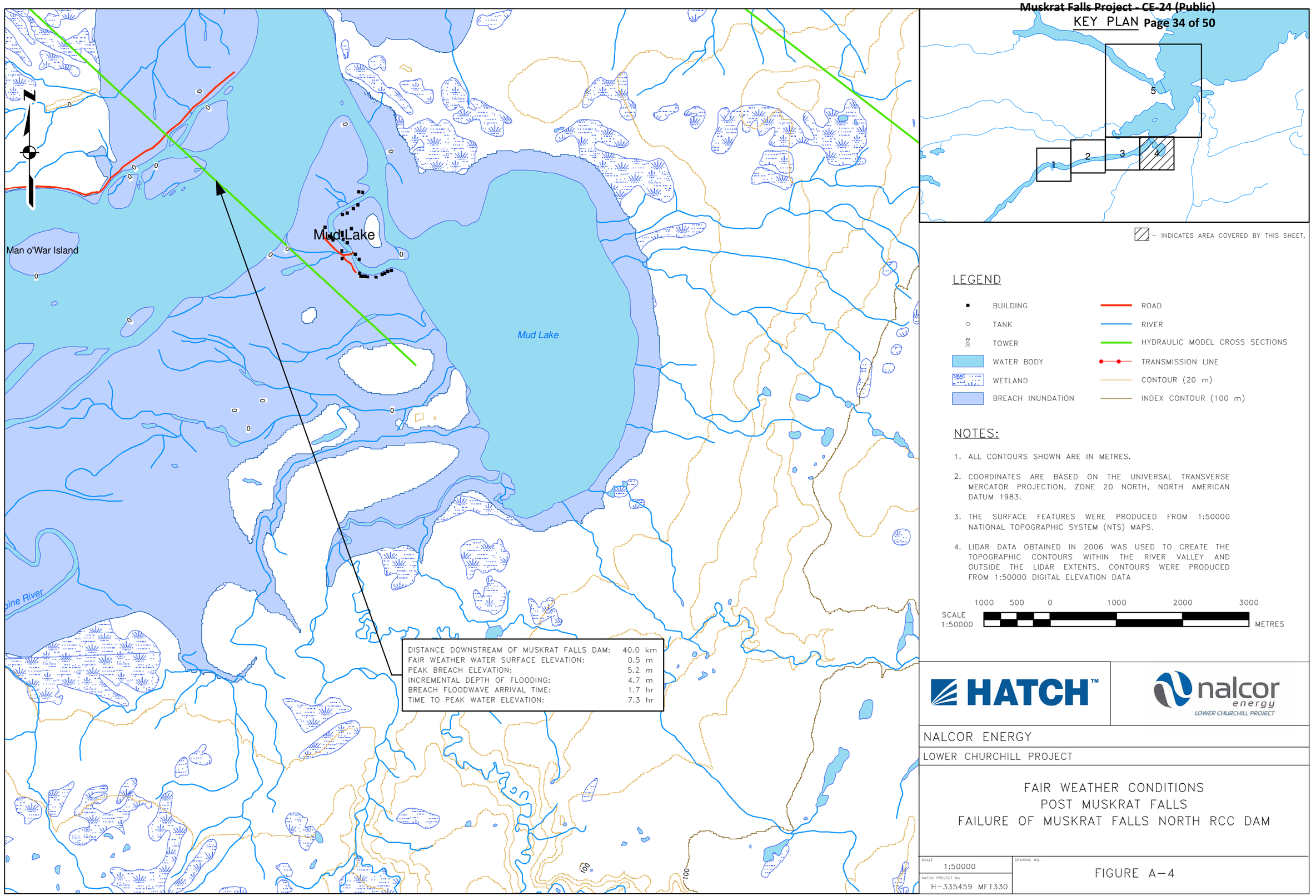
LOWER CHURCHILL PROJECT

FAIR WEATHER CONDITIONS
POST MUSKRAT FALLS
FAILURE OF MUSKRAT FALLS NORTH RCC DAM

SCALE 1:50000

HATCH PROJECT No. H-335459 MF1330

DRAWING NO. FIGURE A-3



KEY PLAN

– INDICATES AREA COVERED BY THIS SHEET.

LEGEND

- BUILDING
- TANK
- TOWER
- WATER BODY
- WETLAND
- BREACH INUNDATION
- ROAD
- RIVER
- HYDRAULIC MODEL CROSS SECTIONS
- TRANSMISSION LINE
- CONTOUR (20 m)
- INDEX CONTOUR (100 m)

NOTES:

1. ALL CONTOURS SHOWN ARE IN METRES.
2. COORDINATES ARE BASED ON THE UNIVERSAL TRANSVERSE MERCATOR PROJECTION, ZONE 20 NORTH, NORTH AMERICAN DATUM 1983.
3. THE SURFACE FEATURES WERE PRODUCED FROM 1:50000 NATIONAL TOPOGRAPHIC SYSTEM (NTS) MAPS.
4. LIDAR DATA OBTAINED IN 2006 WAS USED TO CREATE THE TOPOGRAPHIC CONTOURS WITHIN THE RIVER VALLEY AND OUTSIDE THE LIDAR EXTENTS, CONTOURS WERE PRODUCED FROM 1:50000 DIGITAL ELEVATION DATA

1000 500 0 1000 2000 3000

SCALE 1:50000 METRES

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LOWER CHURCHILL PROJECT

FAIR WEATHER CONDITIONS
POST MUSKRAT FALLS
FAILURE OF MUSKRAT FALLS NORTH RCC DAM

SCALE	DRAWING NO.
1:50000	FIGURE A–4
HATCH PROJECT No. H–335459 MF1330	

Lake Melville

Grand Lake

North West River

Sheshatshiu

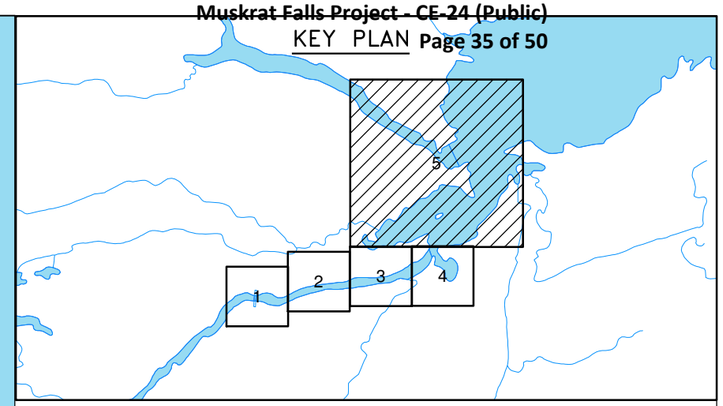
Goose Bay

DISTANCE DOWNSTREAM OF MUSKRAT FALLS DAM:	74.6 km
FAIR WEATHER WATER SURFACE ELEVATION:	0.4 m
PEAK BREACH ELEVATION:	0.6 m
INCREMENTAL DEPTH OF FLOODING:	0.2 m
BREACH FLOODWAVE ARRIVAL TIME:	2.8 hr
TIME TO PEAK WATER ELEVATION:	11.7 hr

DISTANCE DOWNSTREAM OF MUSKRAT FALLS DAM:	64.2 km
FAIR WEATHER WATER SURFACE ELEVATION:	0.4 m
PEAK BREACH ELEVATION:	0.6 m
INCREMENTAL DEPTH OF FLOODING:	0.2 m
BREACH FLOODWAVE ARRIVAL TIME:	2.5 hr
TIME TO PEAK WATER ELEVATION:	11.4 hr

DISTANCE DOWNSTREAM OF MUSKRAT FALLS DAM:	47.6 km
FAIR WEATHER WATER SURFACE ELEVATION:	0.4 m
PEAK BREACH ELEVATION:	1.3 m
INCREMENTAL DEPTH OF FLOODING:	0.9 m
BREACH FLOODWAVE ARRIVAL TIME:	2.0 hr
TIME TO PEAK WATER ELEVATION:	9.5 hr

KEY PLAN



– INDICATES AREA COVERED BY THIS SHEET.

LEGEND

- BUILDING
- TANK
- TOWER
- WATER BODY
- WETLAND
- BREACH INUNDATION
- ROAD
- RIVER
- HYDRAULIC MODEL CROSS SECTIONS
- TRANSMISSION LINE
- CONTOUR (20 m)
- INDEX CONTOUR (100 m)

NOTES:

1. ALL CONTOURS SHOWN ARE IN METRES.
2. COORDINATES ARE BASED ON THE UNIVERSAL TRANSVERSE MERCATOR PROJECTION, ZONE 20 NORTH, NORTH AMERICAN DATUM 1983.
3. THE SURFACE FEATURES WERE PRODUCED FROM 1:50000 NATIONAL TOPOGRAPHIC SYSTEM (NTS) MAPS.
4. LIDAR DATA OBTAINED IN 2006 WAS USED TO CREATE THE TOPOGRAPHIC CONTOURS WITHIN THE RIVER VALLEY AND OUTSIDE THE LIDAR EXTENTS, CONTOURS WERE PRODUCED FROM 1:50000 DIGITAL ELEVATION DATA

SCALE 1:140000

3,000 1,500 0 3,000 6,000 9,000 METRES

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LOWER CHURCHILL PROJECT

FAIR WEATHER CONDITIONS
POST MUSKRAT FALLS
FAILURE OF MUSKRAT FALLS NORTH RCC DAM

SCALE 1:140000

HATCH PROJECT No. H-335459 MF1330

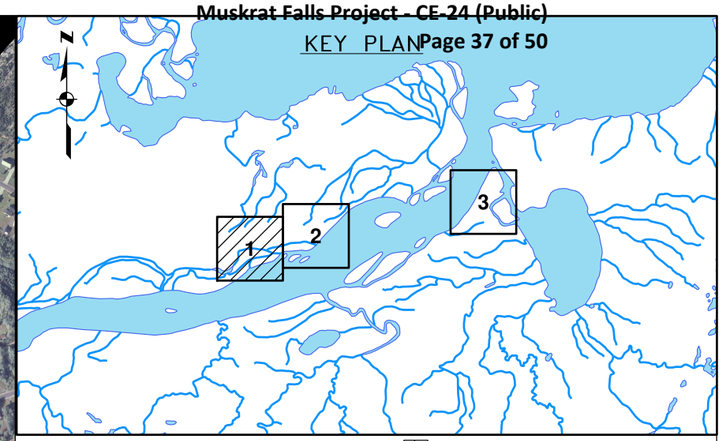
DRAWING NO. FIGURE A-5

Appendix B

"Fair Weather" Inundation Mapping (Aerial Photographs)

Happy Valley – Goose Bay and Mud Lake (1:10,000 Scale)

KEY PLAN



– INDICATES AREA COVERED BY THIS SHEET.

LEGEND

BREACH INUNDATION

NOTES:

1. ORTHOPHOTOS WERE OBTAINED BY NALCOR DURING THE 2006 LIDAR SURVEY.
2. COORDINATES ARE BASED ON THE UNIVERSAL TRANSVERSE MERCATOR PROJECTION, ZONE 20 NORTH, NORTH AMERICAN DATUM 1983.

SCALE 1:10000

200 100 0 200 400 600

METRES

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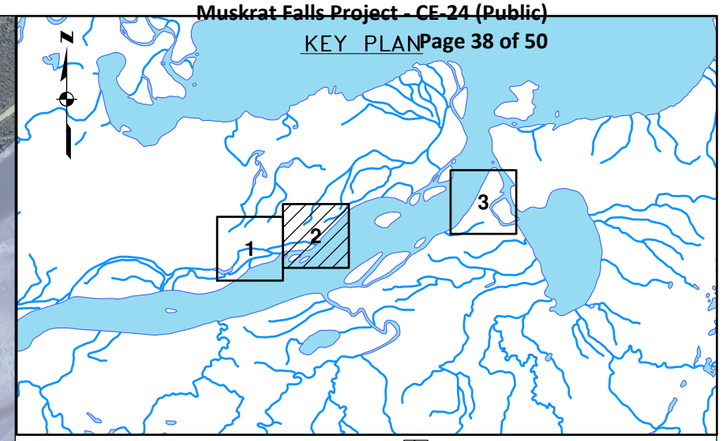
NALCOR ENERGY

LOWER CHURCHILL PROJECT

FAIR WEATHER CONDITIONS
POST MUSKRAT FALLS
FAILURE OF MUSKRAT FALLS NORTH RCC DAM

SCALE	DRAWING NO.
1:10000	FIGURE B–1
HATCH PROJECT No. H–335459 MF1330	

KEY PLAN



– INDICATES AREA COVERED BY THIS SHEET.

LEGEND

BREACH INUNDATION

NOTES:

1. ORTHOPHOTOS WERE OBTAINED BY NALCOR DURING THE 2006 LIDAR SURVEY.
2. COORDINATES ARE BASED ON THE UNIVERSAL TRANSVERSE MERCATOR PROJECTION, ZONE 20 NORTH, NORTH AMERICAN DATUM 1983.

SCALE 1:10000

200 100 0 200 400 600

METRES

HATCH™

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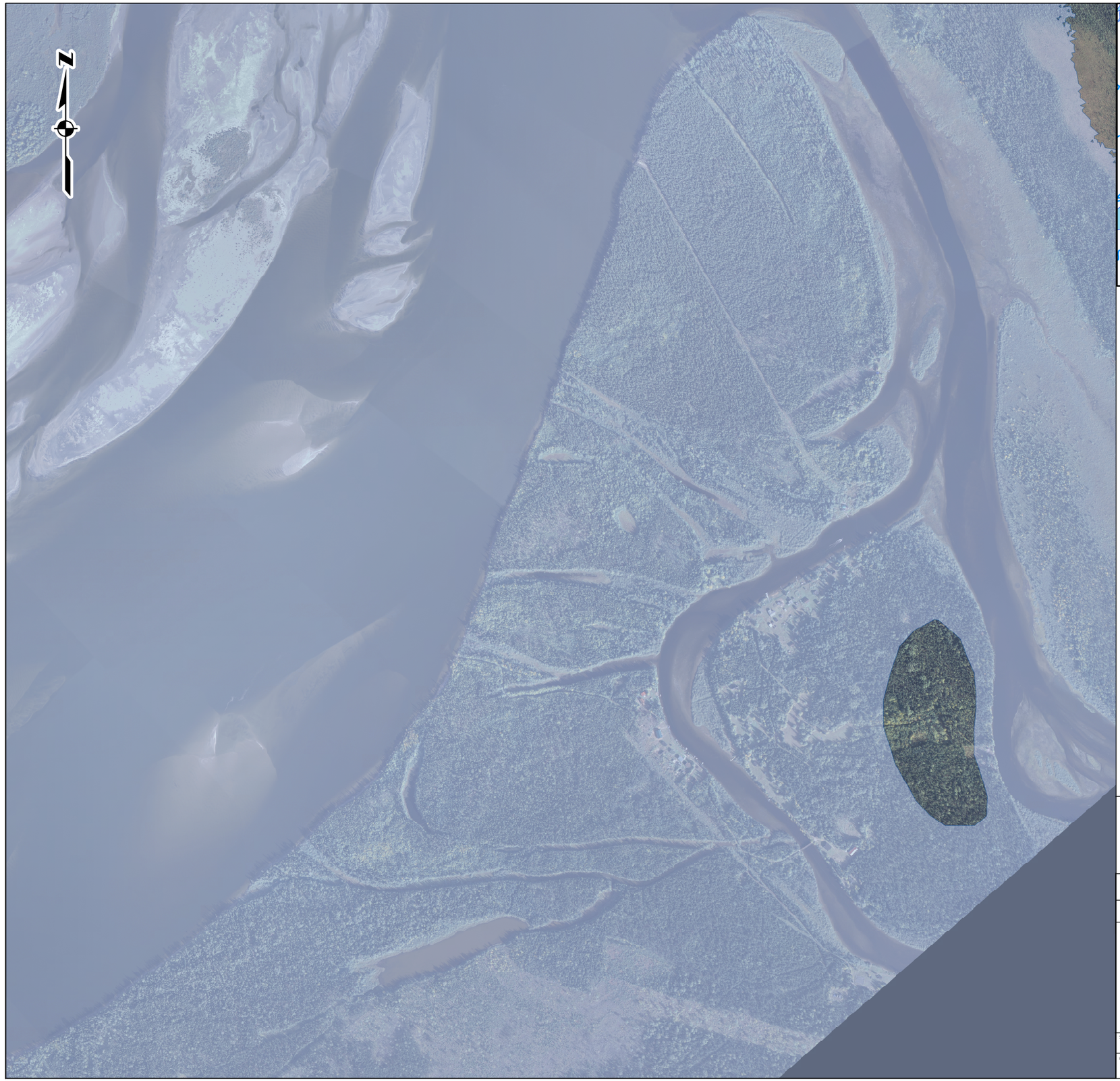
LOWER CHURCHILL PROJECT

NALCOR ENERGY

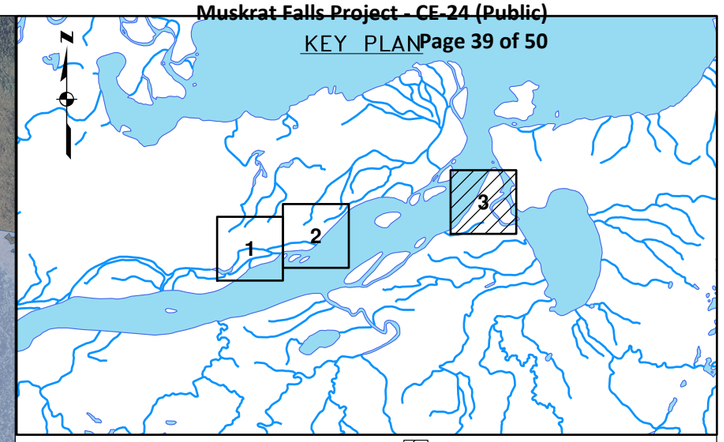
LOWER CHURCHILL PROJECT

FAIR WEATHER CONDITIONS
POST MUSKRAT FALLS
FAILURE OF MUSKRAT FALLS NORTH RCC DAM

SCALE	DRAWING NO.
1:10000	FIGURE B–2
HATCH PROJECT No. H–335459 MF1330	



KEY PLAN



▨ – INDICATES AREA COVERED BY THIS SHEET.

LEGEND

BREACH INUNDATION

NOTES:

1. ORTHOPHOTOS WERE OBTAINED BY NALCOR DURING THE 2006 LIDAR SURVEY.
2. COORDINATES ARE BASED ON THE UNIVERSAL TRANSVERSE MERCATOR PROJECTION, ZONE 20 NORTH, NORTH AMERICAN DATUM 1983.

200 100 0 200 400 600
SCALE 1:10000 METRES

HATCH™

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NALCOR ENERGY

LOWER CHURCHILL PROJECT

FAIR WEATHER CONDITIONS
POST MUSKRAT FALLS
FAILURE OF MUSKRAT FALLS NORTH RCC DAM

SCALE	DRAWING NO.
1:10000	FIGURE B–3
HATCH PROJECT No. H–335459 MF1330	

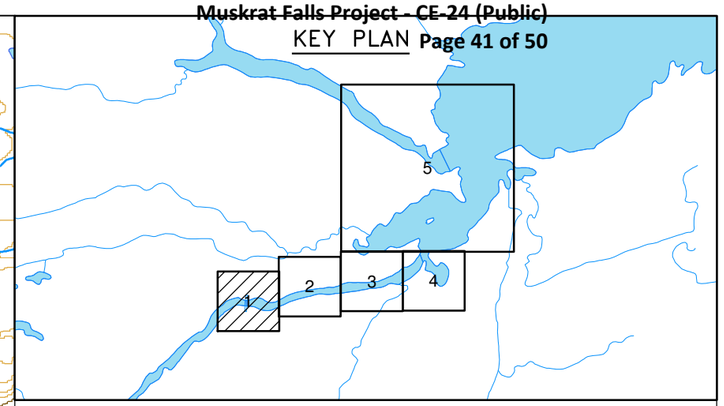
Appendix C

PMF Inundation Mapping

DISTANCE DOWNSTREAM OF MUSKRAT FALLS DAM:	1.5 km
PEAK FLOOD ELEVATION:	11.4 m
PEAK BREACH ELEVATION:	21.1 m
INCREMENTAL DEPTH OF FLOODING:	9.7 m
BREACH FLOODWAVE ARRIVAL TIME:	0 hr
TIME TO PEAK WATER ELEVATION:	3.2 hr

Churchill River
Muskrat Falls
Churchill River
Lower Brook
Mckenzie River

KEY PLAN



– INDICATES AREA COVERED BY THIS SHEET.

LEGEND

- BUILDING
- TANK
- TOWER
- WATER BODY
- WETLAND
- FLOOD INUNDATION
- BREACH INUNDATION
- RIVER
- ROAD
- HYDRAULIC MODEL CROSS SECTIONS
- TRANSMISSION LINE
- CONTOUR (20 m)
- INDEX CONTOUR (100 m)

NOTES:

1. ALL CONTOURS SHOWN ARE IN METRES.
2. COORDINATES ARE BASED ON THE UNIVERSAL TRANSVERSE MERCATOR PROJECTION, ZONE 20 NORTH, NORTH AMERICAN DATUM 1983.
3. THE SURFACE FEATURES WERE PRODUCED FROM 1:50000 NATIONAL TOPOGRAPHIC SYSTEM (NTS) MAPS.
4. LIDAR DATA OBTAINED IN 2006 WAS USED TO CREATE THE TOPOGRAPHIC CONTOURS WITHIN THE RIVER VALLEY AND OUTSIDE THE LIDAR EXTENTS, CONTOURS WERE PRODUCED FROM 1:50000 DIGITAL ELEVATION DATA

1000 500 0 1000 2000 3000

SCALE 1:50000 METRES

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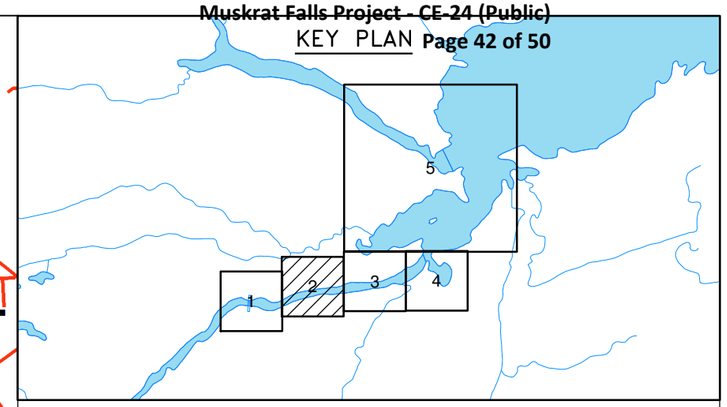
NALCOR ENERGY

LOWER CHURCHILL PROJECT

PROBABLE MAXIMUM FLOOD
POST MUSKRAT FALLS
FAILURE OF MUSKRAT FALLS NORTH RCC DAM

SCALE	DRAWING NO.
1:50000	FIGURE C–1
HATCH PROJECT No. H–335459 MF1330	

KEY PLAN



– INDICATES AREA COVERED BY THIS SHEET.

DISTANCE DOWNSTREAM OF MUSKRAT FALLS DAM:	13.0 km
PEAK FLOOD ELEVATION:	10.0 m
PEAK BREACH ELEVATION:	19.8 m
INCREMENTAL DEPTH OF FLOODING:	9.8 m
BREACH FLOODWAVE ARRIVAL TIME:	0.2 hr
TIME TO PEAK WATER ELEVATION:	3.4 hr

DISTANCE DOWNSTREAM OF MUSKRAT FALLS DAM:	18.7 km
PEAK FLOOD ELEVATION:	8.2 m
PEAK BREACH ELEVATION:	17.3 m
INCREMENTAL DEPTH OF FLOODING:	9.1 m
BREACH FLOODWAVE ARRIVAL TIME:	0.3 hr
TIME TO PEAK WATER ELEVATION:	3.4 hr
DECK ELEVATION:	10.6 m

LEGEND

- BUILDING
- TANK
- TOWER
- WATER BODY
- WETLAND
- FLOOD INUNDATION
- BREACH INUNDATION
- RIVER
- ROAD
- HYDRAULIC MODEL CROSS SECTIONS
- TRANSMISSION LINE
- CONTOUR (20 m)
- INDEX CONTOUR (100 m)

NOTES:

1. ALL CONTOURS SHOWN ARE IN METRES.
2. COORDINATES ARE BASED ON THE UNIVERSAL TRANSVERSE MERCATOR PROJECTION, ZONE 20 NORTH, NORTH AMERICAN DATUM 1983.
3. THE SURFACE FEATURES WERE PRODUCED FROM 1:50000 NATIONAL TOPOGRAPHIC SYSTEM (NTS) MAPS.
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1000 500 0 1000 2000 3000

SCALE 1:50000 METRES

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NALCOR ENERGY

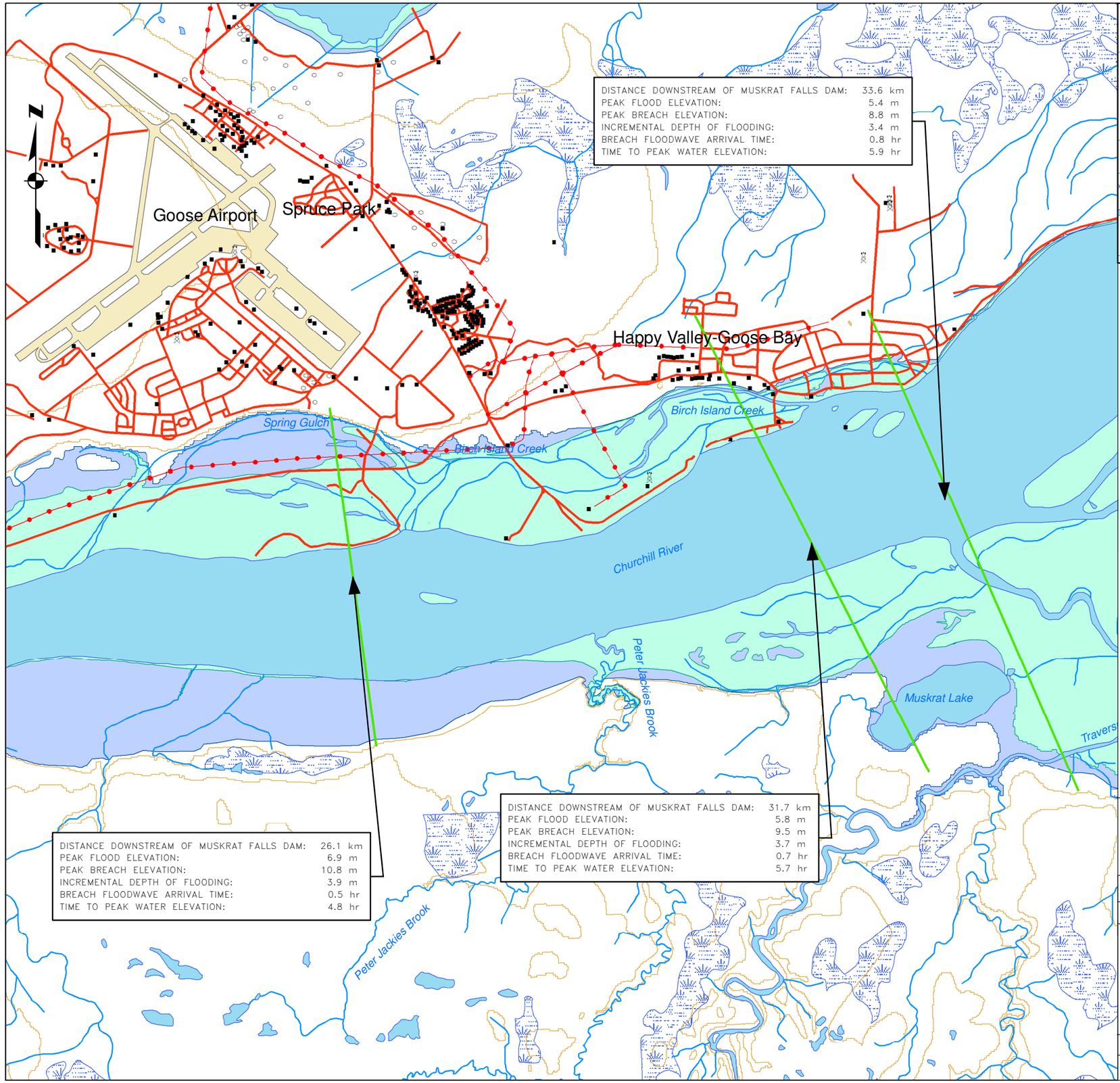
LOWER CHURCHILL PROJECT

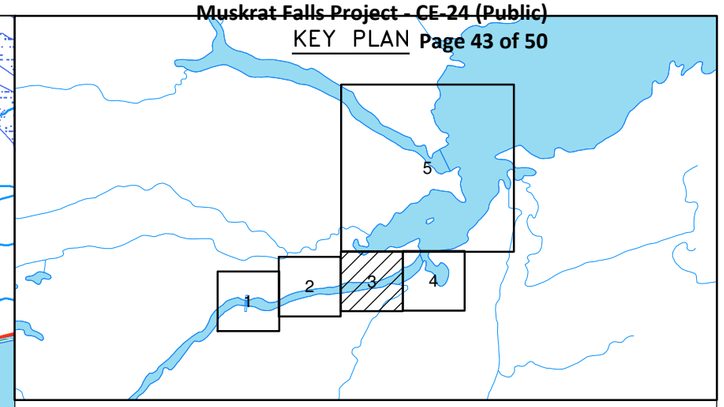
PROBABLE MAXIMUM FLOOD
POST MUSKRAT FALLS
FAILURE OF MUSKRAT FALLS NORTH RCC DAM

SCALE 1:50000

HATCH PROJECT No H-335459 MF1330

DRAWING NO. FIGURE C-2





– INDICATES AREA COVERED BY THIS SHEET.

LEGEND

- BUILDING
- TANK
- TOWER
- WATER BODY
- WETLAND
- FLOOD INUNDATION
- BREACH INUNDATION
- RIVER
- ROAD
- HYDRAULIC MODEL CROSS SECTIONS
- TRANSMISSION LINE
- CONTOUR (20 m)
- INDEX CONTOUR (100 m)

NOTES:

1. ALL CONTOURS SHOWN ARE IN METRES.
2. COORDINATES ARE BASED ON THE UNIVERSAL TRANSVERSE MERCATOR PROJECTION, ZONE 20 NORTH, NORTH AMERICAN DATUM 1983.
3. THE SURFACE FEATURES WERE PRODUCED FROM 1:50000 NATIONAL TOPOGRAPHIC SYSTEM (NTS) MAPS.
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1000 500 0 1000 2000 3000
SCALE 1:50000 METRES

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NALCOR ENERGY

LOWER CHURCHILL PROJECT

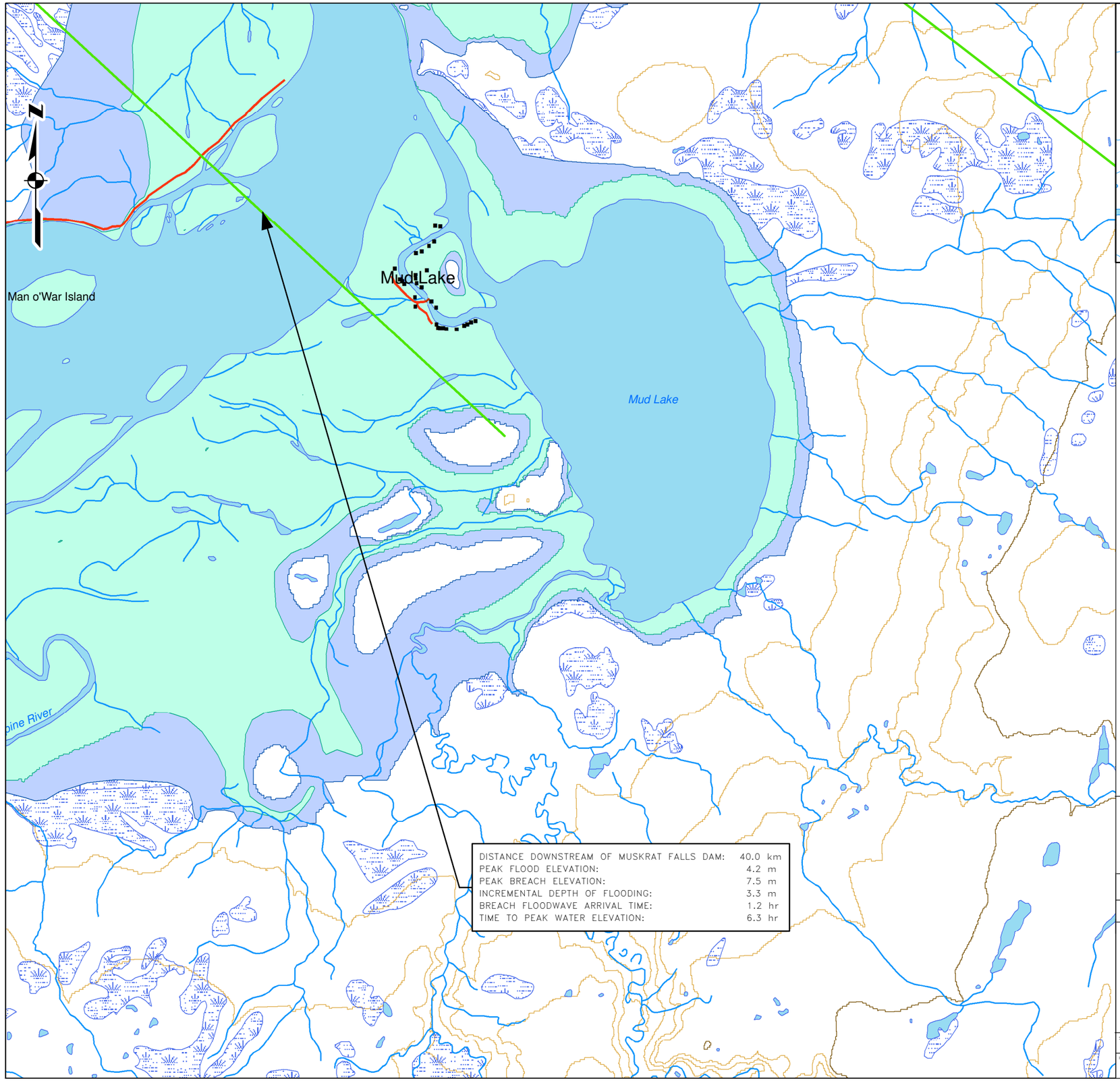
PROBABLE MAXIMUM FLOOD
POST MUSKRAT FALLS
FAILURE OF MUSKRAT FALLS NORTH RCC DAM

SCALE 1:50000

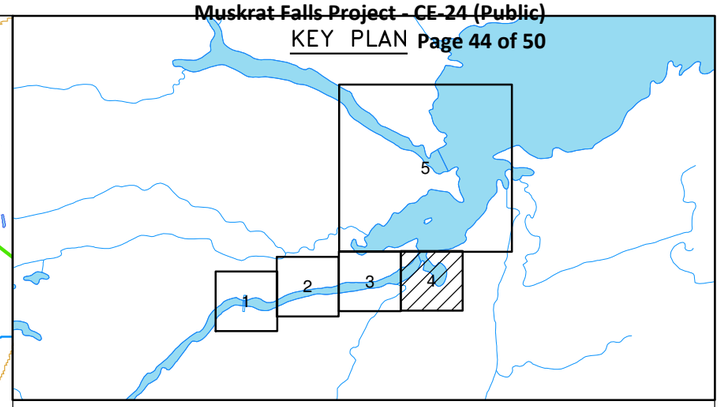
HATCH PROJECT No. H-335459 MF1330

DRAWING NO.

FIGURE C-3



KEY PLAN



– INDICATES AREA COVERED BY THIS SHEET.

LEGEND

- BUILDING
- TANK
- TOWER
- WATER BODY
- WETLAND
- FLOOD INUNDATION
- BREACH INUNDATION
- RIVER
- ROAD
- HYDRAULIC MODEL CROSS SECTIONS
- TRANSMISSION LINE
- CONTOUR (20 m)
- INDEX CONTOUR (100 m)

NOTES:

1. ALL CONTOURS SHOWN ARE IN METRES.
2. COORDINATES ARE BASED ON THE UNIVERSAL TRANSVERSE MERCATOR PROJECTION, ZONE 20 NORTH, NORTH AMERICAN DATUM 1983.
3. THE SURFACE FEATURES WERE PRODUCED FROM 1:50000 NATIONAL TOPOGRAPHIC SYSTEM (NTS) MAPS.
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1000 500 0 1000 2000 3000

SCALE 1:50000 METRES

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NALCOR ENERGY

LOWER CHURCHILL PROJECT

PROBABLE MAXIMUM FLOOD
POST MUSKRAT FALLS
FAILURE OF MUSKRAT FALLS NORTH RCC DAM

SCALE	DRAWING NO.
1:50000	FIGURE C–4
HATCH PROJECT No. H–335459 MF1330	

Lake Melville

Grand Lake

North West River

Sheshatshiu

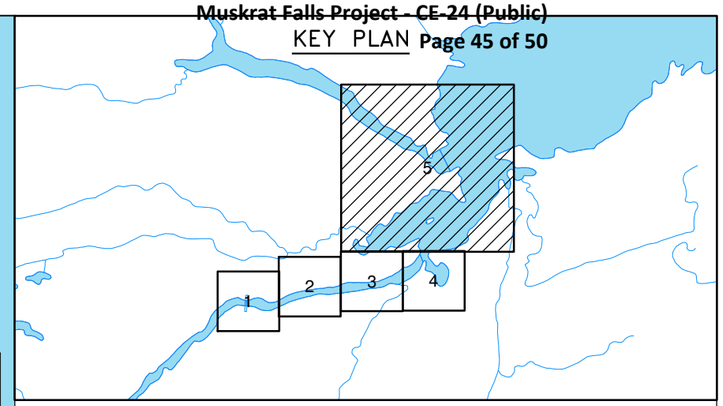
Goose Bay

DISTANCE DOWNSTREAM OF MUSKRAT FALLS DAM:	74.6 km
PEAK FLOOD ELEVATION:	0.6 m
PEAK BREACH ELEVATION:	0.7 m
INCREMENTAL DEPTH OF FLOODING:	0.1 m
BREACH FLOODWAVE ARRIVAL TIME:	2.4 hr
TIME TO PEAK WATER ELEVATION:	11.5 hr

DISTANCE DOWNSTREAM OF MUSKRAT FALLS DAM:	64.2 km
PEAK FLOOD ELEVATION:	0.6 m
PEAK BREACH ELEVATION:	0.8 m
INCREMENTAL DEPTH OF FLOODING:	0.2 m
BREACH FLOODWAVE ARRIVAL TIME:	2.0 hr
TIME TO PEAK WATER ELEVATION:	11.0 hr

DISTANCE DOWNSTREAM OF MUSKRAT FALLS DAM:	47.6 km
PEAK FLOOD ELEVATION:	1.2 m
PEAK BREACH ELEVATION:	2.4 m
INCREMENTAL DEPTH OF FLOODING:	1.2 m
BREACH FLOODWAVE ARRIVAL TIME:	1.5 hr
TIME TO PEAK WATER ELEVATION:	8.8 hr

KEY PLAN



– INDICATES AREA COVERED BY THIS SHEET.

LEGEND

- BUILDING
- TANK
- TOWER
- WATER BODY
- WETLAND
- FLOOD INUNDATION
- BREACH INUNDATION
- RIVER
- ROAD
- HYDRAULIC MODEL CROSS SECTIONS
- TRANSMISSION LINE
- CONTOUR (20 m)
- INDEX CONTOUR (100 m)

NOTES:

1. ALL CONTOURS SHOWN ARE IN METRES.
2. COORDINATES ARE BASED ON THE UNIVERSAL TRANSVERSE MERCATOR PROJECTION, ZONE 20 NORTH, NORTH AMERICAN DATUM 1983.
3. THE SURFACE FEATURES WERE PRODUCED FROM 1:50000 NATIONAL TOPOGRAPHIC SYSTEM (NTS) MAPS.
4. LIDAR DATA OBTAINED IN 2006 WAS USED TO CREATE THE TOPOGRAPHIC CONTOURS WITHIN THE RIVER VALLEY AND OUTSIDE THE LIDAR EXTENTS, CONTOURS WERE PRODUCED FROM 1:50000 DIGITAL ELEVATION DATA

SCALE 1:140000

3,000 1,500 0 3,000 6,000 9,000 METRES

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NALCOR ENERGY

LOWER CHURCHILL PROJECT

PROBABLE MAXIMUM FLOOD
POST MUSKRAT FALLS
FAILURE OF MUSKRAT FALLS NORTH RCC DAM

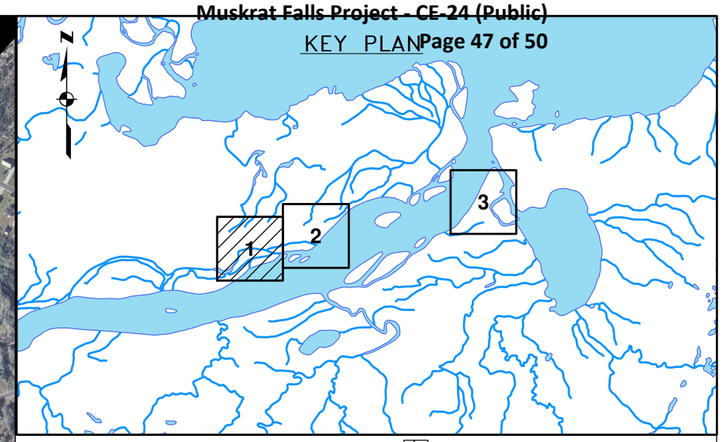
SCALE	1:140000
HATCH PROJECT No.	H-335459 MF1330
DRAWING NO.	FIGURE C-5

Appendix D

PMF Inundation Mapping (Aerial Photographs)

Happy Valley – Goose Bay and Mud Lake (1:10,000 Scale)

KEY PLAN



– INDICATES AREA COVERED BY THIS SHEET.

LEGEND

- FLOOD INUNDATION
- BREACH INUNDATION

NOTES:

1. ORTHOPHOTOS WERE OBTAINED BY NALCOR DURING THE 2006 LIDAR SURVEY.
2. COORDINATES ARE BASED ON THE UNIVERSAL TRANSVERSE MERCATOR PROJECTION, ZONE 20 NORTH, NORTH AMERICAN DATUM 1983.

SCALE 1:10000

200 100 0 200 400 600

METRES

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LOWER CHURCHILL PROJECT

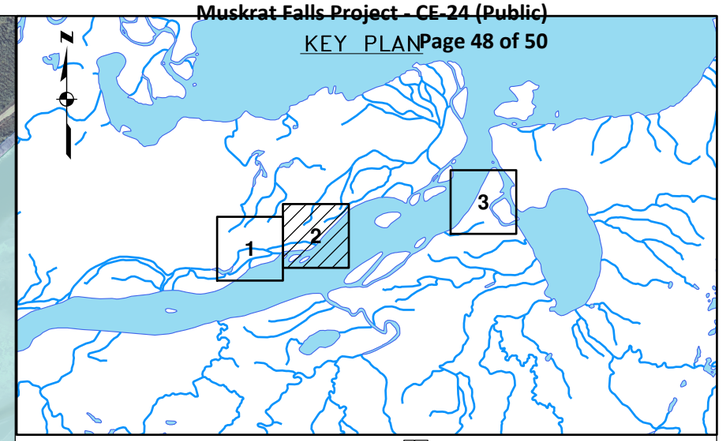
NALCOR ENERGY

LOWER CHURCHILL PROJECT

PROBABLE MAXIMUM FLOOD
POST MUSKRAT FALLS
FAILURE OF MUSKRAT FALLS NORTH RCC DAM

SCALE	DRAWING NO.
1:10000	FIGURE D–1
HATCH PROJECT No.	
H–335459 MF1330	

KEY PLAN



– INDICATES AREA COVERED BY THIS SHEET.

LEGEND

- FLOOD INUNDATION
- BREACH INUNDATION

NOTES:

1. ORTHOPHOTOS WERE OBTAINED BY NALCOR DURING THE 2006 LIDAR SURVEY.
2. COORDINATES ARE BASED ON THE UNIVERSAL TRANSVERSE MERCATOR PROJECTION, ZONE 20 NORTH, NORTH AMERICAN DATUM 1983.

200 100 0 200 400 600

SCALE 1:10000 METRES

HATCH™

nalcor energy
LOWER CHURCHILL PROJECT

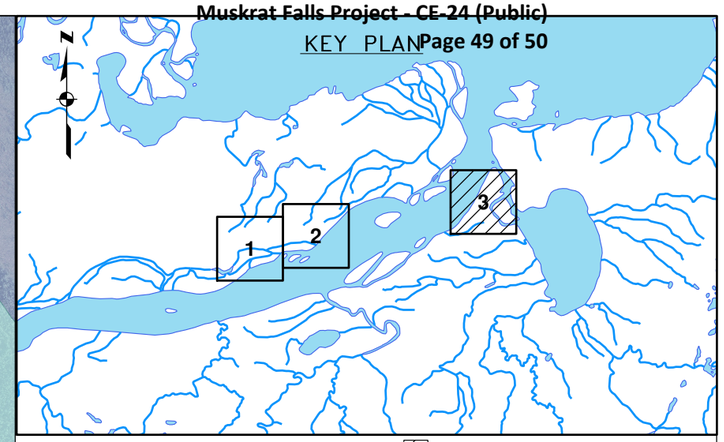
NALCOR ENERGY

LOWER CHURCHILL PROJECT

PROBABLE MAXIMUM FLOOD
POST MUSKRAT FALLS
FAILURE OF MUSKRAT FALLS NORTH RCC DAM

SCALE	DRAWING NO.
1:10000	FIGURE D–2
HATCH PROJECT No.	
H–335459 MF1330	

KEY PLAN



▨ – INDICATES AREA COVERED BY THIS SHEET.

LEGEND

- FLOOD INUNDATION
- BREACH INUNDATION

NOTES:

1. ORTHOPHOTOS WERE OBTAINED BY NALCOR DURING THE 2006 LIDAR SURVEY.
2. COORDINATES ARE BASED ON THE UNIVERSAL TRANSVERSE MERCATOR PROJECTION, ZONE 20 NORTH, NORTH AMERICAN DATUM 1983.

200 100 0 200 400 600

SCALE 1:10000 METRES

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LOWER CHURCHILL PROJECT

PROBABLE MAXIMUM FLOOD
POST MUSKRAT FALLS
FAILURE OF MUSKRAT FALLS NORTH RCC DAM

SCALE 1:10000

HATCH PROJECT No. H-335459 MF1330

DRAWING NO.

FIGURE D-3