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Newfoundland and Labrador Hydro
Lower Churchill Project
Pre-Feed Engineering Services

Muskrat Falls Hydroelectric Project

MF1050 – Spillway Design Review

FINAL

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Newfoundland & Labrador Hydro

LOWER CHURCHILL PROJECT

TECHNICAL REPORT

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EXECUTIVE SUMMARY

In WTO MF1010 - Review of Variants, a layout and cost review was carried out on the short-listed variants presented in the January 1999 Final Feasibility Study for Muskrat Falls[1], in particular Variants 7, 10 and 11.

Variant 7 was, at the time of the above report, the recommended variant of choice. However, in the interim period a highway bridge was constructed across the Churchill River about 18 km downstream of the Muskrat Falls site. With this crossing, it would be possible to achieve construction access to the south shore of the Muskrat Falls site within three months of the project start, and such access would enhance Variant 10 and, to a lesser extent, Variant 11 relative to Variant 7.

From the MF1010 study came the recommendation that Variant 10, through a significantly shorter construction schedule than either Variants 7 or 11, was the current variant of choice. Variant 10 includes a three-bay gated spillway, an inflatable rubber dam and a fixed crest overflow spillway. The river diversion would be through the gated spillway structure.

In this study, the Variant 10 spillway facilities were to be developed further, with particular interest in the use of an inflatable rubber dam, if such a dam were to be part of the recommended scheme.

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

The design parameters for the spillway facilities were that the gated spillway:

- Must pass the construction design flood without overtopping the upstream cofferdam required for the north dam construction;
- Must control the winter diversion flows to maintain a forebay level at elevation 24 m for frazil ice control;

[1] Final Feasibility Study, Muskrat Falls Hydroelectric Development, January 1999, SNC-AGRA.

- Must be able to pass the PMF along with the overflow facilities of the north dam, which may include a rubber dam and/or fixed crest spillway, without exceeding a forebay level of elevation 44 m.

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

- Scheme 1a — 3 bay gated spillway, surface vertical gates 13.75 m wide by 19.4 m high, rubber dam 330 m long and fixed crest 115 m long;
- Scheme 1c — 5 bay gated spillway, surface vertical gates 10.4 m wide by 21.5 m high, no rubber dam, fixed crest 429.5 m long;
- Scheme 1f — 5 bay gated spillway, surface vertical gates 13.75 m wide by 17.7 m high, no rubber dam, fixed crest 409.3 m long;
- Scheme 3b — 4 bay gated spillway, submerged radial gates 12.5 m wide by 14.8 m high, no rubber dam, fixed crest 433.2 m long.

On a quantitative basis, the least expensive case is Scheme 3b. As this is the least complicated arrangement for constructability, requires no rubber dam or overhead service bridge, and has lower operational costs than cases with a rubber dam, it is the recommended scheme of choice.

1 INTRODUCTION

In WTO MF1010 - Review of Variants (MF1010), a layout and cost review was carried out on the variants presented in the January 1999 Final Feasibility Study for Muskrat Falls[1], particularly Variants 7, 10 and 11. The review was to confirm the optimum layout for the project, based on:

- The cofferdam requirements;
- Access roads and new highway bridge;
- Capital costs.

The findings were:

- That the capital costs of all three variants were very similar;
- Variant 10 offered a considerably shorter construction schedule;
- Variant 10 also offered some alternatives for the spillway and site access.

Drawing No. 722850-MF1010-41DD-0003, Arrangement of Principal Structures, Plan and Profile depicts the layout of Variant 10 and the associated spillway structures.

In this study, the Variant 10 spillway facilities were to be developed further, with particular interest in the use of an inflatable rubber dam, if such a dam were to be part of the recommended scheme.

[1] Ibid.

2 SCOPE

The work consisted of a review of the current layout and design concepts for the spillway structures including the gated spillway, the south RCC overflow dam and the north RCC dam with the rubber dam crest. The purpose of this review was to confirm the design concepts, specifically for rubber dams, and to confirm the discharge capacity of the spillway structures in view of the updated Probable Maximum Flood (PMF), which will be determined by others.

With respect to the rubber dam, the review included:

- Confirming the status of technology development for rubber dams,
- Collecting technical data on rubber dams,
- Collecting performance data from owners of existing rubber dams, operating under similar conditions to those at Muskrat, and
- Confirming the design concept proposed for Muskrat Falls, based on the foregoing.

3 DESCRIPTION OF VARIANT 10

In MF1010, the spillway, powerhouse and south dam of Variant 10 would be constructed in the south abutment, complete with approach and discharge channels immediately above the lower falls. The river valley would be closed by the construction of an RCC dam from the spillway to the north abutment.

For the initial phase of construction, the river would remain in its normal channel until Year 3, when it would be diverted through the spillway sluices, temporarily left without rollways. The spillway would have sufficient capacity to pass the summer peak construction floods and would have gated control to maintain high forebay levels in winter for frazil ice control. Upstream and downstream cofferdams would allow dewatering of the river channel for construction of the north dam during Year 4.

The spillway facilities would include a three-bay gated spillway with the gate sills on top of rollways, and a five sectioned rubber dam plus a section of fixed crest overflow spillway located on the north RCC dam. In order of priority, the gated sluices would be operated first, then if required, the rubber dam and then the fixed crest weir. All three of the spillway components would be used to pass the PMF.

First power is expected to be available in July of Year 5, 55 months after project start, as shown in the construction schedule included in Appendix C.

Construction access to the south shore may be from a temporary bridge located above the upper falls, or by an 18 km road from the existing highway bridge downstream of the project site. If the temporary bridge is not constructed, a temporary link between the south and north shores would be required over a small bridge crossing the diversion channel, the upstream cofferdam and a low-level rockfill roadway around the base of the rock knoll at the north abutment.

Permanent access to the power facilities may be from the north over the top of the north dam, spillway, intake structure and south dam, or alternatively, from the upgraded south shore construction road.

4 METHODOLOGY

The layout of the structures adopted for Variant 10 in MF1010 was purposely made similar to that of Variant 7, except for location, to simplify the comparison of the schemes. Having determined that Variant 10 ranked the best for cost and time, the next steps involved re-assessing the design for current practice and experience.

For example, in 1998, RCC overflow dams had conventional concrete on their downstream slopes, whereas today, the slope is the natural stepped RCC. This has been adopted for this study, with resulting cost savings from replacing conventional concrete with lower priced RCC.

Gate sizes and weights are also an important consideration. In 1998, the gates selected were 13.75 m by 20.2 m, 5% larger than those in the Lobstick Control Structure in the Churchill Falls system. Using current practices for determining the maximum practical size of gates, alternative gate sizes were assessed. The alternative of using submerged gates was also evaluated further, and a new configuration was developed. In addition, since radial gates are normally less expensive than vertical gates, this alternative was studied.

The constructability of the layout was looked at closely with respect to the stability of the structures during construction, to ensure that required access is available to the site, and to ensure that areas needing to be dewatered have suitable cofferdams or guide walls included in the design.

Site access was also considered, both temporary and permanent. Early access to the south shore is mandatory if the construction schedule provided in MF1010 is to be met. The necessity for the transfer of materials between the north and south shores during construction requires a site link, by bridge or over the upstream cofferdam. Permanent access to the power facilities may be from the north or south, but utilizing a south shore access road would allow the deletion of the high level permanent access road excavated in rock around the rock knoll at the north abutment.

Section 5 of this report records the main input and design criteria used in the study, Section 6 reviews the mechanical constraints associated with the use of various gate options, and Section 7 describes the alternative layout arrangements.

Sections 8 and 9 outline the qualitative and quantitative assessments of the alternatives, and Section 10 identifies the most attractive schemes.

5 DESIGN CONSIDERATIONS AND CRITERIA

5.1 POWERHOUSE

5.1.1 Arrangement

The design of the powerhouse, except for its location, is unchanged since the January 1999 report, which shows it to contain four (4) generating units, three (3) of which are 206 MW propeller units, and the other a 206 MW Kaplan unit. The intake structure is shown close-coupled with the powerhouse, which has concrete spiral cases. It is 187.5 m long, including a 43 m long service bay.

In the Variant 10 arrangement, the powerhouse would be located on the right abutment to allow it, along with the spillway structure to be constructed in the dry. The total available length between the powerhouse left wall and the north end of the north dam would be approximately 528 m. This length includes the 10 m wide concrete bulkhead dam located between the powerhouse and the right spillway wall and a 20 m long north-end abutment. Of this length, about 498 m can be utilized for a combination of gated spillway, inflatable rubber dam and fixed crest overflow dam as a spillway system to permit the passage of the PMF.

The powerhouse could be moved further south into the south abutment in order to increase the space available for the spillway facilities, however, the quantity of rock to be excavated for the approach and discharge channels, as well as the powerhouse foundations, would increase considerably.

5.1.2 Schedule

With reference to the construction schedule in Appendix C, at the time of diversion in July of Year 3, the intake structure and powerhouse first stage concrete would be substantially complete. The bulkhead dam between the gated spillway and the powerhouse would be complete.

It is intended that rock plugs be left in place in the approach and discharge channels following diversion until late in Year 4, about the time when the units have met their “pit free” dates. Guide walls on the south side of the spillway structure approach and discharge channels are required to maintain the intake and draft tubes in a dry state. The intake gates may take an additional three (3) to four (4) months to complete, and the turbine erection is expected to take another year and one-half.

5.2 SPILLWAY STRUCTURE

The spillway structure would be located on the north side of the powerhouse and the 10 m long bulkhead dam. As originally conceived, it would contain three (3) 13.75 m wide sluices with rollways having a sill elevation of 18.8 m, and with piers/sidewalls 4 m thick, an overall width of 57.25 m. The vertical gates would be 20.2 m high.

The spillway is the primary structure of this study, which may be revised by varying the size and number of gates, by changing the operation of the gates from surface to submerged, and by changing the type of gates, vertical to radial.

The top elevation of the base slab of the spillway structure was set at 5 m for diversion flows and/or as the permanent base for the submerged gate alternatives. Rollways required for surface vertical gate alternatives would be added to the base slab during the latter stage of construction.

The spillway, along with the 10 m wide bulkhead dam, is intended to be constructed simultaneously with the intake structure and the powerhouse first stage concrete. Prior to diversion, a gravity dam, possibly of RCC would be constructed on the north side of the spillway at right angles to the main dam axis as a closure dam for the upstream cofferdam. This dam would provide additional stability for the north wall of the spillway structure. The south sidewall of the spillway structure would be supported by the 10 m wide bulkhead dam and the intake structure.

5.3 NORTH DAM

5.3.1 General

The north dam is an overflow RCC gravity structure that can be configured as part of the spillway facilities with a rubber dam and fixed crest sections. About 498 m, less the width of the spillway structure, is available for the north dam spillway. With the gated spillway providing the primary spillway flow control; secondary control would be by the inflatable rubber dam segment (where applicable), with the balance by the fixed crest segment.

In the case where permanent access is from the north, there would be an overhead bridge set on piers over the full length of the north dam, which would reduce the effective spillway length of inflatable rubber crest and/or fixed crest. In the case where permanent access is from the south shore, a lightweight overhead bridge deck would be required over the rubber dam section for servicing, but not over the fixed crest section.

5.3.2 Inflatable Rubber Dam Segment

For the alternatives studied herein, the inflated crest of the rubber dam was set at elevation 39.5 m, and the deflated level at elevation 37.1 m and 35.9 m for different alternatives.

The rubber dam will be fabricated to suit the installation, but would generally comprise of 33 m long sections, separated by 2 m wide piers at 35 m centers.

The advantage of the rubber dam is that it offers a high unit discharge capacity when deflated, at relatively low cost, which displaces higher unit cost gated spillway capacity. The main disadvantage is that in the event of replacement, it could mean a complete plant shutdown if the foundation sill is below the minimum recommended operating level of the plant.

5.3.3 Fixed Crest Segment

The remaining length of the north dam, not occupied by the rubber dam, would be used as a fixed crest overflow spillway. The crest would be set at elevation 39.5 m, the same as the inflated crest of the rubber dam, for wind surge, waves and a small allowance for forebay control variation.

5.4 DESIGN FLOW CONDITIONS

5.4.1 Diversion Phase – Non-Winter

As shown in the summary implementation schedule in Appendix C, two (2) years would be needed to build the spillway for passage of the diversion flows: one (1) spring flood, two (2) consecutive summers. It is assumed that no construction would be going on during the winter. The maximum forebay water level is based on the following operating conditions:

- The 1:20 year total peak inflow to Muskrat Falls, based on a 5% risk for a diversion over a single peak flood season. Since the 1:20 year inflow was unavailable, the 1:40 year flood value of 5,300 m^3/s was used;
- All spillway bays would be built and the gates and hoists operational;
- The rollways for the schemes with vertical surface gates would be temporarily left out, and all bays would have a horizontal invert at El. 5.0 m;
- The north dam would not yet be constructed;
- The upstream cofferdams would have at least a 2.0 m freeboard protection and the downstream cofferdam would have a 1.0 m freeboard; and
- The tail water elevation for the design flow of 5,300 m^3/s would be 5.8 m.

Refer to Appendix A for hydrological and hydraulic data and criteria.

5.4.2 Diversion Phase – Winter

All conditions presented in Section 5.4.1 are applicable in addition to the following:

- The forebay has to be maintained at or near elevation 24 m in order to create upstream conditions favourable for the creation of an ice cover to minimize frazil ice formation during the diversion phase;
- The most difficult condition for winter regulation at elevation 24 m is when the diversion flow is very low. Based on the daily flow series taking into

consideration Churchill Falls regulation and no regulation at Gull Island (Figure A-2 in Appendix A) a minimum design flow of 800 m^3/s was considered; and

- For winter forebay regulation with small inflows at Muskrat Falls, only one spillway gate is recommended to be operated and the minimum gate opening should be in excess of 10% of the gate height in order to minimize vibration.

5.4.3 Completion of Rollways

In some of the spillway schemes, the rollways would be finalized during the latter part of the diversion period, but prior to impounding. The north dam would be nearly complete. The rollways would be constructed sequentially behind stoplogs during the off-peak flood season to minimize the forebay level and the required height of the stoplogs. The stoplog guides would extend down to the invert at elevation 5.0 m. As each rollway is completed however, the level of the forebay would increase during the construction of the next rollway.

For completion of the schemes with rollways, two (2) distinct locations for upstream stop log guides were considered in order to minimize the overall weight for the upstream stoplogs:

- Conventional permanent guides and stoplogs located immediately upstream of the spillway gates, on the top of the rollways, for the long term maintenance;
- Temporary guides located upstream of the rollways, required for the finalization of the rollways.

The upstream stoplogs required for construction of the rollways comprise two (2) types of stop logs:

- Stoplog sill upstream of the main gate sill, near the top of the rollway for the permanent stoplogs;
- Stoplog sill upstream of the rollway on the base slab for the temporary stoplogs.

All upstream stop logs (temporary and permanent) would be handled from the spillway service bridge.

The maximum forebay water level for the design of the height of the temporary upstream stop logs was computed for the following operating conditions:

- A total peak inflow to Muskrat Falls of 3,000 m^3/s during the summer and fall;
- All spillway bays, gates, hoists and rollways would be completed and operational except for one (1) bay under stop logs;
- Stop logs or equivalent would be in place to protect the power intake against forebay levels up to about El. 33 m;
- The top of the upstream stop logs set in the temporary upstream guides would be 0.5 m higher than the computed maximum forebay water elevation.

5.4.4 Permanent Operations

The extreme forebay water level during the PMF would be El. 44.0 m under the following operating conditions:

- The PMF presents a total peak inflow of 22,100 m^3/s at Muskrat Falls;
- All spillway bays would be operational and completed with gates, hoists, rollways and/or walls;
- Tail water would be at El. 12.2 m;
- The Muskrat powerhouse would not be operational; and
- The north dam would be operational.

Due to high flow velocities downstream of the north dam and gated spillway, the natural rock surface would need to be lined with concrete from the downstream toe of the structures to the edge of the river tailpond.

6 MECHANICAL CONSTRAINTS FOR GATES

6.1 UPSTREAM STOPLOGS

Considering practical mechanical constraints for manufacturing and operation, the maximum head acceptable on the sill of sliding stop logs for various spillway bay widths would be (see Curve 2, Figure 6-1):

- 47 m of head with a gate width of 10.5 m;
- 34 m of head with a gate width of 12.5 m; and
- 28 m of head with a gate width of 13.75 m.

For schemes with submerged vertical and/or radial gates, the maximum hydrostatic head on the sill during operation would be 34 m (FSL 39.0 – 5.0 = 34.0 m). The maximum width of the spillway bays based on stoplog limitations for these schemes was therefore set at 12.5 m (see Curve 2, Figure 6-1).

Each stop log lift is limited to about 20 t.

6.2 SURFACE VERTICAL GATES

Based on existing spillway surface gates built for the La Grande Phase 1 & 2, a maximum gate weight of about 160 t and a hoisting capacity of 200 t was used for the present comparative analysis. The following maximum vertical gate dimensions were considered:

- 10.5 m W x 24.5 m H;
- 11.5 m W x 23.0 m H;
- 12.2 m W x 21.5 m H; and
- 13.75 m W x 19.4 m H.

The above gate heights include a 0.5 m freeboard.

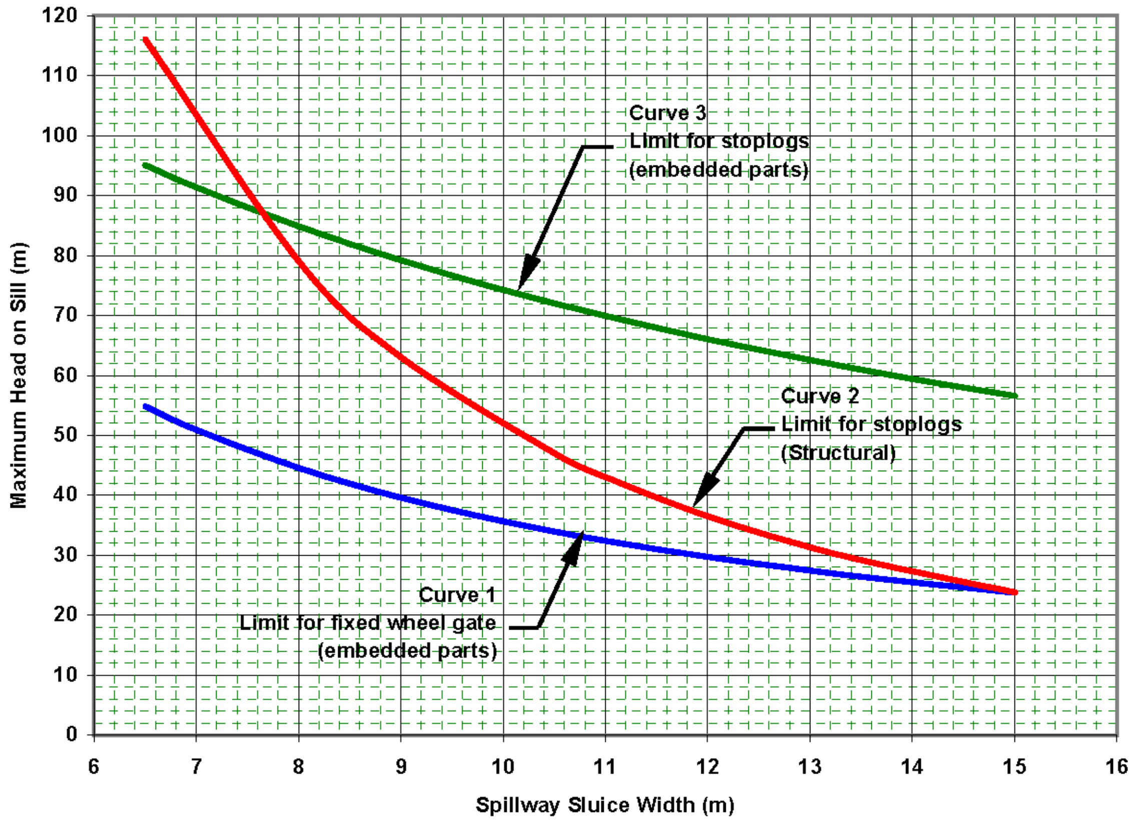


Figure 6-1: Maximum Acceptable Head for Vertical Gates on Fixed Wheels & Sliding Stop Logs

"Based on in-house SNC-Lavalin standards and Hydro Quebec practice"

6.3 SUBMERGED VERTICAL GATES

Given the maximum hydrostatic head of 34 m on the sill (FSL 39.0 – 5.0 = 34.0 m) and the mechanical limitations, the maximum acceptable width of submerged vertical gates would be 10.5 m (see Curve 1, Figure 6-1).

The maximum height of the gate would be 10.5 m in order to limit the gate weight to about 160 t.

6.4 SUBMERGED RADIAL GATES

The hydrostatic pressure of 34 m on the upstream stop logs sill limits the width of each spillway sluice and the submerged radial gate to 12.5 m (see Curve 1, Figure 6-1).

For the present comparative analysis, the maximum hydrostatic pressure on the gate was limited to 50 MN (see Table 6-1) and the maximum acceptable gate height was 15.5 m.

No overflow was permitted over the spillway vertical and/or radial gates.

The radial gates would be operated by hydraulic cylinders or individual cable hoists. Stoplogs may be handled by a gantry or mobile crane.

The service bridge would be located on the upstream side of the control structure.

Table 6-1: Existing Large Submerged Radial or Segment Gates

Year	Project	Qty	Span (m)	Height (m)	Area (m^3)	Head on sill (m)	Hydrostatic load (MN)	Manufacturer
1965	Mangala	9	10.97	13.00	142.61	48.50	58.76	Krupp
1994	Berke	2	10.00	10.30	103.00	63.00	58.45	VA TECH Hydro
1972	Tarbela	4	4.88	7.30	35.62	135.60	46.11	VA TECH Hydro
1965	Tweeriivieren	2	8.38	5.18	43.41	103.48	42.96	Kure
1981	Tabka		5.50	12.00	66.00	67.00	39.50	
1969	Cabora Bassa	8	6.00	7.80	46.80	82.30	35.99	Sorefame
1970	Reza Shah Kabir	4	8.00	6.70	53.60	71.50	35.83	ALSTOM
1979	Jebba	6	12.00	9.50	114.00	36.00	34.95	Mitsubishi
	Wuquiangxi	1	9.00	12.00	108.00	38.70	34.64	
1962	Roseires	5	6.00	11.30	67.80	55.30	33.02	ALSTOM
	Toktogul		5.00	6.00	30.00	112.20	32.14	
	Nourek		5.00	6.00	30.00	110.00	31.49	
	Sayano-Sushenskoe		5.00	5.50	27.50	116.70	30.74	
1949	Castelo do Bode	2	14.00	8.50	119.00	30.00	30.06	ALSTOM
1981	Magat	2	6.00	12.50	75.00	46.50	29.61	VA TECH Hydro
1991	Aguamilpa	6	12.00	19.34	232.08	22.40	28.98	VA TECH Hydro
1962	Roseires	7	10.00	13.20	132.00	27.50	27.06	ALSTOM
1972	P. K. Le Roux	4	15.00	9	135.00	23.00	24.50	Sorefame
1974	Saddam	2	5.00	7.50	37.50	68.00	23.64	VA TECH Hydro
1960	Garrison	3	5.49	7.49	41.12	58.20	21.97	
1948	Chastang	2	13.60	9.50	129.20	22.00	21.86	ALSTOM
1974	Sobradinho	12	9.80	7.50	73.50	33.87	21.72	VOITH
1960	Mechra-Klila	4	16.00	12.30	196.80	16.90	20.75	ALSTOM
	Miranda	4	24.00	8.73	209.52	14.00	19.80	ALSTOM
1965	Achi	1	6.50	4.30	27.95	74.00	19.70	Waagner-Biro
1961	Khashm El Girba	7	7.00	7.30	51.10	42.50	19.48	Riva-Calzoni

7 ALTERNATIVE SCHEMES

7.1 GENERAL

Due to the number of variables, i.e.:

- number and size of gates in the gated spillway;
- inclusion or not of an inflatable rubber dam;
- height and length of the rubber dam;
- crest elevation and length of the fixed crest spillway;

a large number of alternatives are possible which may satisfy the main criteria of being able to:

- pass the required construction floods through the diversion channels of the gated spillway without exceeding the upstream cofferdam elevation;
- maintain the forebay water level at elevation 24 m in winter to promote the formation of an upstream ice cover;
- pass the PMF without exceeding the maximum flood level.

Using the maximum gate size criteria of the previous section, and the Variant 10 base case design, a limited number of preferred spillway schemes were selected for study. A comparative evaluation, qualitative and quantitative, was carried out on the preferred schemes and is presented in Sections 9 and 10.

Whenever possible, the width of 13.75 m was selected for the spillway bays. This compares with the existing Lobstick Control Structure and the proposed Gull Island Development.

All spillway schemes presented in Table 8-1 are considered to be technically feasible and only differ by their various characteristics. Brief descriptions of the schemes follow.

7.2 SURFACE VERTICAL GATE SCHEMES (1A TO 1F)

The surface vertical gate schemes all have fixed wheel gates. The rollways would be built in the latter stage of the diversion period. The gates would be required for winter flow regulation during the diversion period while operating on sills at elevation 5.0 m.

Schemes 1a and 1b have three (3) gated spillway bays, an inflatable rubber dam plus a length of fixed crest overflow dam with the crest set at elevation 39.5 m. The rubber bladder height would be 2.4 m for Scheme 1a and 3.6 m for Scheme 1b.

Schemes 1c to 1f have no rubber dam, but have five (5) gated spillway bays and a length of fixed crest overflow dam with the crest at elevation 39.5 m. Gate width varies from 10.5 to 13.75 m wide.

There are two (2) upstream stop logs guides and two (2) sets of upstream stop logs: one (1) permanent and one (1) temporary.

7.3 SUBMERGED VERTICAL GATE SCHEMES (2A AND 2B)

The submerged vertical gate schemes have fixed wheel gates with upstream seals against a vertical wall. All bays, vertical headwalls and spillway equipment would be completed prior to commencement of the diversion phase.

As no rollways are required, there would only be one (1) upstream stop log guide and permanent stop logs with downstream seals against the vertical wall with sill at El. 5.0 m. The maximum hydrostatic head on the upstream stop log sill would be 34.0 m and for this reason the gate width was limited to a maximum of 10.5 m. Both schemes 2a and 2b have the capacity to control the forebay level during winter, pass the design construction flood and, in permanent operation, pass the PMF.

Scheme 2a has a four (4) bay gated spillway with the permanent gate sill at elevation 5.0 m. It has a 2.4 m high rubber dam with an inflated crest elevation of 39.5 m, 325 m long (10 bays). A 116 m long fixed crest overflow weir at elevation 39.5 m completes the north dam. A service bridge would be required over the rubber dam.

Scheme 2b has a five (5) bay gated spillway with the permanent gate sill at elevation 5.0 m. It has no rubber dam, and a fixed crest overflow section on the north dam 440 m long with the crest at elevation 39.5 m. No service bridge would be required over the fixed crest dam.

7.4 SUBMERGED RADIAL GATE SCHEMES (3A AND 3B)

The submerged radial gate schemes have upstream seals against a vertical headwall. All bays, vertical headwalls and spillway equipment would be required to be completed prior to the commencement of the diversion phase. The gates would have permanent sills at elevation 5.0 m. Two (2) such schemes were identified:

- Scheme 3a, comprising a three (3) bay gated spillway, with submerged radial gates 10.5 m wide by 10.5 m high, a rubber dam 2.4 m high and 120 m long, and a fixed crest overflow section on the north dam with the weir crest at elevation 39.5 m.

- Scheme 3b, comprising a four (4) bay gated spillway, with submerged radial gates 12.5 m wide by 14.8 m high, no rubber dam, and a fixed crest overflow section on the north dam with the weir crest at elevation 39.5 m.

There would only be one (1) upstream guide and the stop logs would have downstream seals against the vertical wall with the sill at elevation 5.0 m. The maximum hydrostatic head would be 34.0 m on the upstream stop log sill and for that reason the maximum width of the spillway bays was set at 12.5 m. A height of 15.5 m for the Scheme 3a gates would result in a maximum acceptable gate weight of 160 t.

Schemes 3a and 3b can regulate the forebay during the winter.

For scheme 3b the design flood during the diversion phase is capable of being spilled with the forebay elevation below elevation 24.0 m. However, for scheme 3a, the reservoir would be at elevation 25.3 m so would require the upstream cofferdam to be set at elevation 27.3 m.

7.5 TECHNICAL SUMMARY

Table 7-1 on the following page summarizes the spillway alternatives studied herein.

TABLE 7.1 Description of Spillway Schemes

Item	Unit	Schemes									
		Surface Vertical Gates without rollway during Diversion						**Submerged Vertical Gates**		**Submerged Radial Gates**	
		1a	1b	1c	1d	1e	1f	2a	2b	3a	3b
Objective of scheme		With Rubber Dam	With Rubber Dam	No Rubber Dam	No Rubber Dam	No Rubber Dam	No Rubber Dam	With Rubber Dam	No Rubber Dam	With Rubber Dam	No Rubber Dam
Spillway during Normal Operation											
Crest type	-	Parabolic	Parabolic	Parabolic	Parabolic	Parabolic	Parabolic	Broad crest	Broad crest	Broad crest	Broad crest
Number of bays	-	**3**	**3**	**5**	**5**	**5**	**5**	**4**	**5**	**3**	**4**
Type of gate	-	Vertical gate on fixed wheels								Radial gate	
Gate location	-	Surface						Submerged		Submerged	
Width	m	**13.75**	**13.75**	**10.5**	**11.5**	**12.2**	**13.75**	**10.5**	**8.5**	**12.5**	**12.5**
Total width of spillway	m	55.3	55.3	70.5	76.7	81.1	90.8	57.0	58.0	50.7	66.8
Total length of Fixed and Rubber Dam Crests	m	442.8	442.8	427.5	421.3	416.9	407.3	441.0	440.0	447.3	431.2
Freeboard	m	0.5	0.5	0.5	0.5	0.5	0.5	N/A	N/A	N/A	N/A
Max. gate height (< 200 t hoisting capacity)	m	19.4	19.4	24.5	23.0	21.5	19.4	10.5	16	15.5	15.5
Selected gate height	m	**19.4**	**19.4**	**21.5**	**20.2**	**19.3**	**17.7**	**10.5**	**15.9**	**15.5**	**14.8**
Maximum pressure on sill	m	**18.9**	**18.9**	**21.0**	**19.7**	**18.8**	**17.2**	**34.0**	**34.0**	**34.0**	**34.0**
Final Sill El.	m	20.1	20.1	18.0	19.3	20.2	21.8	5.0	5.0	5.0	5.0
North Dam - Fixed Crest Section											
Crest El.	m	39.5	39.5	39.5	39.5	39.5	39.5	39.5	39.5	39.5	39.5
Length	m	112.8	277.8	427.5	421.3	416.9	407.3	116.0	440.0	327.3	430.0
North Dam - Rubber Dam Section											
Deflated Crest El.	m	37.1	**35.9**	37.1	37.1	37.1	37.1	37.1	37.1	37.1	37.1
Inflated Crest El.	m	39.5	39.5					39.5		39.5	
Length	m	330.0	**165.0**	**0.0**	**0.0**	**0.0**	**0.0**	**325.0**	**0.0**	**120.0**	**0.0**
Permanent Service bridge length	m	442.8	442.8	0.0	0.0	0.0	0.0	441.0	0.0	447.3	0.0
Permanent left bank access road	km	18.0	18.0	0.0	0.0	0.0	0.0	18.0	0.0	0.0	0.0
Capacity under Forebay El 44m											
Tentative Forebay El.	m	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0
Spillway gates	cm/s	9 244	9 244	13 349	13 538	13 584	13 792	8 539	13 085	11 255	14 329
Rubber Dam	cm/s	10 684	7 228	0	0	0	0	11 193	0	4 133	0
North Dam	cm/s	2 178	5 708	8 785	8 657	8 567	8 369	2 384	9 041	6 725	8 800
		22 106	**22 180**	**22 134**	**22 195**	**22 151**	**22 161**	**22 116**	**22 126**	**22 113**	**23 129**
Spillway during Diversion Phase - Peak inflow											
Diversion Sill El.	m	5.0	5	5	5	5	5	5	5	5	5
Design flow 1:40 (Spring)	cm/s	5 300	5300	5300	5300	5300	5300	5300	5300	5300	5300
Maximum Forebay level	m	**24.0**	**24.0**	**21.2**	**20.2**	**19.6**	**18.5**	**20.0**	**23.6**	**25.3**	**21.7**
Flow over North Dam and Rubber Dam	cms	0	0	0	0	0	0	0	0	0	0
								Submerged	Free flow	Free flow	Free flow
Spillway during Diversion Phase - Reservoir regulation for frazil											
Minimum daily winter flow	cm/s	800	800	800	800	800	800	800	800	800	800
Minimal acceptable opening (no vibration 10% of gate height)	m	1.94	1.94	2.15	2.02	1.93	1.77	1.05	1.59	1.55	1.48
Gate opening	m	**4.30**	**4.30**	**5.64**	**5.15**	**4.85**	**4.30**	**5.64**	**6.96**	**4.74**	**4.74**
Number of gates for winter regulation		1	1	1	1	1	1	1	1	1	1
Required forebay elevation (gate regulation)	m	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0
Top of gate	m	**28.70**	**28.70**	**32.1**	**30.3**	**29.2**	**27.0**	**21.1**	**27.9**	**25.2**	**24.5**
Acceptable for winter regulation		**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Downstream cofferdam crest El. (5 300 cms)	m	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8
Permanent Upstream Stoplog Guides											
Sill El.	m	19.7	19.7	17.6	18.9	19.8	21.4	5.0	5.0	5.0	5.0
Height	m	24.3	24.3	26.4	25.1	24.2	22.6	39.0	39.0	39.0	39.0
Max. Hydrostatic pressure on sill from El 39m	m	19.3	19.3	21.4	20.1	19.2	17.6	34.0	34.0	34.0	34.0
Permanent Downstream Stoplog guides											
Sill El.	m	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Total Design flow for maintenance of one spillway bay	cms	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000
Tailwater El	m	3.84	3.84	3.84	3.84	3.84	3.84	3.84	3.84	3.84	3.84
Height of stoplog	m	**1.5**	**1.5**	**1.5**	**1.5**	**1.5**	**1.5**	**1.5**	**1.5**	**1.5**	**1.5**
Maximum Hydrostatic pressure on sill	m	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Temporary Upstream Stoplog Guides											
Design flood (Summer and Fall)	cms	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000
Forebay Water El during placement of U/S stoplogs on the last bay											
N-1 bays finished		2	2	4	4	4	4	3	4	2	3
Forebay Water Level	**m**	**34.9**	**34.9**	**29.2**	**29.8**	**30.3**	**31.1**	**18.5**	**13.5**	**20.8**	**17.0**
Discharge over the North Dam	cms	0	0	0	0	0	0	0	0	0	0
Discharge over th Rubber Dam	cms	0	0	0	0	0	0	0	0	0	0
Discharge Through the Spillway	cms	3 000	3 000	3 019	3 002	3 004	2 992	2 997	1 616	3 011	2 990
Total computed discharge	cms	3 000	3 000	3 019	3 002	3 004	2 992	2 997	1 616	3 011	2 990
Final Upstream stoplog height	m							**35.0**	**35.0**	**35.0**	**35.0**
Maximum Hydrostatic pressure on sill (permanent)	m	**18.9**	**18.9**	**21.0**	**19.7**	**18.8**	**17.2**	**34.0**	**34.0**	**34.0**	**34.0**
Maximum Hydrostatic pressure on sill (temporary)	m	**29.9**	**29.9**	**24.2**	**24.8**	**25.3**	**26.1**	**N/A**	**N/A**	**N/A**	**N/A**

8 QUALITATIVE EVALUATION

8.1 SURFACE VERTICAL GATE SCHEMES

The hydraulic characteristics of these schemes are shown in Table 7-1 as Schemes 1a to 1f. All of these schemes can regulate the forebay during the winter and can spill the 5,300 m^3/s flood with forebay levels equal or less than the required winter requirement of elevation 24.0 m. The upstream north dam cofferdam would be constructed to a crest elevation of 26.0 m with the downstream cofferdam at elevation 7.8 m.

The Schemes 1a and 1b (three (3) bays with rubber dam) have 29.9 m of hydrostatic head on the upstream stop log sill. This is slightly higher than the tentative maximum mechanical guidelines. If either of these schemes were to be selected, the gate sill during the Diversion might have to be increased to El. 7.0 m.

Scheme 1a (three (3) bays and a rubber dam 2.4 m high) was selected for qualitative evaluation as the base scheme (Figure D-1 in Appendix D), as it is the most similar to the Variant 10 scheme outlined in MF1010.

When compared to Scheme 1a, Scheme 1b (three (3) bays and a rubber dam 3.6 m high) has the same number of bays, a higher rubber dam and a 50% reduced rubber dam length. Scheme 1b does not provide significant advantage compared to scheme 1a and was therefore not considered in the quantitative evaluation.

Schemes 1c to 1f have no rubber dams, and provide spillway gates with ratios of height/width from 2.0 to 1.4. Schemes 1c and 1f were retained for quantitative analysis in order to provide order of magnitude comparative costs. Scheme 1f is shown in Figure D-2 of Appendix D. Schemes 1d and 1e have wider and shorter gates than 1c, so they would raise the forebay higher than 1c does during construction of the rollways. As they have no particular benefits over Scheme 1c, they were not considered in the quantitative evaluation.

8.2 SUBMERGED VERTICAL GATE SCHEMES

Scheme 2a, has three (3) gated spillway bays, a 325 m long rubber dam and a 116 m long fixed crest. No rollways are required. For three (3) bays, it is necessary to have a minimum width of 10.5 m in order to be able to pass the diversion flows. For this width, the highest acceptable gate height for hydrostatic and weight limitations is 10.4 m. The gate weight would be 160 t, and would require a 200 t hoist capacity. This gate size would satisfy operational flow requirements, however, the equal width to height dimensions are not recommended due to the possibility of jamming in the guides. For this reason, this scheme was not considered in the quantitative evaluation.

Scheme 2b has five (5) bays at 8.5 m width, no rubber dam and a 440 m long fixed crest at elevation 39.5 m. No rollways are required. For this gate width, a longer gate is acceptable for hydrostatic pressure and weight limitations. To satisfy both diversion and operational requirements, a length of 15.9 m was selected. Each gate would weigh 123 t and would require a 155 t lifting capacity, well within the maximum limitations. This scheme appears acceptable, and appears more attractive than the Scheme 1 series without rubber dams as the gated spillway is smaller and requires no rollways to be constructed. Compared to Scheme 3b, however, it has an extra bay and no compensating advantages. For this reason, Scheme 2b was not considered in the quantitative evaluation.

8.3 SUBMERGED RADIAL GATE SCHEME

Scheme 3a requires the upstream cofferdam to be raised from El. 26.0 m to El. 27.3 m and it requires gates of the maximum recommended size. For these reasons, this scheme was not included in the quantitative analysis.

Scheme 3b was retained for the quantitative evaluation since it is the narrowest spillway scheme with no rubber dam. It does not require the later addition of rollways, but has more complex reinforcing requirements in the sidewalls to accommodate the radial gate trunnion forces. The fixed crest of the north dam would be raised slightly to elevation 39.5 m, and the length adjusted to 430 m to allow more freeboard between the full storage level and the crest.

A sketch of Scheme 3b is presented in Figure D-3 in Appendix D.

9 QUANTITATIVE EVALUATION

Comparative quantities for Schemes 1a, 1c, 1f and 3b were derived from the 3D models and comparative cost estimates were prepared using the updated 2007 base unit prices from the project cost estimate in MF1010. The comparative cost estimates, including variable operational costs and energy benefits, are presented in Appendix B.

9.1 CONSTRUCTION PHASE

The comparative quantitative evaluations are presented in Appendix B as follows:

- Table B1 - Scheme 1a;
- Table B2 – Scheme 1c;
- Table B3 – Scheme 1f; and,
- Table B4 – Scheme 3b.

Civil

The breakdown of quantities for the north dam, including the fixed crest weir portion, the rubber dam portion, and the gated spillway is presented for:

- overburden excavation;
- rock excavation;
- concrete in structures;
- the permanent access road on the south river bank. No service bridge over the north dam was considered for the cases without a rubber dam. A service bridge is required on top of the spillway control structure for all schemes.
- the overall fill volume for the upstream cofferdam for the north dam.

Hydraulic

Comparative cost elements are:

- the spillway gates: the gate, the embedded parts and the support/hoist weight;
- the temporary and permanent upstream stop logs and embedded parts weight;
- the downstream permanent stop logs and embedded parts weight;
- the rubber dam length.

9.2 OPERATIONS PHASE

The net present value of loss of revenues and repair costs associated with the maintenance of the rubber dam was computed using the following conditions:

- major maintenance of the rubber dam every ten (10) years;
- duration of the maintenance two (2) months;
- loss of head from El. 39 m to the deflated rubber dam crest level;
- loss of generation at Muskrat Falls based on an average annual generation of 5.53 TWh/y and a nominal head of 35 m;
- discounted rate of 8%; and,
- average generation unit rate of 0.06 cent/kWh.

9.3 COMPARATIVE COSTS

Comparative costs, detailed in Appendix B, are as follows:

- Scheme 1a (3 bays, surface gates 13.75 m wide and rubber dam): $[redacted];
- Scheme 1c (5 bays, surface gates 10.5 m wide and no rubber dam): $ [redacted];

- Scheme 1f (5 bays, surface gates 13.75 m wide and no rubber dam): $ [redacted]; and

- Scheme 3b (4 bays, submerged radial gates 12.5 m wide and no rubber dam): $ [redacted].

It should be noted that while the rubber dam cases have the low capital costs, future operational losses add significantly to their total costs.

10 RECOMMENDATIONS

All of the schemes for which comparative cost estimates were shown in Section 10 are technically feasible and since they are within a 2% spread of the estimated total project cost, a selection may be made on issues other than price.

The least expensive scheme is Scheme 3b with 4 submerged radial gates, 12.5 m wide by 14.8 m high with permanent sills at elevation 5.0 m. It has no rubber dam and it is not necessary to have an overhead service bridge above the fixed crest of the north dam. This scheme appears to be the simplest to construct and operate, and as such it is the recommended preferred scheme.

Should detailed engineering proceed on the basis of Scheme 3b, it is suggested to:

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

Recent information on experience with rubber dams was included as an appendix to the report on MF1010. Since a layout using a rubber dam is not part of the recommended scheme, no further details on rubber dams have been provided.

APPENDIX A

HYDROLOGIC AND HYDRAULIC DATA

DIVERSION CRITERIA

<u>Construction flood</u>

From Section 4.2 of the 1998 report

- 5% risk per year, which is a 1 in 40 year return period flood (Q_{40}).
- Assuming modified flood handling procedures at Upper Churchill, the magnitude of this flood was determined to be **5,300 m^3/s**.
- Period during which this flood may occur is from 25 May to end of June.
- From 15 May to 25 May, and from end of June to end of July, Q_{40} = **3500 m^3/s**.
- Balance of year, Q_{40} = **2600 m^3/s**.

<u>Frazil Ice Control</u>

From Section 4.4 of the 1998 report

- It was concluded that ice control could be reliably obtained by maintaining the upstream water level at a minimum of El. 23.0 m regardless of flow, however it was recommended that a minimum level of 24 m be adopted.

From Table 4.2 Summary of Ice Observations

- For the period 1974 to 1992, the average maximum stage above the upper falls was observed to be **17.59 m**, and the maximum elevation was **20.13 m**.

<u>Tailrace Rating Curve</u>

Refer to Figure 5.2 of the 1998 study report.

From the data on the curve, the stage/discharge relationship may be approximated by the second-degree polynomial:

$$\text{Elev} = -2.5062\text{E-}08Q^2 + 1.065\text{E-}03Q + 0.874$$

Rating Curve Upstream of Upper Falls

From LaSalle Ice Study:

- $Elev = Q^{.429}/3.6808 + 10.177$

Spillway Flood Criteria

Maximum Design Flood

From Section 3.5 of Appendix B

- Use PMF
- Flood routing effect is negligible
- Spillway design flow (PMF) = 22,100 m^3/s (1999 report).
- Maximum design flood level at PMF = 44 m

HYDRAULIC CRITERIA

For surface gates fully opened, the uncontrolled discharge is given by:

- $Q = n\ b\ c\ (2g)^{0.5}\ (H\text{-}Zcrest)^{1.50}$

With

- n: number of bays;
- b: gate width (m);
- g: 9.81 (m/s^2);
- H: fore bay energy level (m);
- Zcrest: apex of parabolic crest (m);
- c = 0.453 on the spillway parabolic rollway;

- c = 0.486 on the ogee crest of the north concrete dam;
- c = 0.429 on the deflated rubber dam with deflated crest El. 35.9 or 37.1 m;
- c = 0.35 on a broad or flat spillway crest at El. 5.0 m during the diversion phase;
- C = 0.50 for gate partially open.

For submerged vertical and/or radial gates fully opened with the vertical wall abutting both the upstream stop logs and the submerged gate, the discharge is given by:

- $Q = n\ b\ a\ c\ (2g)^{0.5}\ (H\text{-}Zsill)^{0.50}$

With

- n: number of bays;
- b: gate width (m);
- a: gate full opening (m);
- g: 9.81 (m/s^2);
- H: fore bay energy level (m);
- Zsill: level of sill (5.0 m);
- c = 0.70.

For winter regulation with gates partly opened, the upstream fore bay level has been checked with HECRAS.

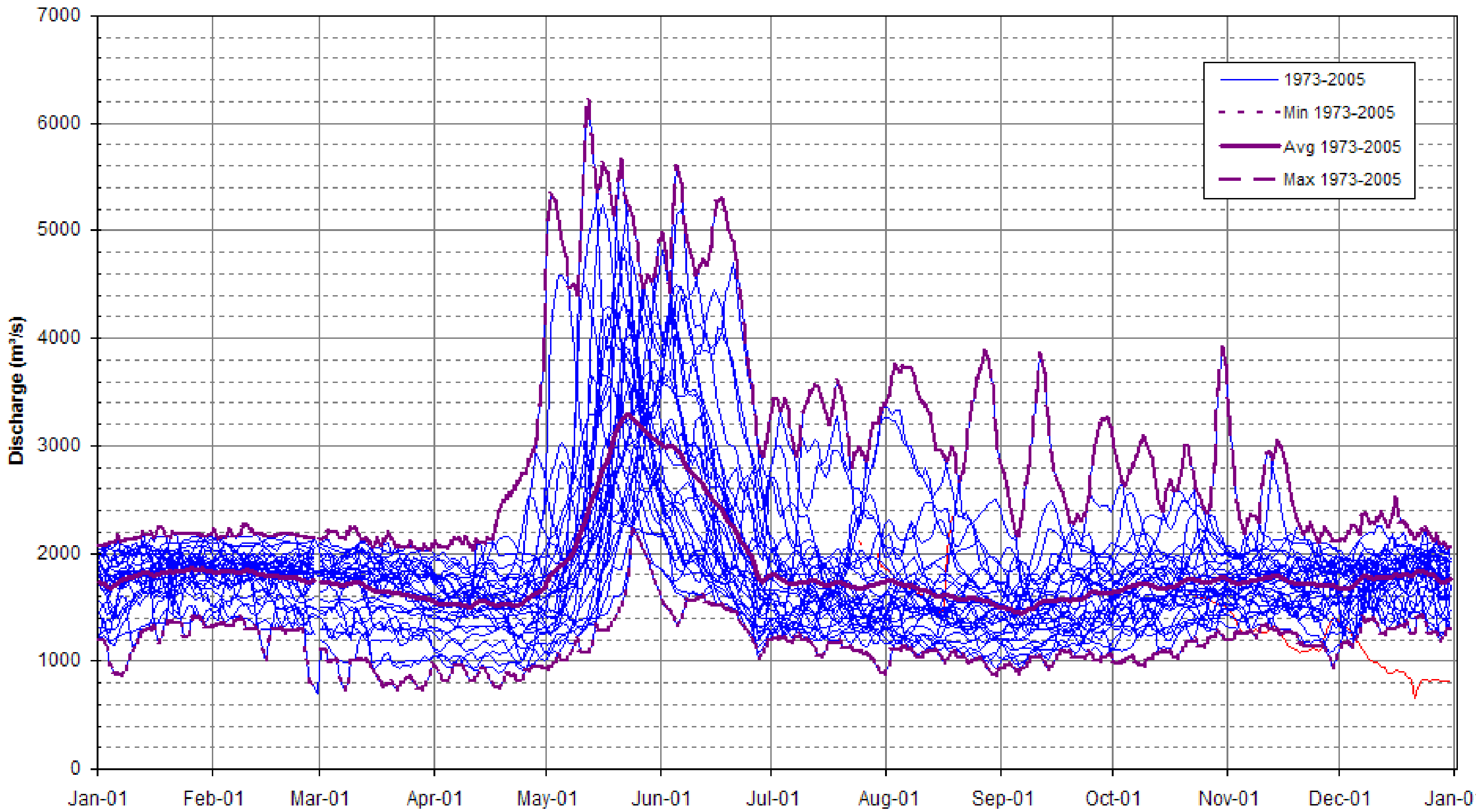


Figure A-1 – Reconstituted Daily Inflow at Muskrat Falls (1973-2004)

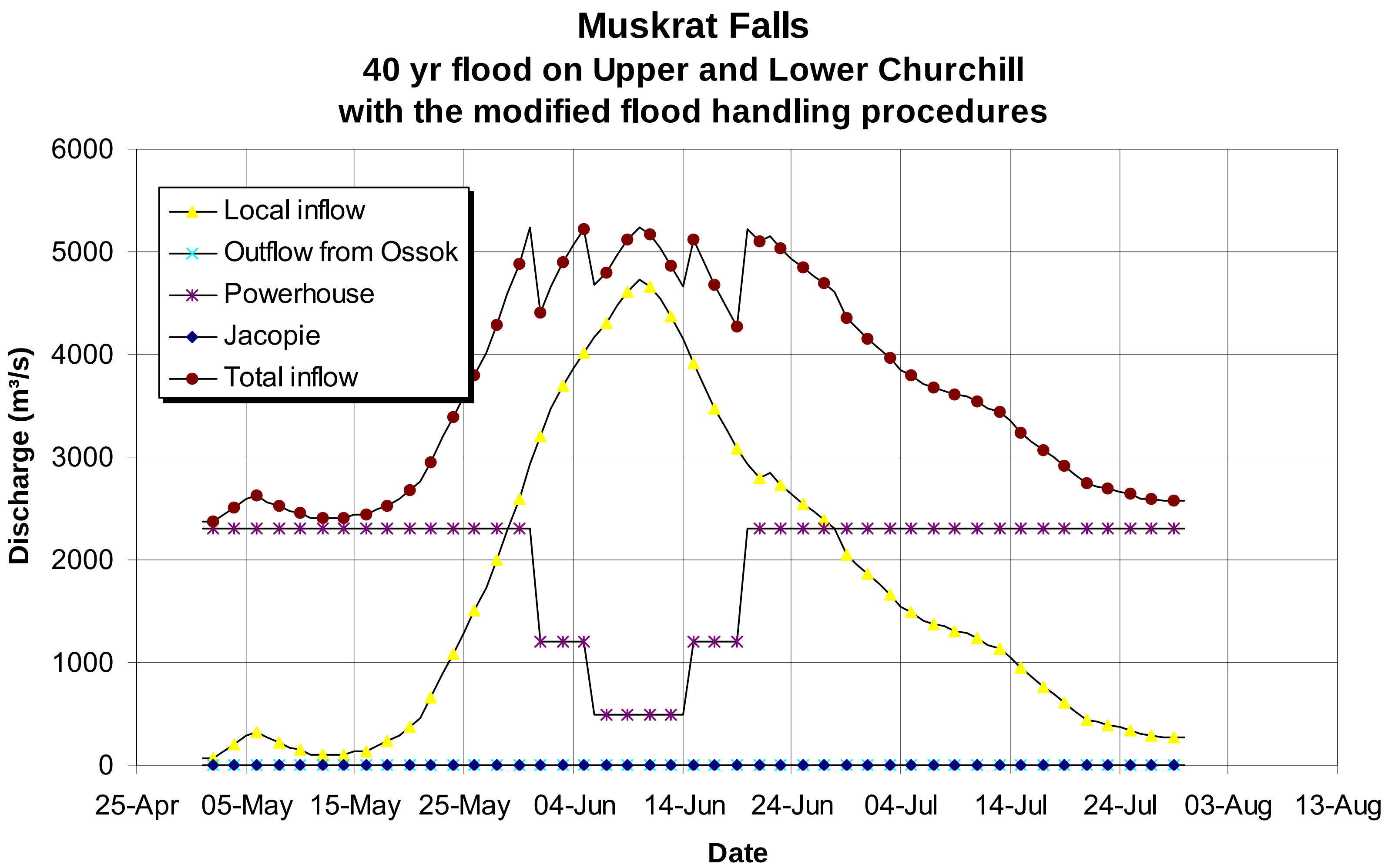


Figure A-2 – 40 Year Flood at Muskrat Falls

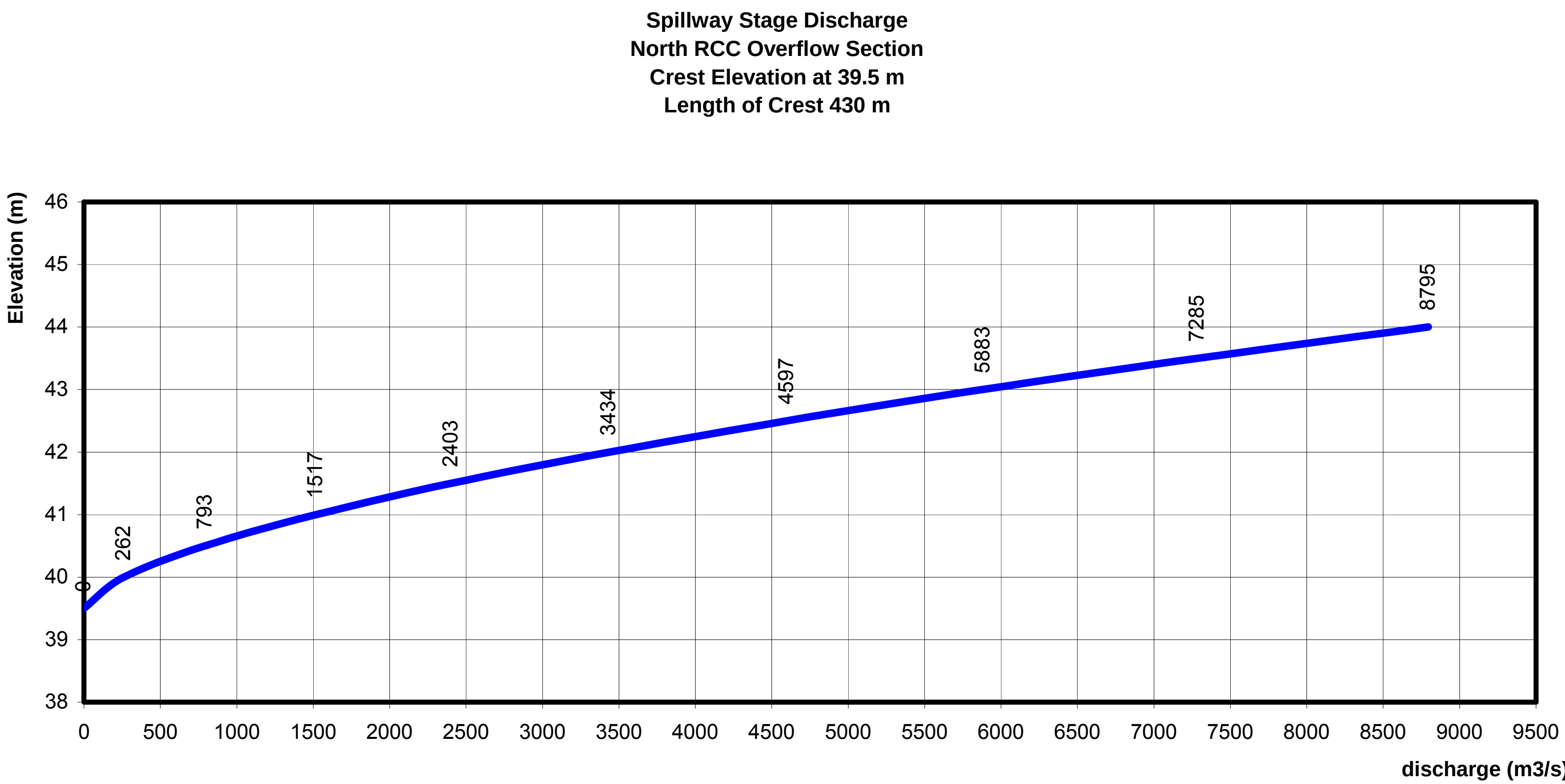


Figure A-3 – Fixed Crest Overflow Spillway Rating Curve for Scheme 3b

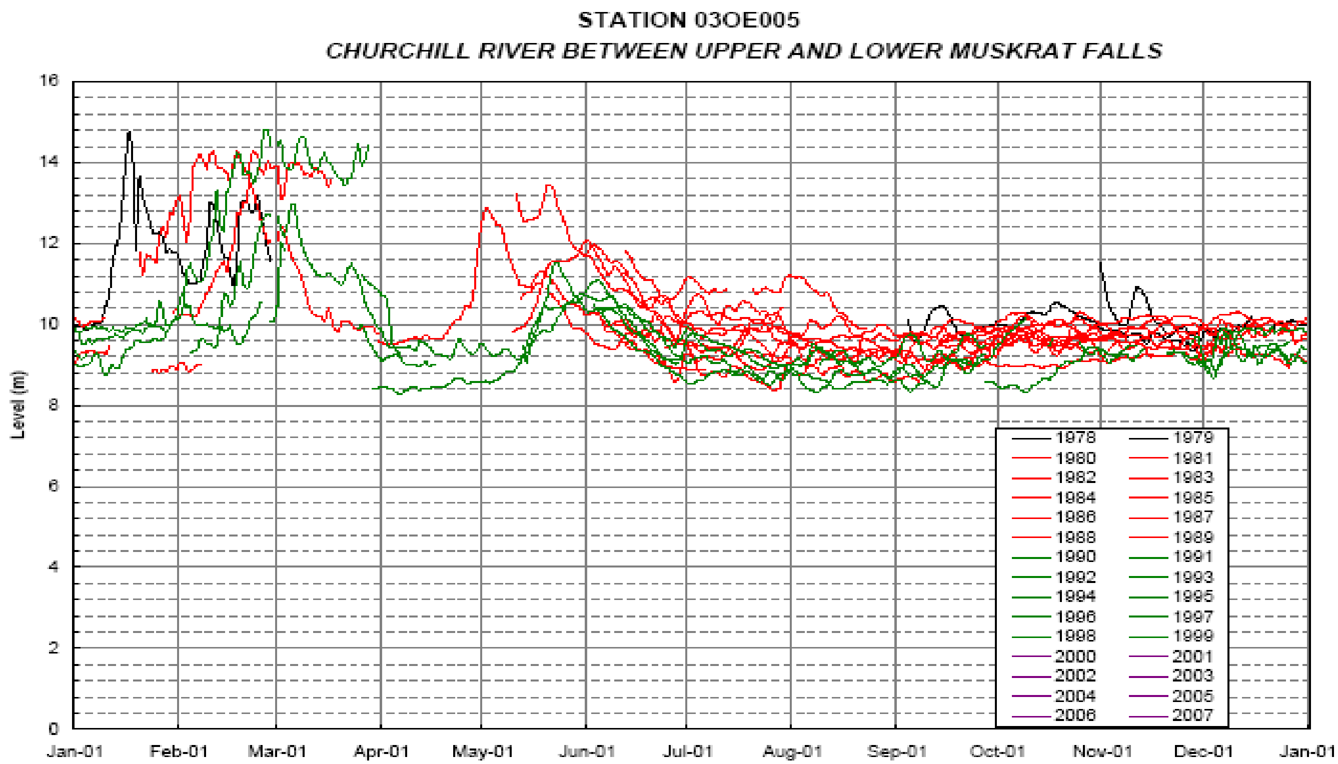


Figure A-4 – Station 03OE005 Between the Falls Stage Readings

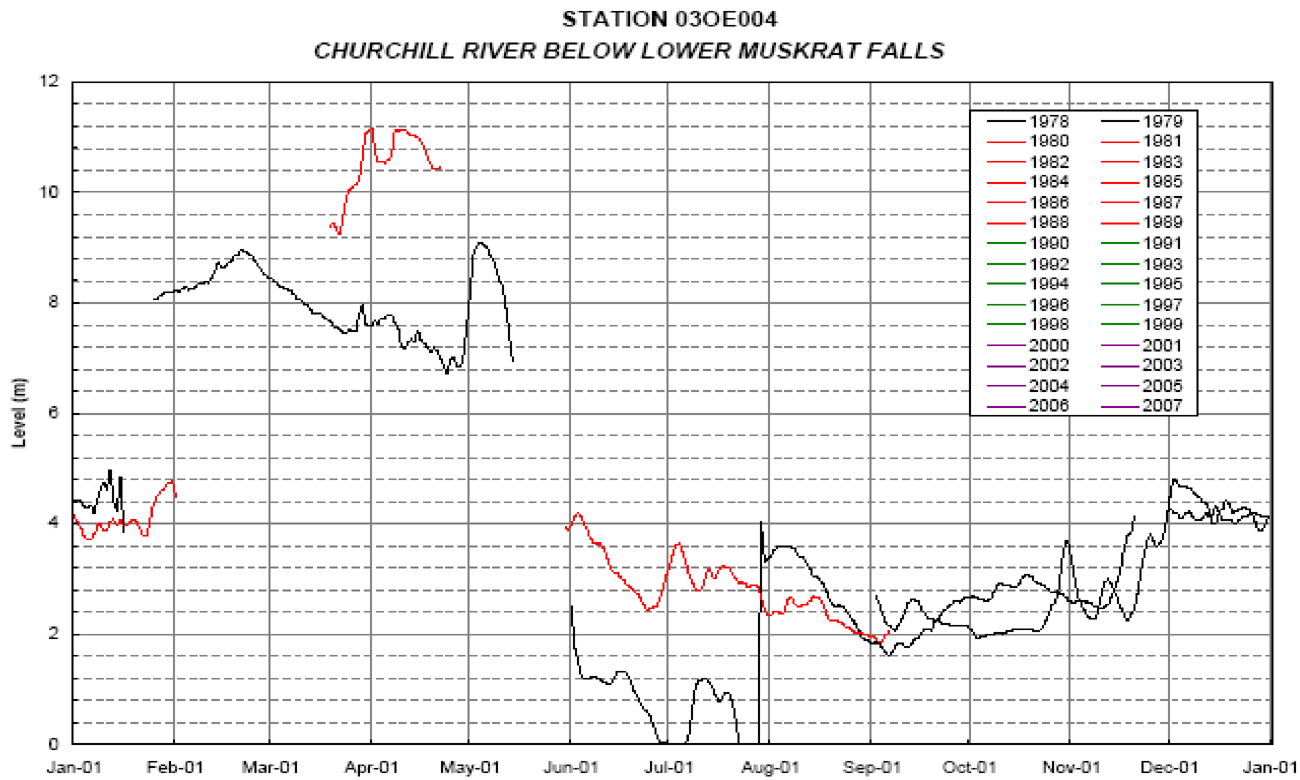


Figure A-5 – Station 03OE004 Below Muskrat Falls Stage Readings

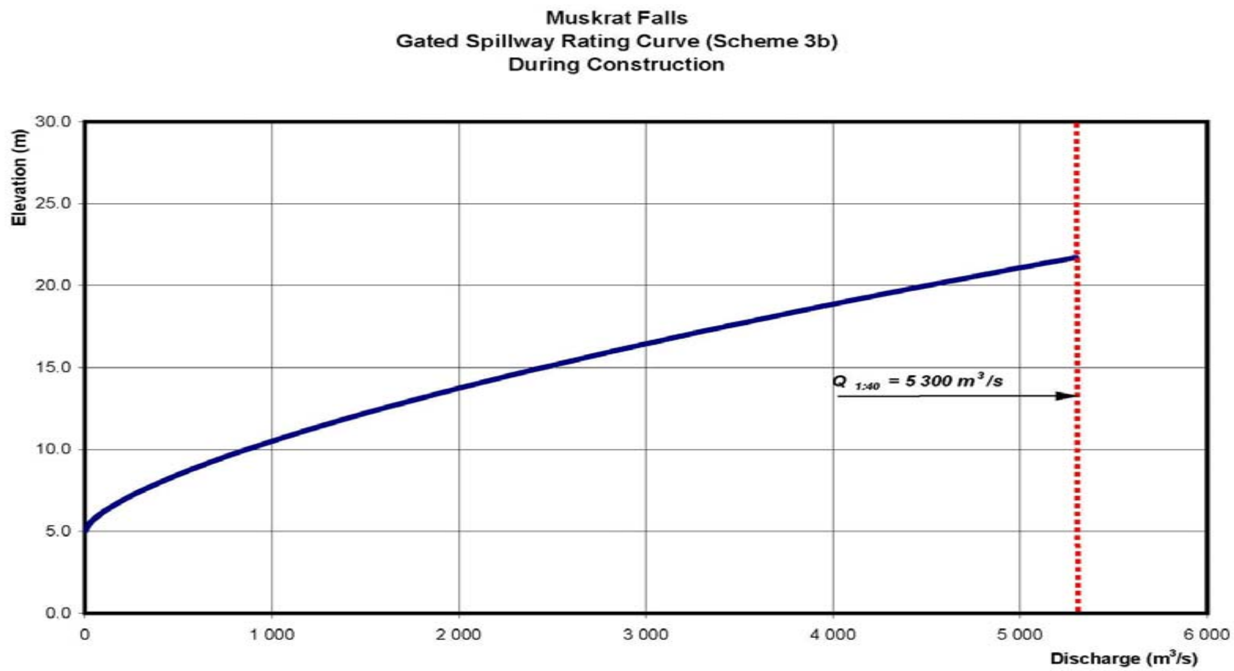


Figure A-6 – Diversion Rating Curve

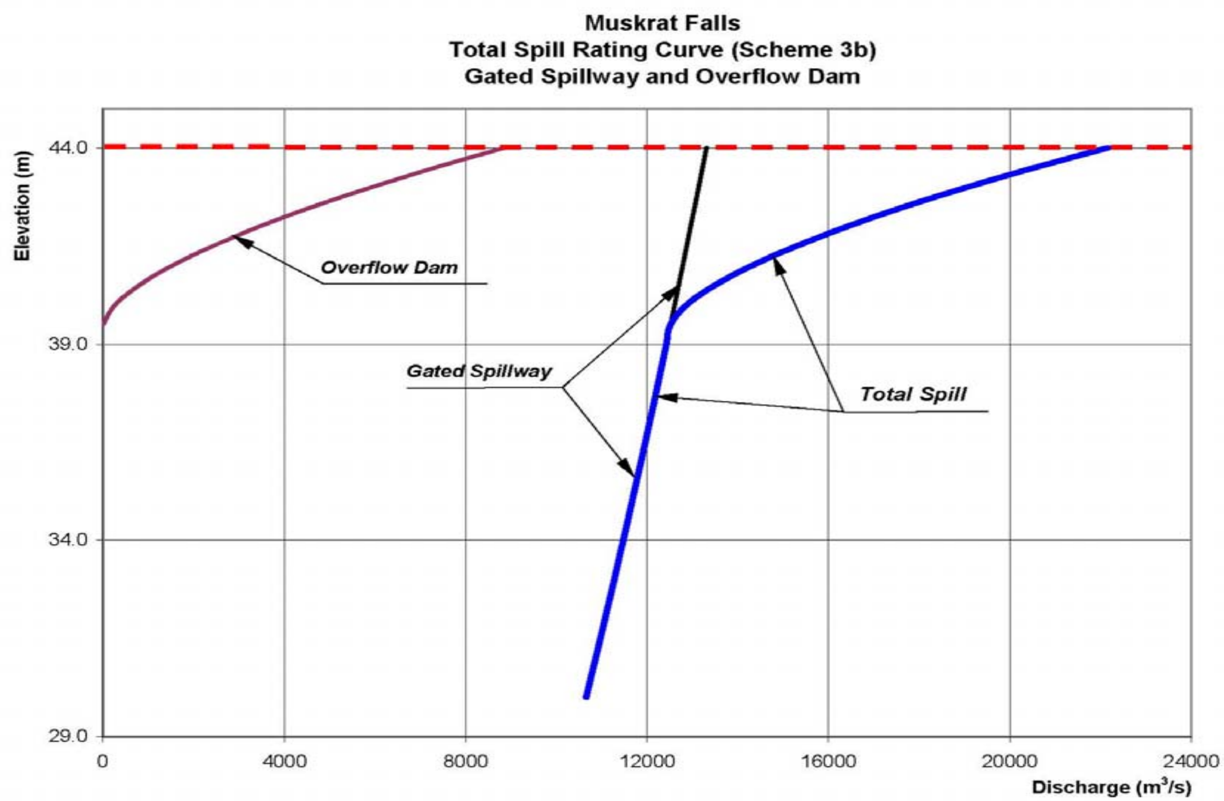


Figure A-7 – Spillway Rating Curve

APPENDIX B

COMPARATIVE COSTS

Capital costs removed from Public version

APPENDIX C

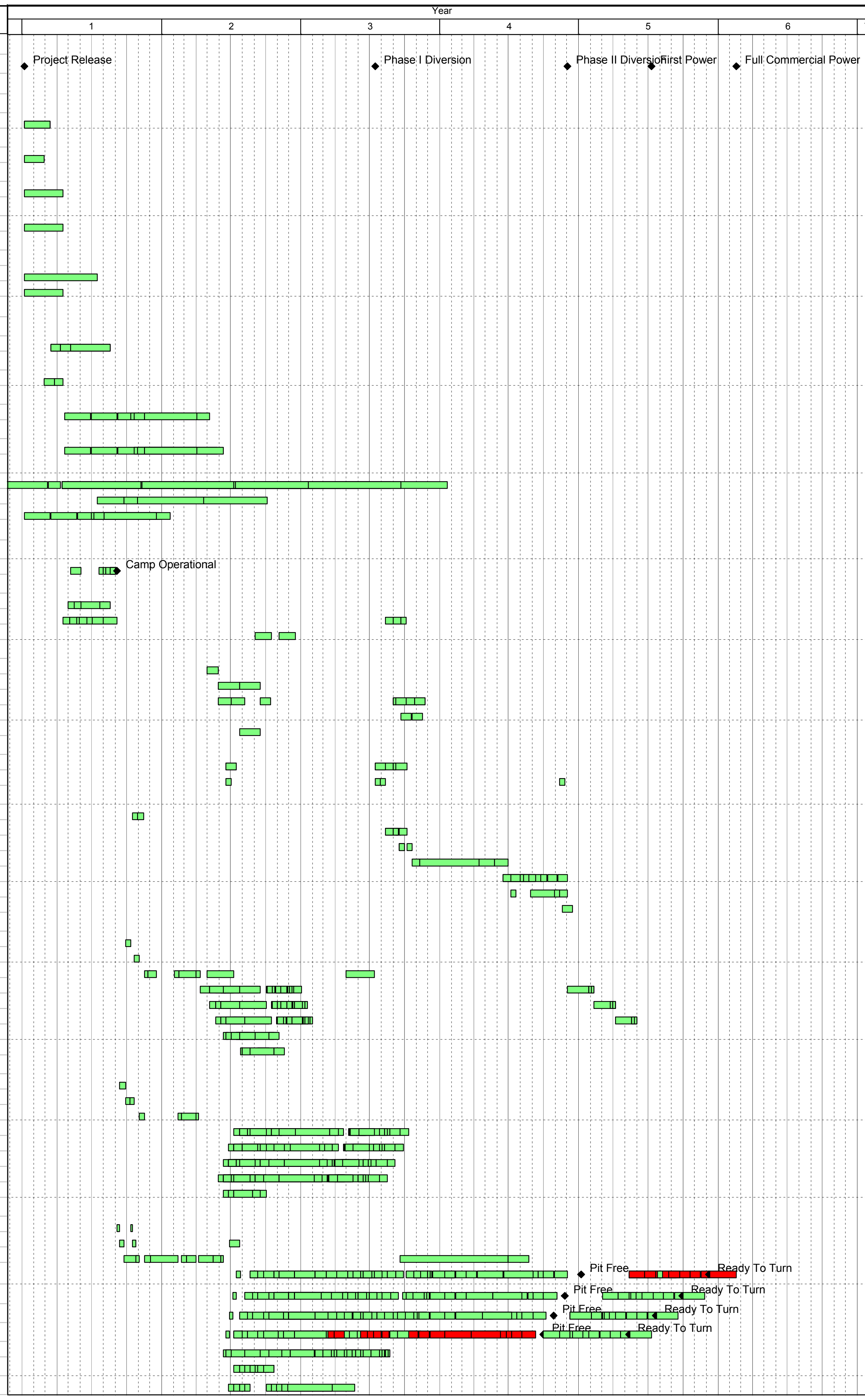
CONSTRUCTION SCHEDULE

Muskrat Falls Hydroelectric Project

22-Nov-07 10:14

Variant 10 - Summary Schedule

Activity ID	Activity Name
	General
	Milestones
	Engineering
	Site Facilities
	Construction Camp
	Site Access
	Temporary Site Roads
	Spillway
	Gates & Stoplogs
	Intake
	Traskracks, Bulkhead Gates & Service Gates
	Powerhouse
	Turbine Generator
	Overhead Crane
	Draft Tube Gates
	Procurement
	Site Facilities
	Construction Camp
	Site Access
	Temporary Site Roads
	Spillway
	Gates & Stoplogs
	Intake
	Traskracks, Bulkhead Gates & Service Gates
	Powerhouse
	Turbine Generator
	Overhead Crane
	Draft Tube Gates
	Construction
	Site Facilities
	Construction Camp
	Site Access
	Permanent Site Roads
	Temporary Site Roads
	Temporary Bridges
	North Spur
	Clearing
	Overburden Excavation
	Fill
	Relief Wells
	Pump Wells
	Cofferdams
	Upstream Cofferdam
	Downstream Cofferdam
	Dam
	Clearing
	Overburden Excavation
	Foundations
	RCC
	Concrete
	Rubber Dam
	Miscellaneous
	Spillway
	Clearing
	Overburden Excavation
	Rock Excavation
	Left Abutment
	Pier 1
	Pier 2
	Right Abutment
	Gravity Section
	Intake
	Clearing
	Overburden Excavation
	Rock Excavation
	Unit 4
	Unit 3
	Unit 2
	Unit 1
	Gravity Section
	Powerhouse
	Clearing
	Overburden Excavation
	Rock Excavation
	Unit 4
	Unit 3
	Unit 2
	Unit 1
	Erection Bay
	Substation
	South Dam



Remaining Work ◆ ◆ Milestone
Critical Remaining Work

Figure C2

APPENDIX D

VIEWS AND DRAWINGS

Figure D-1: Base Scheme 1a (3 Surface Vertical Gates 13.75 m Wide with a Rubber Dam) – Sheets 1/4

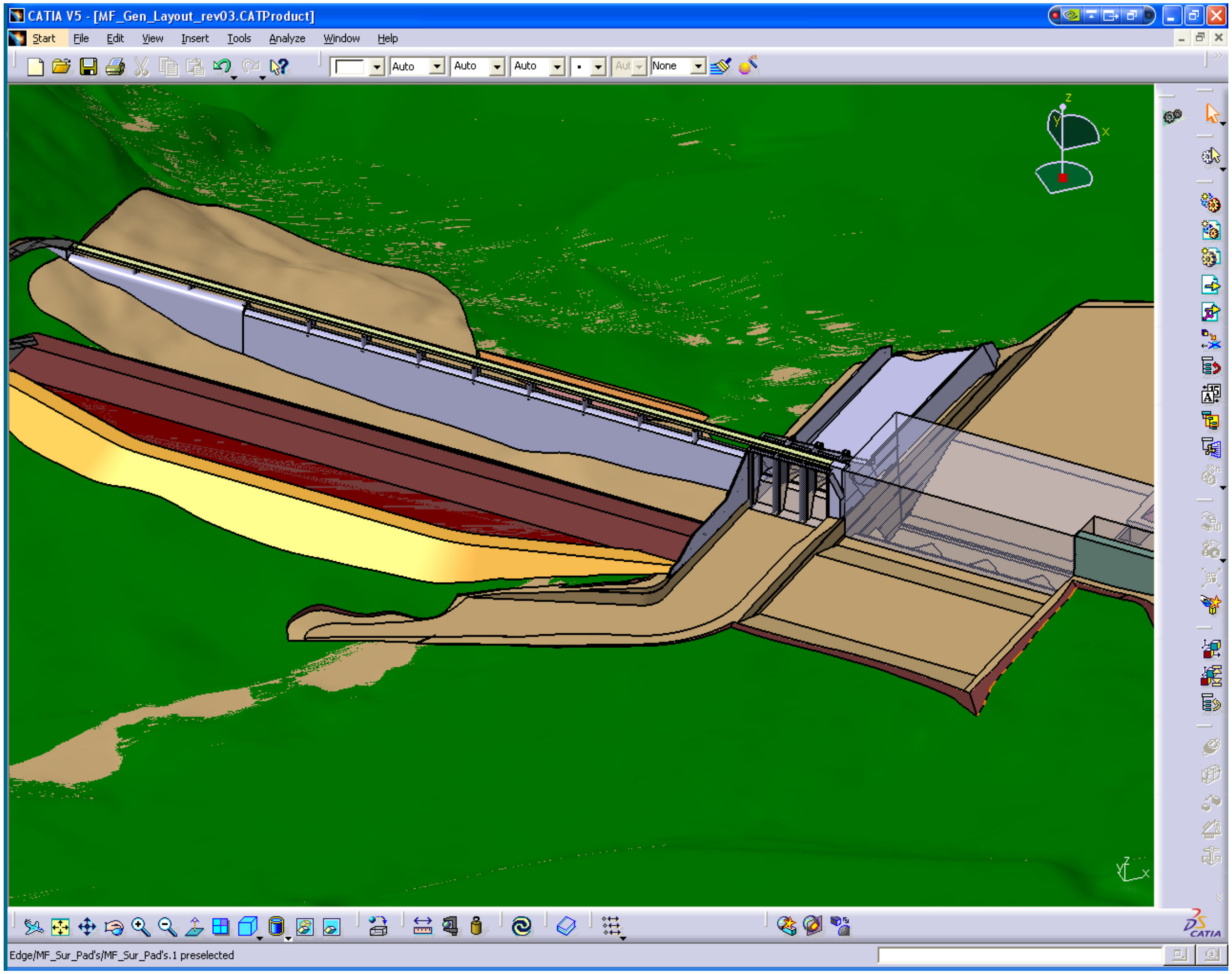


Figure D-1: Base Scheme 1a – Sheet 2/4

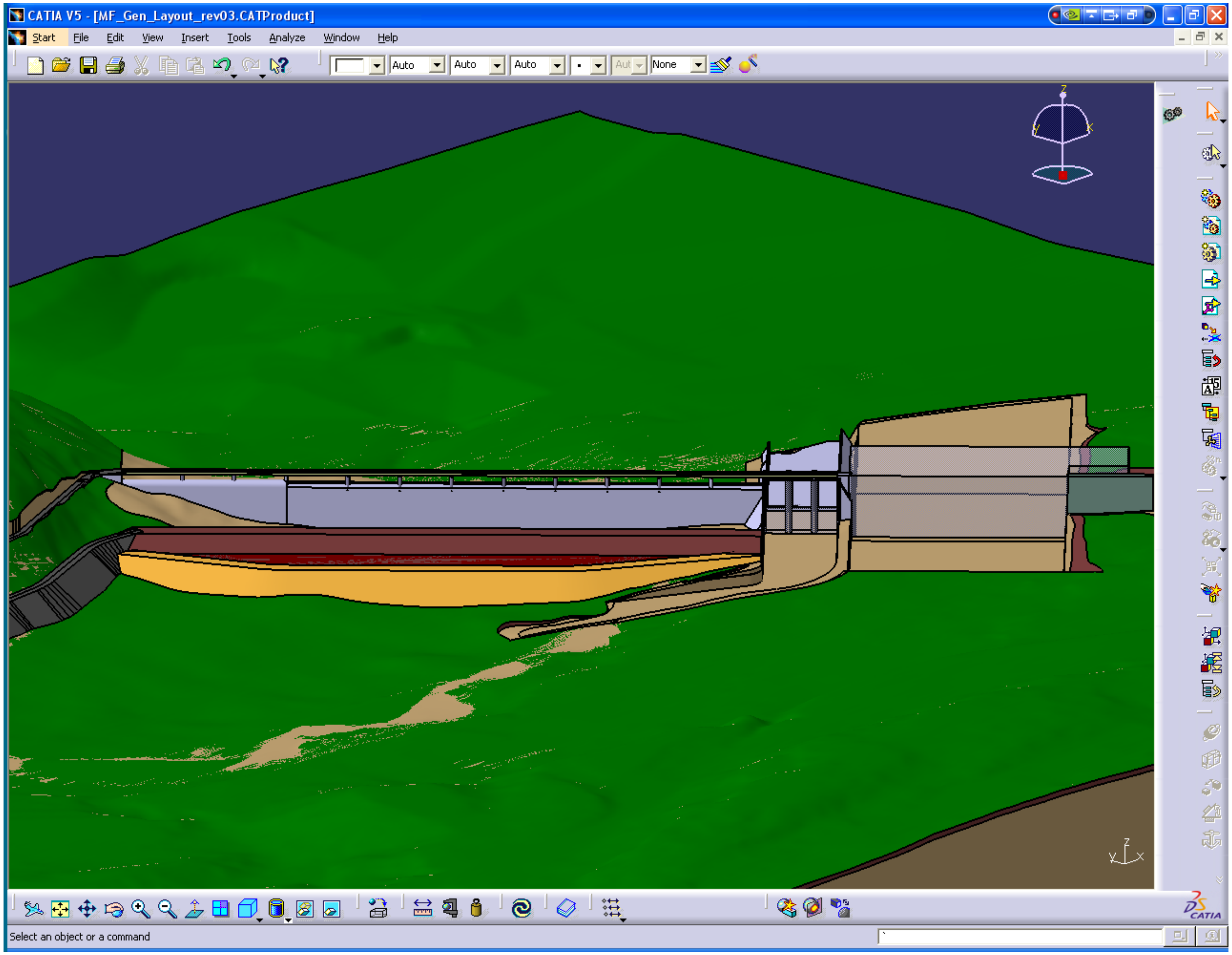


Figure D-1: Base Scheme 1a – Sheet 3/4

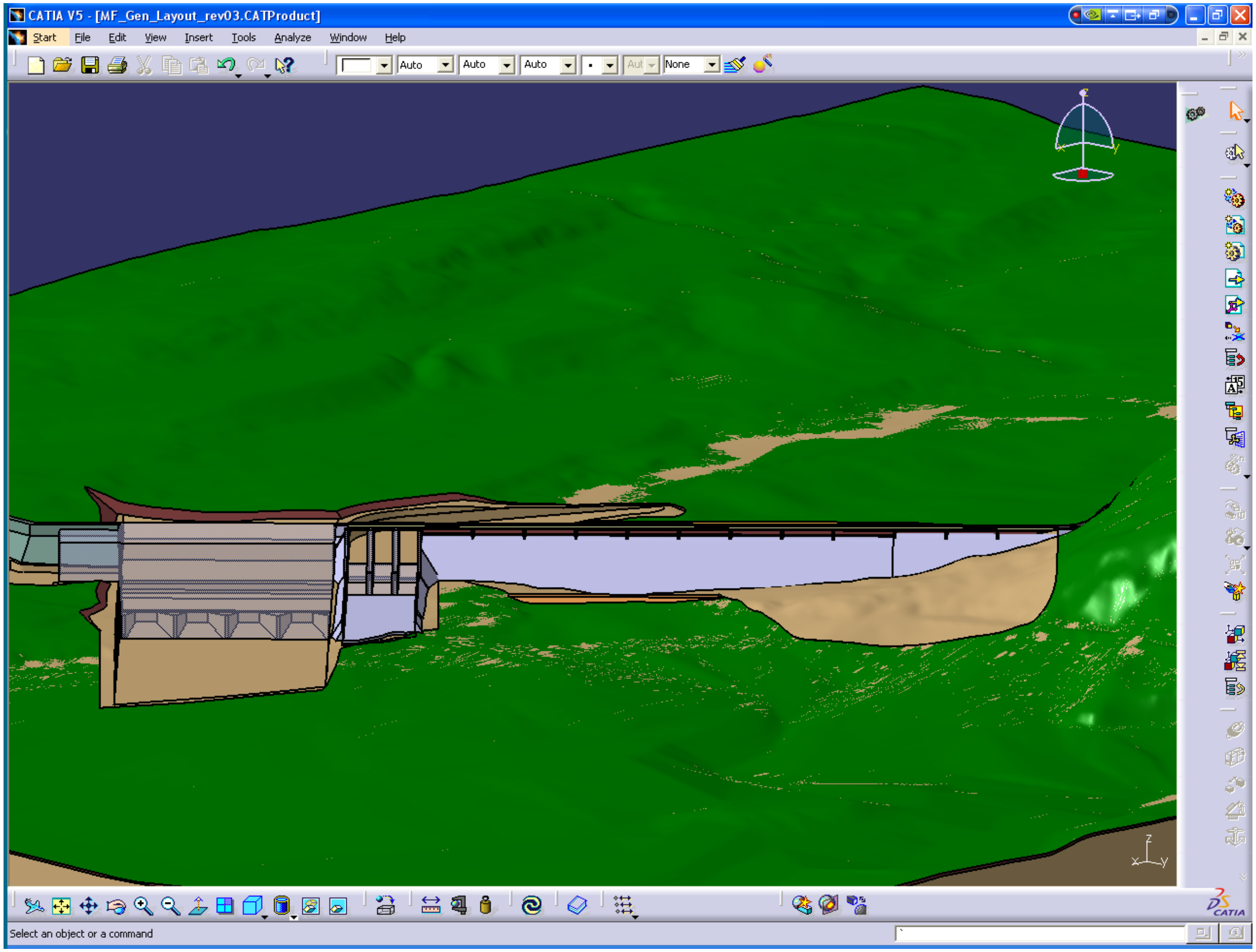


Figure D-1: Base Scheme 1a – Sheet 4/4

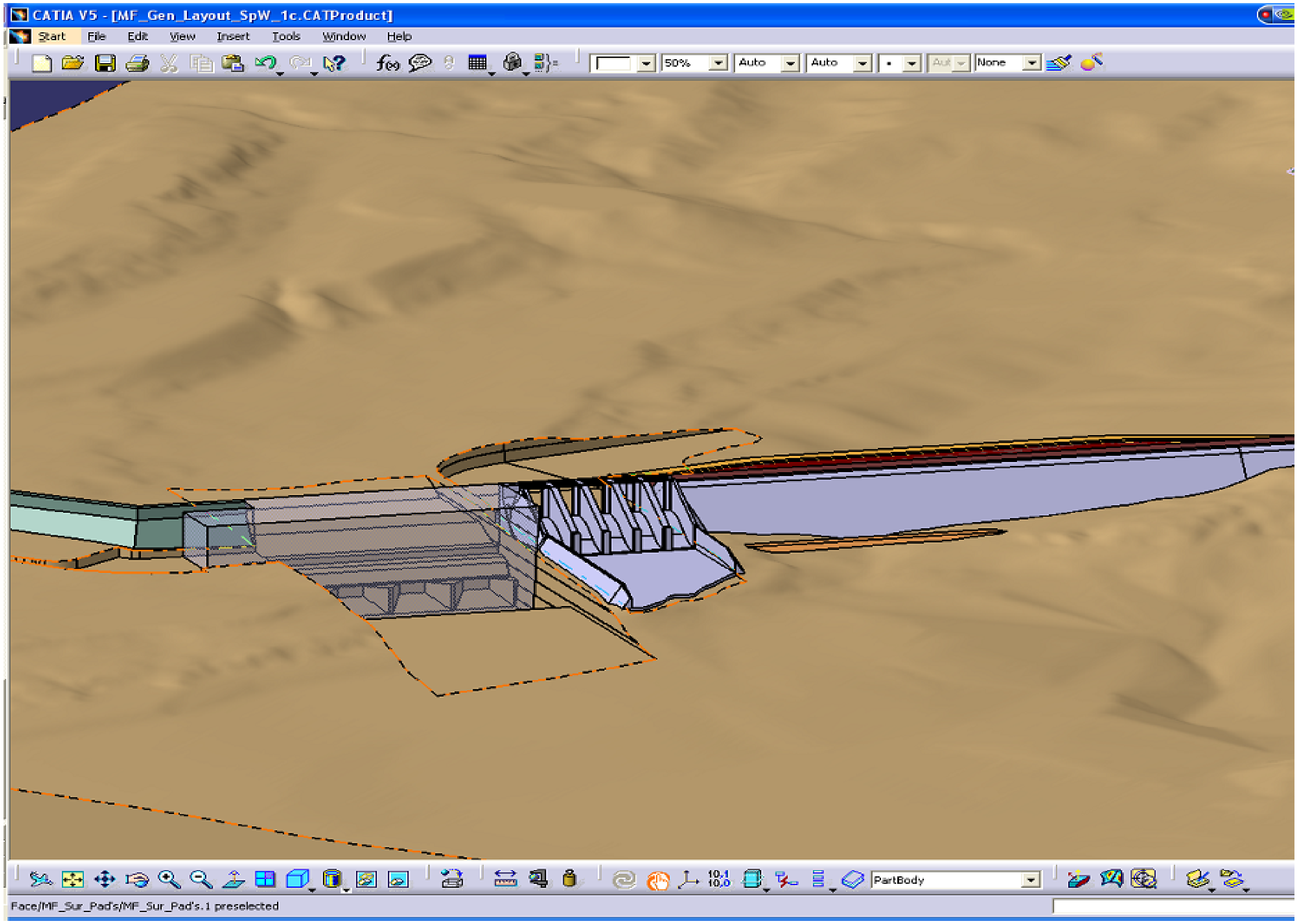


Figure D-2: Scheme 1f (5 Surface Vertical Gates 13.75 m Wide and No Rubber Dam)

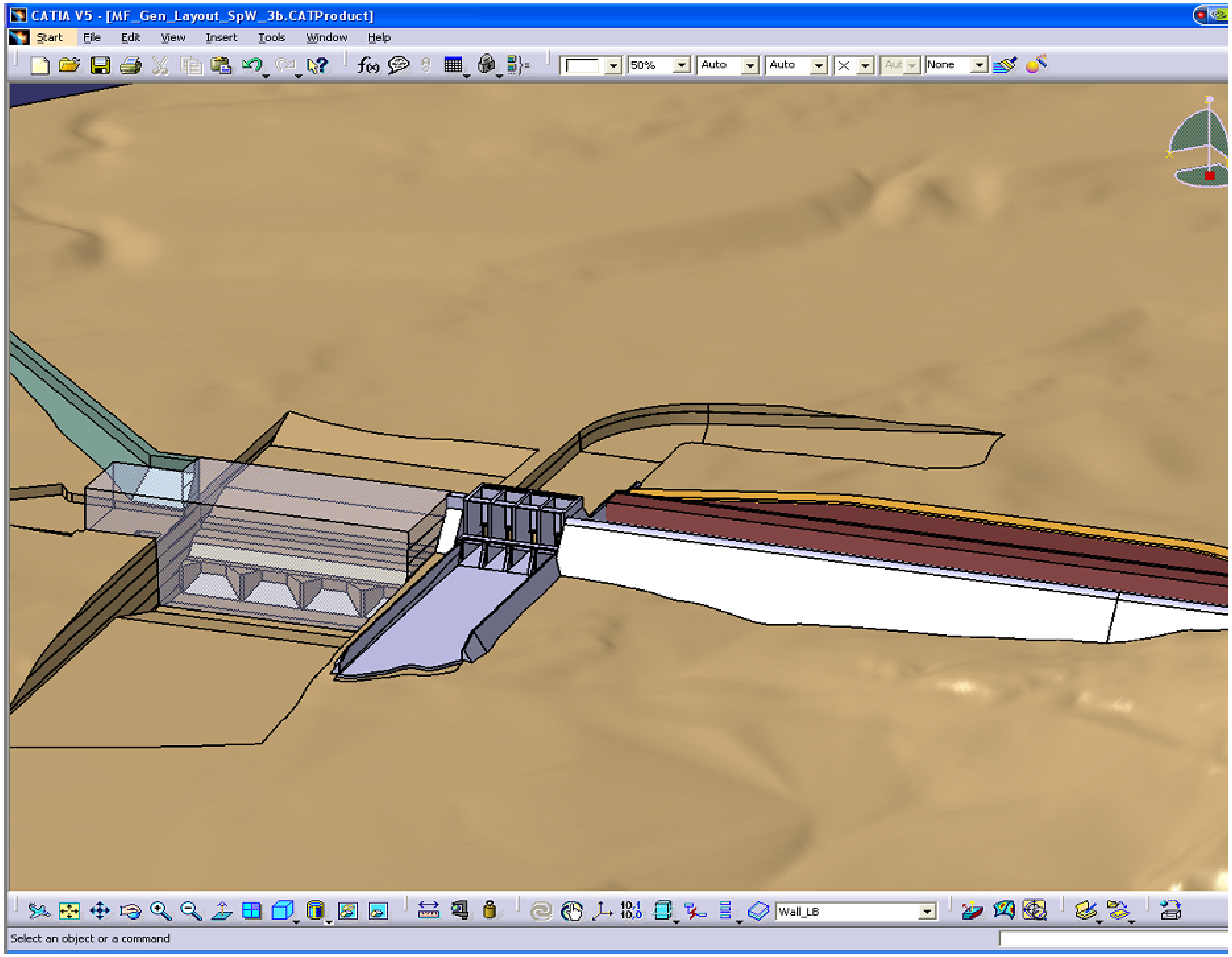


Figure D-3: Scheme 3b (4 Submerged Radial Gates 12.5 m Wide and No Rubber Dam) Sheet 1/3

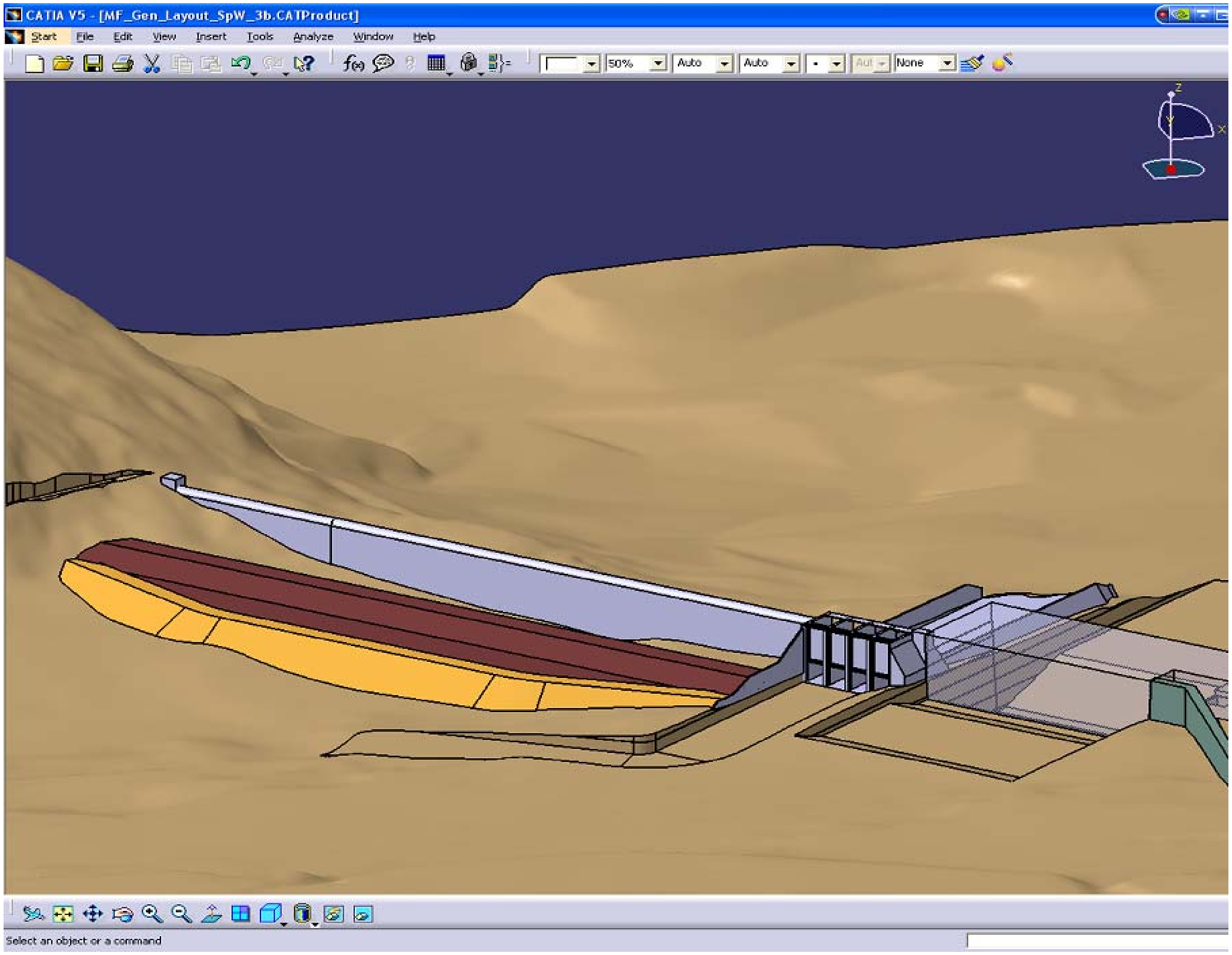


Figure D-3: Scheme 3b (4 Submerged Radial Gates 12.5 m Wide and No Rubber Dam) – Sheet 2/3

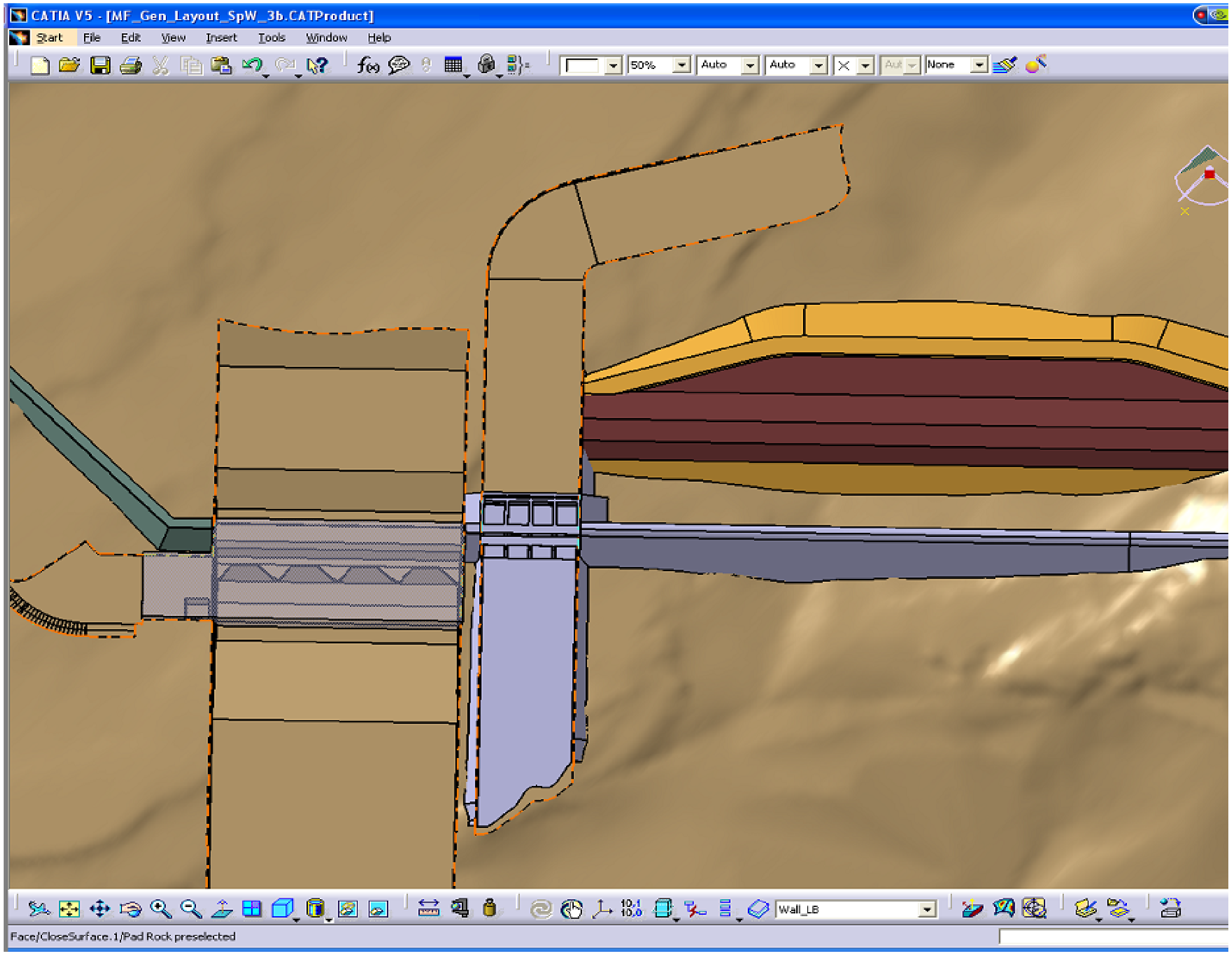


Figure D-3: Scheme 3b (4 Submerged Radial Gates 12.5 m Wide and No Rubber Dam) – Sheet 3/3

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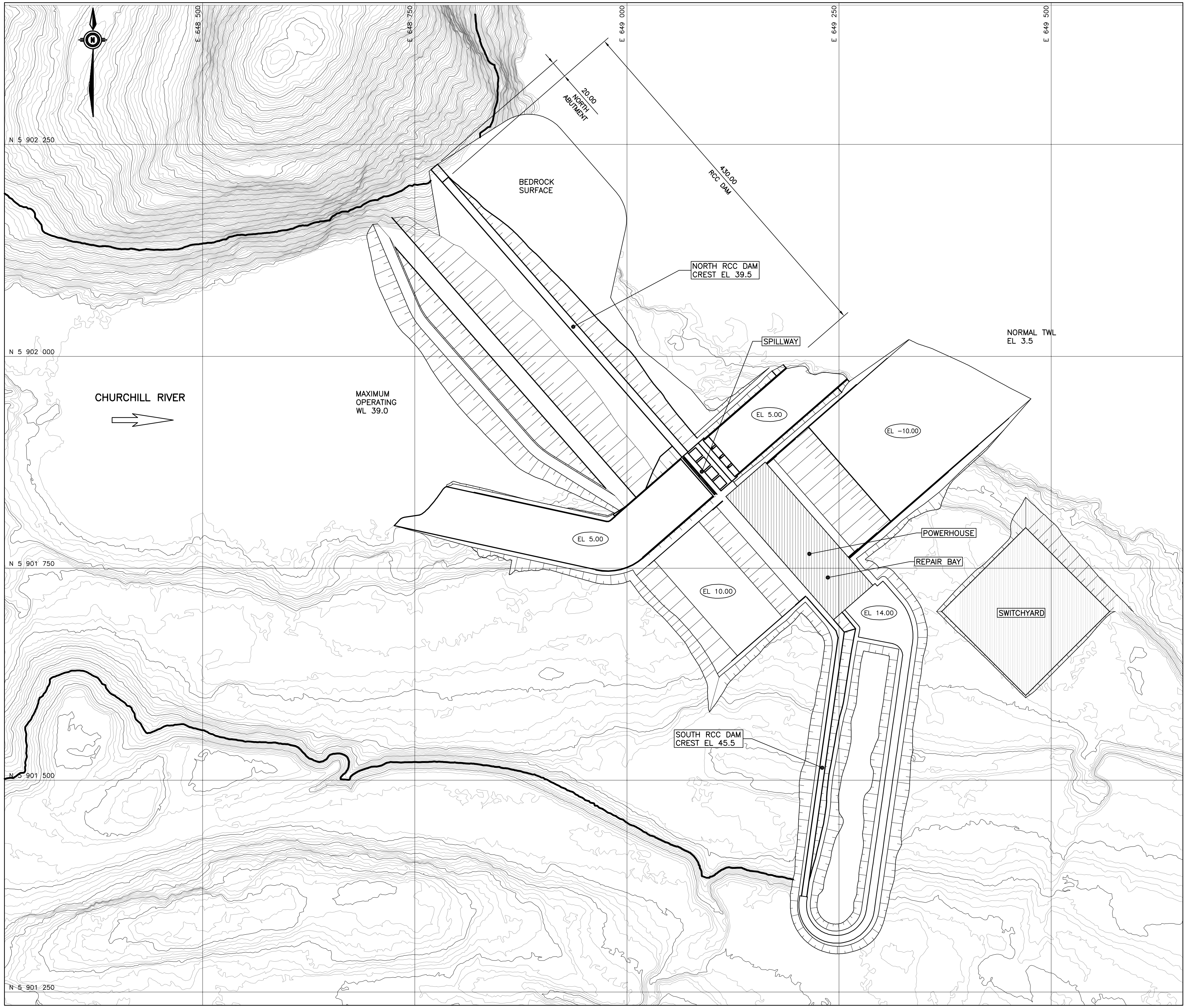
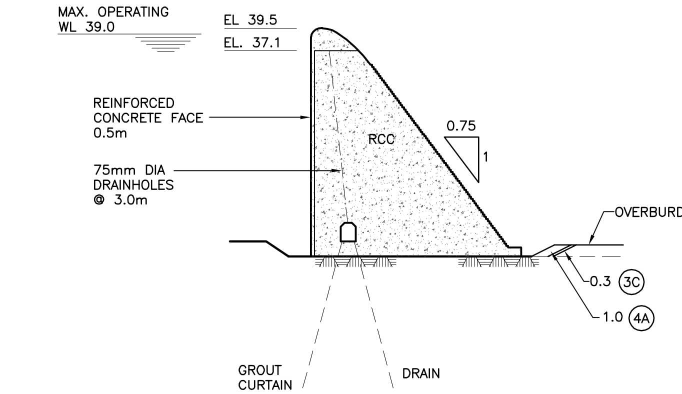
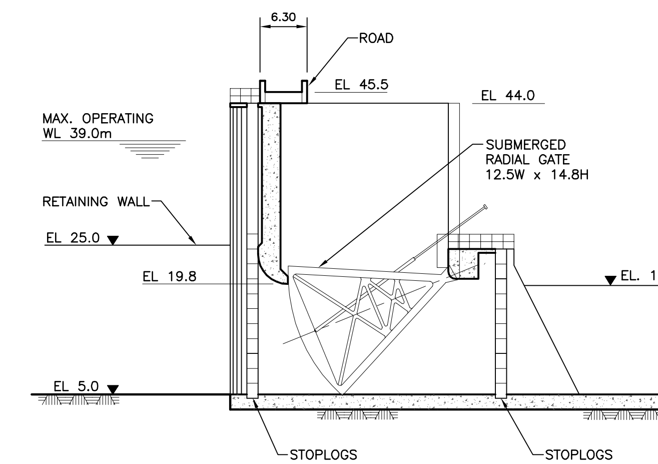




SECTION THRU NORTH RCC DAM

0 5 10 15 20 25 30 35
METRES



SECTION THRU SPILLWAY

0 5 10 15 20 25 30 35
METRES

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TRANS.	DRAWN:
MECH.	DATE:
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HYDRO

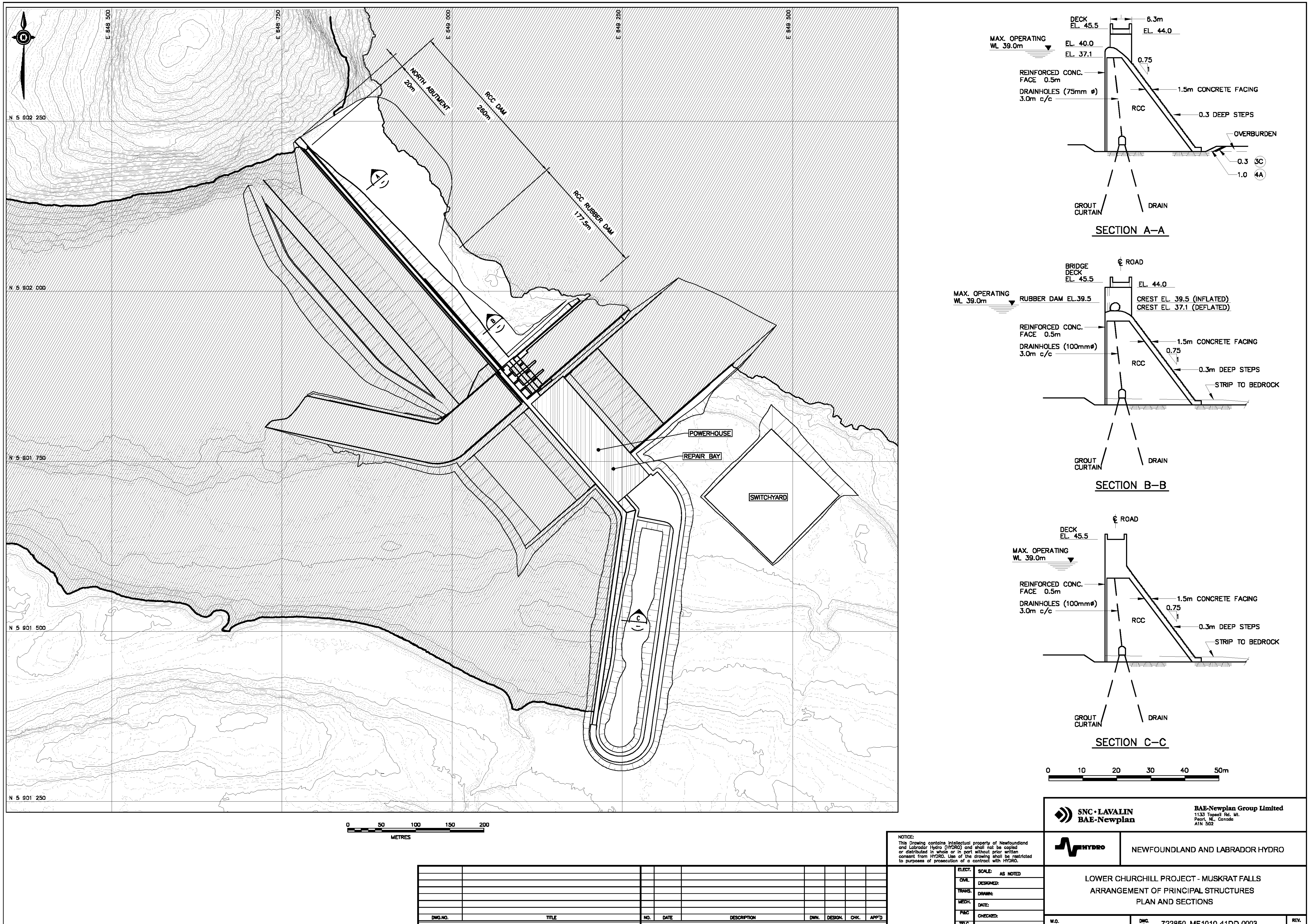
NEWFOUNDLAND AND LABRADOR HYDRO

LOWER CHURCHILL PROJECT - MUSKRAT FALLS
ARRANGEMENT OF PRINCIPAL STRUCTURES - VARIANT 10
SPILLWAY SCHEME 3B (SUBMERGED RADIAL GATES)

W.O. NO.

DWG. NO. 722850-MF1050-41DD-0001

REV.


N 5 902 250
N 5 902 000
N 5 901 750
N 5 901 500
N 5 901 250
E 648 500
E 648 750
E 649 000
E 649 250
E 649 500
NORTH ABUTMENT
20m
RCC DAM
280m
RCC RUBBER DAM
177.5m
POWERHOUSE
REPAIR BAY
SWITCHYARD
0 50 100 150 200
METRES
DECK
EL. 45.5
6.3m
EL. 44.0
MAX. OPERATING
WL 39.0m
EL. 40.0
EL. 37.1
0.75
1
REINFORCED CONC.
FACE 0.5m
1.5m CONCRETE FACING
DRAINHOLES (75mm ø)
3.0m c/c
RCC
0.3 DEEP STEPS
OVERBURDEN
0.3 3C
1.0 4A
GROUT
CURTAIN
DRAIN
SECTION A–A
BRIDGE
DECK
EL. 45.5
℄ ROAD
EL. 44.0
MAX. OPERATING
WL 39.0m
RUBBER DAM EL.39.5
CREST EL. 39.5 (INFLATED)
CREST EL. 37.1 (DEFLATED)
REINFORCED CONC.
FACE 0.5m
1.5m CONCRETE FACING
DRAINHOLES (100mmø)
3.0m c/c
0.75
1
RCC
0.3m DEEP STEPS
STRIP TO BEDROCK
GROUT
CURTAIN
DRAIN
SECTION B–B
℄ ROAD
DECK
EL. 45.5
MAX. OPERATING
WL 39.0m
REINFORCED CONC.
FACE 0.5m
1.5m CONCRETE FACING
DRAINHOLES (100mmø)
3.0m c/c
0.75
1
RCC
0.3m DEEP STEPS
STRIP TO BEDROCK
GROUT
CURTAIN
DRAIN
SECTION C–C
0 10 20 30 40 50m
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APPROVED:
LOWER CHURCHILL PROJECT - MUSKRAT FALLS
ARRANGEMENT OF PRINCIPAL STRUCTURES
PLAN AND SECTIONS
W.O.
NO.
DWG.
NO.
722850- MF1010-41DD-0003
REV.
DWG.NO.
TITLE
REFERENCE DRAWINGS
NO.
DATE
DESCRIPTION
DWN.
DESIGN.
CHK.
APP'D
REVISIONS

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