



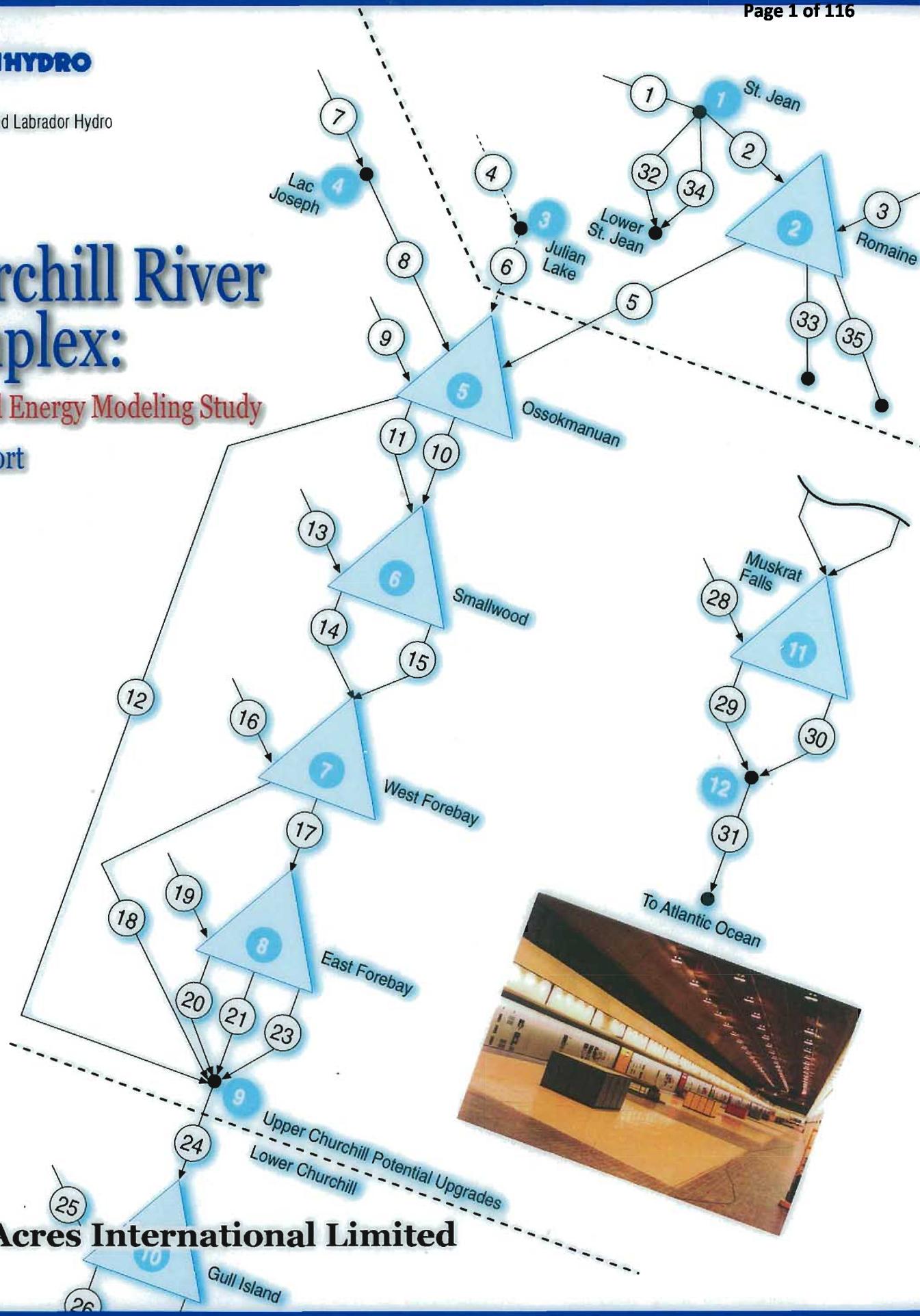
Newfoundland and Labrador Hydro

# Churchill River Complex:

Power and Energy Modeling Study

Final Report

July 1998





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Final Report

July 1998



Acres International Limited



July 14, 1998  
P12817.00

Newfoundland and Labrador Hydro  
P.O. Box 12400  
Hydro Place, Columbus Drive  
St. John's, Newfoundland A1B 4K7

**Attention: Mr. M. Rana, Director  
Generation Engineering and Telecontrol**

Dear Sir:

**Churchill River Complex Power and  
Energy Modeling Study**

We are pleased to submit the final report of the Churchill River Complex Power and Energy Modeling Study. We have provided 12 copies of Volume 1 and six copies of Volumes 2 and 3 containing detailed output. The first copy of Volume 1 contains diskettes with electronic versions of the model setup and post-processor for your use.

The model as setup in this study is suitable for use in evaluating the proposed projects in the Churchill River Complex.

It has been a pleasure to work with you and your staff on this project and we look forward to continuing involvement with the Churchill River Complex studies.

Yours very truly,

A handwritten signature in black ink, appearing to read "S. R. Gill".

SHR:sjc

for R.J. Gill, P.Eng.  
Vice President, Atlantic Region

Enclosure

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## **Executive Summary**

## Executive Summary

This report documents the work carried out for Newfoundland and Labrador Hydro by Acres International Limited to develop a power and energy model of the Churchill River system. The model includes the existing and proposed projects in the Churchill River Complex. The Complex consists of

- the existing Churchill Falls hydroelectric station;
- a 1000 MW proposed extension to the Churchill Falls station;
- the proposed diversion of water from two rivers in Québec into the Churchill Falls system via the Atikokan River;
- a 2264 MW proposed hydroelectric station at Gull Island, on the Lower Churchill River; and
- a 824 MW proposed hydroelectric station at Muskrat Falls, on the Lower Churchill River.

Acres Reservoir Simulation Package (ARSP) was used as the basis for the model setup. The required output was average and firm energy from the total Complex for various combinations of projects. A post-processor was also developed to determine the energy available at the Québec-Labrador border, taking into account energy requirements to Labrador and to the Island of Newfoundland via a proposed transmission line infeed, and transmission losses to the border. Electronic copies of the model setups were provided to Newfoundland and Labrador Hydro.

The model setup required

- review of existing information,
- initial model setup,
- comparison of model results with recorded data and with previous estimates, and
- final model setup.

The estimated firm and average energy output from the proposed projects is summarized in Table S-1, together with the increment over the existing generation.

The energy for sale at the Québec-Labrador border is shown in Table S-2. These results apply to a particular combination of losses and loads agreed upon for the purposes of this study.

The model is recommended for Newfoundland and Labrador Hydro's use in further evaluation of projects in the Churchill River Complex.

**Table S-1**  
**Estimated Firm and Average Energy**

Model Setups	Installed Capacity (MW)	Firm Energy (TWh/yr)	Incremental Firm Energy (TWh/yr)	Average Energy (TWh/yr)	Incremental Average Energy (TWh/yr)
Existing (CF1)	5600	31.37	--	34.50	--
CF1 + Gull	7864	42.16	10.79	46.28	11.78
CF1 + Gull + Muskrat	8688	46.24	14.87	50.69	16.19
Diversions + CF1 + CF2 (New CF)	6600	36.00	4.63	39.42	4.92
New CF + Gull	8864	47.91	16.54	52.42	17.92
New CF + Gull + Muskrat	9688	52.40	21.03	57.19	22.69
New CF + Gull + Lobstick	9024	48.80	17.43	53.50	19.00
New CF + Gull + Lobstick + Muskrat	9848	53.29	21.92	58.28	23.78

**Table S-2**  
**Energy for Sale at Québec-Labrador Border**

Model Setup	Available Energy for Sale at Québec-Labrador Border	
	Total (TWh)	Incremental (TWh)
Existing (CF1)	31.18	--
CF1 + Gull	38.84	7.66
CF1 + Gull + Muskrat	43.10	11.92
Diversions + CF1 + CF2 (New CF)	36.02	4.84
New CF + Gull	44.88	13.70
New CF + Gull + Muskrat	49.49	18.31
New CF + Gull + Lobstick	45.91	14.73
New CF + Gull + Lobstick + Muskrat	50.53	19.35

*muskrat diversions*

*11.78 for GI  
4.41 for NF*

*$\Delta = 4.08$  firm  
 $\Delta = 4.41$  avg  
when MF added + 0  
CF1*

*$\Delta = 4.76$*

## **Introduction**

## 1 Introduction

In February, 1998 Newfoundland and Labrador Hydro (NLH) engaged Acres International Limited to develop a comprehensive power and energy model of the Churchill River system. Such a model would allow NLH to evaluate firm and average energy for a number of proposed developments on the river. This report documents the analyses required to develop the model and presents the results for the various developments.

### 1.1 Background

The Churchill Falls Hydroelectric Project was designed during the late 1960's and constructed between 1969 and 1974. It consists of an 11-unit underground powerhouse with a nominal installed capacity of 5,428.5 MW, two large storage reservoirs, two forebays and a number of water control structures. Potential developments on the Lower Churchill represent some of the largest untapped hydro power resources in North America. Proposed sites of energy generation on the Churchill River system include Gull Island, Muskrat Falls, and Lobstick water control structure. The proposed new developments also include additional capacity at the existing station, using diverted water from rivers in the province of Québec.

### 1.2 Objectives

The objectives of the study were

- to develop a comprehensive model based on ARSP (Acres Reservoir Simulation Package), capable of determining firm and average energy for the existing and proposed developments on the Churchill River;
- to provide a post-processor for determining the available energy for sale at the Québec-Labrador border taking into account Island infeed and Labrador loads and transmission losses to the border; and
- to provide NLH with electronic copies of final model setups of the power and energy model for use by NLH staff.

## 1.3 Approach

The initial planned approach was to take an existing power and energy model and the physical data and hydrology in this model and use it to set up the ARSP model. During the course of the work, it became evident that most of the data required confirmation and consultation with NLH. In addition, information on physical characteristics of some structures was available, which could be incorporated into the model. The activities undertaken in the study were therefore as follows.

- Review existing models and information related to the Churchill River system and proposed developments.
- Set up a power and energy model that matches the results of previous power and energy models, while documenting possible changes and concerns in model input values.
- Update the power and energy model to include all the physical characteristics of the Churchill River system and the most up-to-date data.
- Calibrate the updated model with recorded plant data.
- Meet with NLH to discuss progress and identify any concerns in the model setup and update the model based on NLH comments.
- Determine the preliminary firm and average energy for existing and proposed developments on the Churchill River system.
- Present and discuss preliminary results with NLH staff and make any changes to the model to reflect any concerns or questions from the presentation.
- Determine the firm and average energy for existing and proposed developments on the Churchill River system.
- Review the transmission layout for the Churchill River system and develop a post-processor for determining the available energy for sale at the Québec-Labrador border taking into account Island infeed and Labrador loads for existing and proposed developments.
- Tabulate the available energy for sale at the Québec-Labrador border.

- Document results.

A list of the information and sources is provided in Appendix A.

## **System Description**

## 2 System Description

The Churchill River drains an area of 92,355 km<sup>2</sup>, and flows from west to east from the Québec-Labrador border to Lake Melville, as shown on Figure 2.1. For the purpose of this study, the total drainage area of the Churchill River was taken above Muskrat Falls (just upstream of Goose Bay).

The Upper Churchill River basin includes drainage into Ossokmanuan Reservoir, Smallwood Reservoir, and local drainage to the forebays above Churchill Falls. This area provides flows for the existing Churchill Falls hydroelectric station. Additional flow for potential energy generation for the system is available from projects on the Lower Churchill River (below Churchill Falls) and from diverted water from Québec.

The following section summarizes the system characteristics of the Upper Churchill River, Lower Churchill River, and diverted basins from Québec.

### 2.1 Upper Churchill River

The Upper Churchill River drains a total area of 69,267 km<sup>2</sup> from the upper reaches of the Ossokmanuan Reservoir basin to the Churchill Falls Hydroelectric Station. The system is composed of two large storage reservoirs, two forebays and a number of water control structures as listed below and shown in Figure 2.2. The total nominal installed capacity of the system is 5,428.5 MW. The maximum continuous operating capacity available from the plant is 5,600 MW with a maximum historic peak of 5,765 MW. Reservoir and water control structures in the system are listed below.

#### Storage Reservoirs and Forebays

- Ossokmanuan Reservoir
- Smallwood Reservoir
- West Forebay
- East Forebay

#### Water Control Structures

- Ossokmanuan Control Structure (Spillway)
- Gabbro Control Structure
- Lobstick Control Structure
- Jacopie Spillway

- Whitefish Falls Control Structure
- East Forebay Spillway.

There are also two large lakes, Lac Joseph and Atikonak Lake, providing natural regulation above Ossokmanuan Reservoir. Lac Joseph flows uncontrolled from the west into Atikonak Lake which, in turn, flows uncontrolled to Ossokmanuan Reservoir. The water from the proposed diversions would flow into Atikonak Lake from the southeast.

## 2.2 Lower Churchill River

The drainage area of the Lower Churchill River includes the drainage area of the Upper Churchill River at 69,267 km<sup>2</sup> plus that of the Lower Churchill River above Muskrat Falls at 23,088 km<sup>2</sup>.

The proposed hydroelectric developments on the Lower Churchill River are located at Gull Island and Muskrat Falls, approximately 80 km and 40 km upstream of Goose Bay, respectively. These would be essentially run-of-the-river developments, operated with essentially constant headpond levels. The proposed installed capacities of the generating stations are approximately 2,264 MW for Gull Island and approximately 824 MW for Muskrat Falls.

## 2.3 Churchill Falls Additional Capacity (CF2)

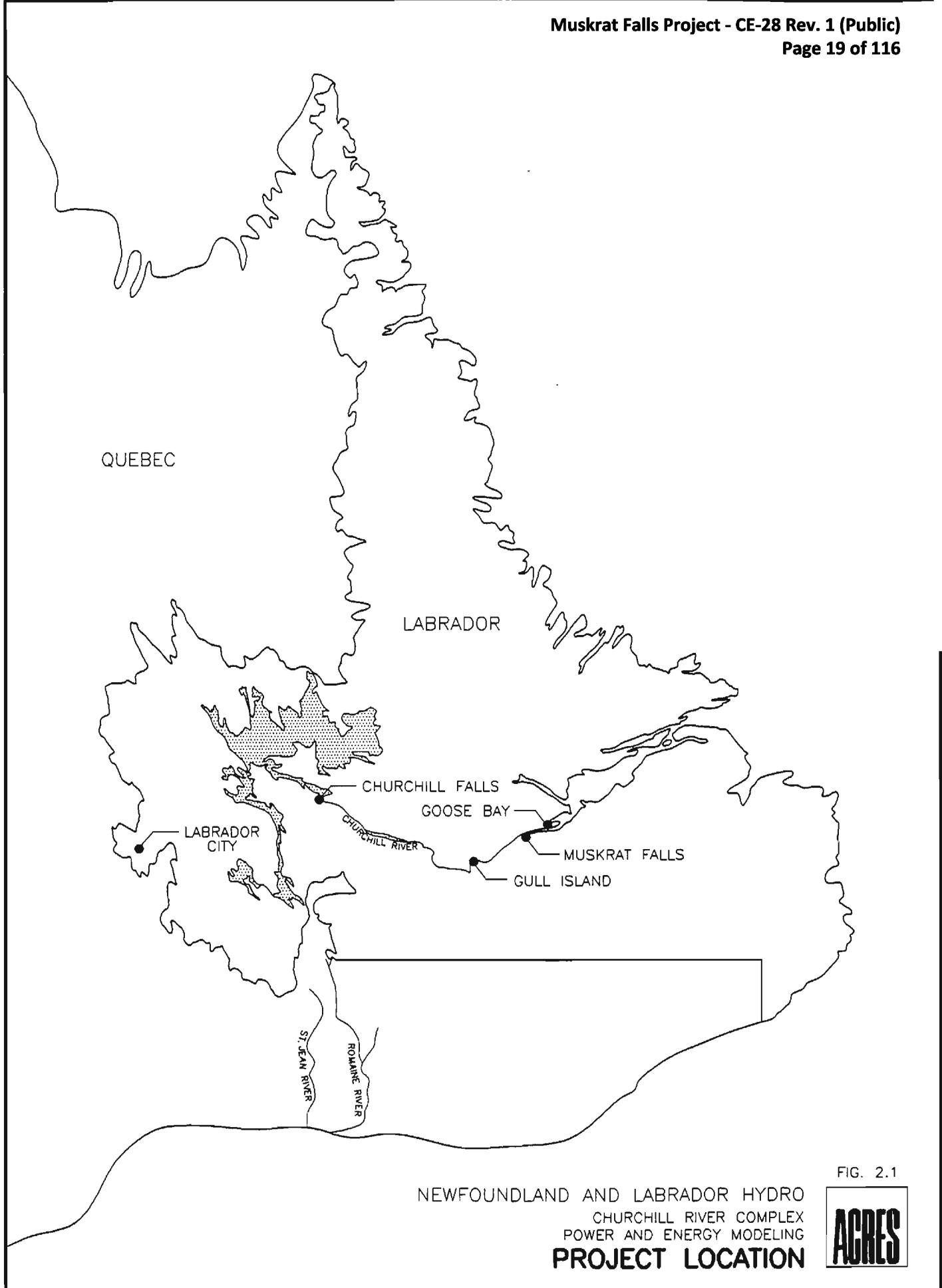
The proposed CF2 generation would come from an additional 1,000 MW at Churchill Falls, supplied by water diverted from two rivers, the St. Jean River and the Romaine River, in the province of Québec. These rivers which now flow south into the Gulf of St. Lawrence would be diverted into Atikonak Lake, and from there would flow into the Ossokmanuan Reservoir. The St. Jean River would be diverted through a diversion channel to the Romaine River. A storage reservoir would be constructed on the Romaine River, and flows would either be stored, spilled or diverted to the Upper Churchill River basin depending on energy demands. The flows diverted to the Churchill River basin would be regulated by a control structure located upstream of Atikonak Lake. No additional spillway capacity is planned in the Upper Churchill River; flood handling will be reviewed separately.

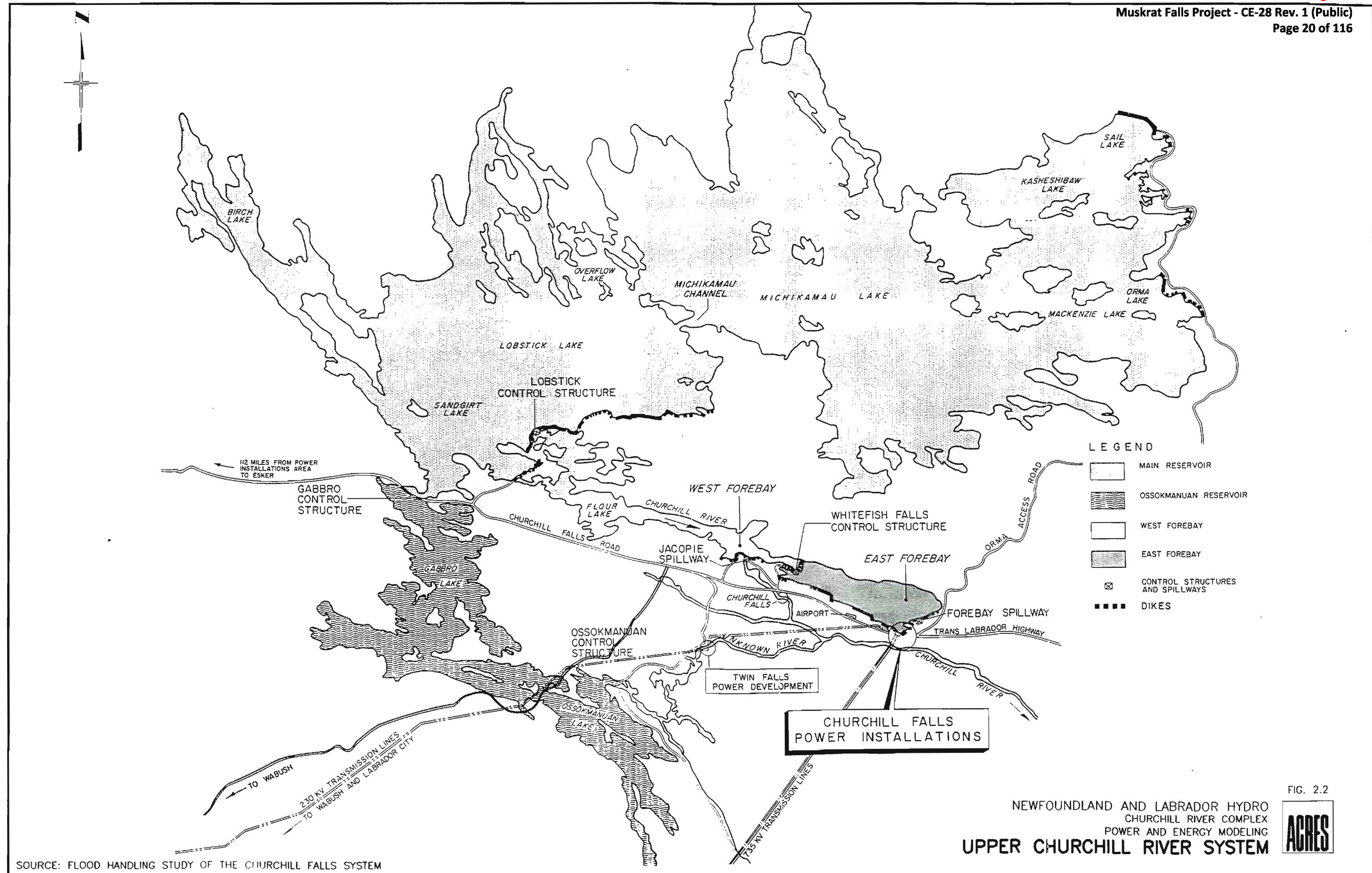
The diversion structures on the St. Jean and Romaine Rivers would include structures for release of fishery flows to the lower portion of the rivers.

The local and cumulative drainage areas for the Upper and Lower Churchill River and the diversions are summarized in Table 2.1.

## Muskrat Falls Project - CE-28 Rev. 1 (Public)

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**Table 2.1****Local and Cumulative Drainage Areas**

<b>Basin</b>	<b>Sub-Basin/ River</b>	<b>Local Drainage Area (km<sup>2</sup>)</b>	<b>Cumulative Drainage Area (km<sup>2</sup>)</b>	
			<b>Without Diversions</b>	<b>With Diversions</b>
Diversions from the Province of Quebec	St. Jean River above diversion	1217	-	1217
	Romaine River above diversion	8402	-	9619
Upper Churchill	Lac Joseph	7070	7070	16689
	Ossokmanuan Reservoir	15362	22432	32051
	Smallwood Reservoir	45110	67542	77161
	West Forebay	1108	68650	78269
	East Forebay	617	69267	78886
Lower Churchill	Gull Island	19832	89099	98718
	Muskrat Falls	3256	92355	101974

Source: Churchill River Complex Energy Report (January 1991)

Hydro-Quebec Presentation Notes (February 1998)

## **Streamflow Sequences**

## 3 Streamflow Sequences

In order to assess the power and energy benefits of the proposed alternatives, a monthly flow simulation model was set up to represent the Churchill River system. Representative inflow sequences for each of the sub-basins in the system were required as input data for the simulation model. Based on available data, inflow sequences for 54 years were developed. The three main sub-basins requiring inflow sequences are as follows.

### (1) Upper Churchill River

- Lac Joseph local inflows.
- Ossokmanuan Reservoir local inflows (including Atikonak Lake).
- Smallwood Reservoir local inflows.
- West Forebay local inflows.
- East Forebay local inflows.

### (2) Lower Churchill River

- Gull Island local inflows.
- Muskrat Falls local inflows.

### (3) Diversions

- St. Jean River local inflows (above diversions).
- Romaine River local inflows (above diversions).

## 3.1 Data Sources

The data sources used for developing the streamflow sequences were as follows.

- *Gull Island Power Development: Review of Engineering and Capital Cost Estimate Final Report, Volume 2: Detailed Calculation of Energy Simulation* (October 1997).
- *Churchill Falls Inflows Harmonization of Hydro-Québec and CF(L)Co Data Bases* (October 1997).
- Partial Diversions of Upper St. Jean and Romaine Rivers: Preliminary Studies - Hydro-Québec Presentation Notes (February 1998).

- A Development Scenario for the Upper Churchill Watershed - Hydro-Québec Presentation Notes (September 1997).

Using these sources, inflow sequences were developed for each of the sub-basins as discussed in the following section.

### **3.2 Inflows**

During the initial stages of the study, inflow sequences from the Gull Island Power Development Report (October 1997) were used directly for both Upper and Lower Churchill River sub-basins. During meetings with NLH and correspondence with Churchill Falls (Labrador) Corporation CF(L)Co staff, it was agreed that the Harmonization Report (October 1997) inflows should be used, where available, in developing inflow sequences.

The Harmonization Report (October 1997) included flows for the Upper Churchill River for the period 1976 to 1996 only. Therefore, the Gull Island Power Development Report (October 1997) hydrology was used for the years before 1976. For the Lower Churchill River basin, the hydrology from the Gull Island Power Development Report (October 1997) only was used because the Harmonization Report (October 1997) did not include any information on this basin.

For the diversions, the only flow information provided was average inflow above the diversion for St. Jean and Romaine Rivers from the two sets of Hydro-Québec Presentation Notes (September 1997 and February 1998). The average inflow for St. Jean and Romaine Rivers was stated as 29 m<sup>3</sup>/s and 186 m<sup>3</sup>/s, respectively, giving a total diverted inflow of 215 m<sup>3</sup>/s. The approach used to develop an inflow sequence for these two rivers was to prorate the local inflows to Ossokmanuan Reservoir based on the ratio of average inflows. In general, this assumes that the diversion inflows follow the same pattern as the Ossokmanuan Reservoir inflows.

The sources of the inflow sequences are summarized in the table below.

Sub-basins	Inflow Sequence
Upper Churchill - Lac Joseph - Ossokmanuan Reservoir - Smallwood Reservoir - West Forebay - East Forebay	1943-1975 <sup>1</sup> ; 1976-1996 <sup>2</sup> 1996 - 1997 <sup>1</sup>
Lower Churchill - Gull Island - Muskrat Falls	1943-1997 <sup>1</sup>
Diversions - St. Jean River - Romaine River	1943-1997 Ossokmanuan local inflows prorated based on average local inflows

<sup>1</sup> Gull Island Power Development Report (October 1997)

<sup>2</sup> Harmonization Report (October 1997)

The inflow sequences for each of the sub-basins used for the final model setups and results are provided in Appendix B.

When the mean annual runoff (MAR) for the Upper Churchill basin was compared with the MAR for the Lower Churchill basin for the period of record (length of inflow sequence), it was noticed that the MAR for Smallwood was about 5 percent higher than for Gull Island. In general, given the general climate and topography, it might have been expected that the Lower Churchill MAR would be higher than the Upper Churchill MAR.

As a comparison, the MAR for the overlapping period of record January 1985 to December 1995 was determined for hydrometric stations in or adjacent to the Lower Churchill River. The results, as presented in Table 3.1, showed that the MAR's for the gauged basins are higher than the MAR of the Lower Churchill River. This suggests that the reference streamflow sequence used for the Lower Churchill River may be underestimating flow.

This comparison is provided for information only, since it was not in the scope of work of this study to update the hydrology. This question may be addressed separately.

**Table 3.1**

### **Mean Annual Runoff (MAR) for Churchill River and Adjacent Hydrometric Stations**

<b>Basin</b>	<b>Drainage Area (km<sup>2</sup>)</b>	<b>Average Flow Jan 85-Dec 95 (m<sup>3</sup>/s)</b>	<b>MAR (mm)</b>
Smallwood local Inflow*	45,110	795.0	556
Gull Island local Inflow*	19,832	335.0	533
Minipi River Below Minipi Lake	2,330	51.5	698
Naskaupi River Below Naskaupi Lake	4,480	79.6	561
Little Mecatina River Above Lac Fourmont	4,540	83.6	581
Churchill River Above Upper Muskrat Falls**	92,500	1651.0	563

\*Flows were taken from Gull Island Power Development Report (October 1997). Others are Environment Canada Hydrometric Stations.

\*\*1989 is missing from this record, but it is just slightly above average. MAR could be expected to be a few millimetres higher.

## **Churchill River Model Setup**

## 4 Churchill River Model Setup

This section of the report gives a detailed description of the model setup of the Churchill River system. The ARSP model was used to evaluate the existing and proposed energy generation. ARSP uses a simplified network of channels, reservoirs, nodes (connecting points for channels), structures, and power stations to represent a water system. A detailed description of the ARSP program is provided in Appendix C.

The following section describes the model setup, the physical data used in the model, and the calibration of the model.

### 4.1 Model Representation

In general, the model for the Churchill River system takes monthly inflows and uses the water to first satisfy fishery demands (where required) and then to generate energy, based on various physical and operational constraints. The portion of the inflow not used for energy generation is either stored or spilled.

The input data required to set up the model include

- representative inflow sequences;
- reservoir characteristics;
- power station characteristics;
- structure data; and
- operational data.

The representative inflow sequences have been described in Section 3. The remaining input data are discussed in the following sections. A model schematic of the Churchill River system, including both existing and potential generation facilities and diversions, is presented in Figure 4.1.

The approach to setting up the model was as follows.

- Review existing information.
- Set up power and energy model using input data from previous study.
- Match previous power and energy results.
- Update model to include all physical characteristics of system.
- Calibrate model to existing data.

- Discuss results with NLH staff.
- Update model input based on calibration results and comments from NLH staff.
- Determine preliminary firm and average energy for Churchill River system.
- Present and discuss results with NLH.
- Update model based on discussions with NLH.

## 4.2 Comparison with Previous Energy Results

The most recent previous estimates of the existing and potential energy generation of the Churchill River system are summarized in the Gull Island Power Development Report (October 1997). This report estimated the existing energy of the Churchill Falls facility and the potential energy generation if Gull Island and Muskrat Falls were added to the system. The three cases investigated were

- Churchill Falls existing;
- Churchill Falls existing plus Gull Island; and
- Churchill Falls existing plus Gull Island plus Muskrat Falls.

The appendices to the report provided echoes of the input data used to estimate the power and energy. This information was input to ARSP and reworked where required to match the input requirements of ARSP. The ARSP model of the three cases was then run using the same input parameters, and the results were compared.

Table 4.1 shows that both models, when using similar input data and run for the same firm energy, produce similar results, as expected. The slight difference in the energy values can be attributed to the different manner in which the two models handle the power plant characteristics.

In developing the ARSP model and reviewing the input variables, it became evident that additional information could be usefully incorporated in this study. Ossokmanuan control structure was added, structure discharge curves were specified for all structures, and the East and West Forebays were modeled separately.

Modeling all structures and structure curves is more important when the diversions are included to ensure that no structure is limiting or acting as a control in the system.

## 4.3 Physical Data for Model Calibration

The physical data used for the model calibration and subsequent model setups of potential energy generation were derived from the following sources.

- CF(L)Co correspondence, storage curves (November 1996), structure curves, and recorded site data (May 1985 to April 1997).
- Gull Island Power Development Report - Volumes 1 and 2 (October 1997).
- Churchill River Complex Energy Studies Final Report - Volume 1 (January 1991).
- Flood Handling Study of the Churchill Falls System (March 1989).
- Hydro-Québec Presentation Notes (September 1997 and February 1998).

In general, CF(L)Co data were used for input values to the model. In the case where there were no CF(L)Co data on file, the Gull Island Power Development Report - Volumes 1 and 2 (October 1997), Flood Handling Study Report (March 1989), and Churchill River Complex Energy Report (January 1991) were used to derive the required input values.

### 4.3.1 Reservoir Characteristics

As previously noted, the existing Churchill River system consists of two storage reservoirs and two forebays. These include Ossokmanuan and Smallwood Reservoirs, and West and East Forebays. CF(L)Co has developed and updated storage curves for the reservoirs and forebays; the most recent curves are presented in Appendix D. These curves were used to represent the storage in the model. Key reservoir elevations, such as full supply level, dead storage level, and surcharge level, were taken from both CF(L)Co data and the Flood Handling Study Report (March 1989).

Smallwood Reservoir consists of three reservoirs - Hook Bay, Orma Lake, and Lobstick. At low levels, the reservoir is separated into three separate reservoirs connected by channels. For the purpose of modeling, the Smallwood Reservoir was modeled as one reservoir, but the storage curve accounted for reduced storage at low levels. The difference in levels due to the hydraulic connections was not modeled. It would be possible to model the three reservoirs separately if the channel characteristics were known for the channels connecting the reservoirs.

For the run-of-the-river projects at Gull Island and Muskrat Falls, it was assumed that the reservoirs remain at a constant level on a monthly time step. For the purpose of this study, the information on storage curves and reservoir levels was taken from the Gull Island Power Development Report (October 1997) and the Churchill River Complex Energy Report (January 1991), and this data was used in the current modeling.

The only information available for the diversions was Hydro-Québec Presentation Notes (September 1997 and February 1998). Storage is provided at the Romaine River diversion only.

Key reservoir features, storage curves, and reservoir levels are presented in Tables 4.2 and 4.3 for the Upper and Lower Churchill River system and the diversions.

#### **4.3.2 Power Station Characteristics**

Power station characteristics were required for the following stations.

- Churchill Falls Existing Station.
- Lobstick Structure Proposed Power Station.
- Proposed Additional Capacity at Churchill Falls Station.
- Gull Island Proposed Station.
- Muskrat Falls Proposed Station.

Power station characteristics for Churchill Falls, Gull Island and Muskrat Falls were taken from the Gull Island Power Development Report (October 1997).

Characteristics for the proposed Lobstick station were taken from the Churchill River Complex Energy Report (January 1991) and were used with minor adjustments.

Power plant characteristics for CF2 were derived from Hydro-Québec presentation notes (February 1998) and information on the existing station.

Plant characteristics used in the final setup of ARSP are presented in Table 4.4. Table 4.5 presents the tailwater curves for each station. As shown in this table, the tailwater curves for Churchill Falls (and CF2) and Gull Island differ depending on the development of downstream power stations. In general,

Churchill Falls tailwater is affected by the development of Gull Island, and Gull Island tailwater is affected by the development of Muskrat Falls.

In addition to these plant characteristics, the model also requires the available capacity of the stations (availability curve) and the demand pattern for the system.

These two items are discussed below.

### **Availability Curve**

Due to higher water temperatures in the river, the availability of the power stations is reduced in the summer. The availability curve used in previous work suggested that the available capacity varied from a maximum of 5,460 MW to a minimum of 4,833 MW. CF(L)Co staff noted, however, that the maximum continuous summer availability of the plant is 5,100 MW and the maximum continuous winter availability of the plant is 5,600 MW. Although one or two units would generally be down in the summer for scheduled maintenance, if water were available in the summer that would otherwise be spilled, CF(L)Co would postpone the maintenance. Using this information from CF(L)Co, an availability curve was developed in consultation with NLH. This curve assumes 5,600 MW is available in winter (December to April) and 5,100 MW in summer (June to October). Availability in November and May was taken as 5,350 MW, the average of winter and summer availability.

This same pattern of availability was used for each of the proposed new systems, except for CF2. For these units, it was assumed that the availability throughout the year would be 100 percent, except in April. It was assumed that each unit would be down for 2 weeks maintenance in April, and availability would then be 50 percent.

The availability curves used in this study and the Gull Island Power Development Report (October, 1997) are presented in Figure 4.2.

### **Demand Pattern**

Energy loads on the existing and potential system originate from four points. These include

- Labrador;
- station site services and Twin Falls loads;

- Québec; and
- HVDC infeed to the island.

Demand patterns, as provided by NLH (Appendix E) for year 2008, were reviewed and compared with demand patterns used in the Gull Island Power Development Report (October 1997). This comparison showed that the demand pattern provided by NLH when combined with Hydro-Québec loads was similar to the pattern used for previous work. Therefore, the demand pattern used in the Gull Island Power Development Report (October 1997) was used for this study. The resulting monthly demand factors, defined as the ratio of the energy demand during the month to the total annual energy demand are presented in Table 4.6. These are shown as ratios of both GWh and MWc.

#### **4.3.3 Structure Data**

Structure curves (stage/discharge curves) were required for the following water control structures.

##### **Upper Churchill**

- Ossokmanuan Control Structure (Spillway)
- Gabbro Control Structure
- Lobstick Control Structure
- Whitefish Control Structure
- Jacopie Control Structure
- East Forebay Spillway

##### **Lower Churchill**

- Gull Island Spillway
- Muskrat Falls Spillway

##### **Diversions from Québec**

- Romaine Spillway
- Atikona Control Structure

For the Upper Churchill Falls development, structure curves and tables were provided by CF(L)Co for the main water control structures at Gabbro, Lobstick and Whitefish (Appendix F). For the remaining structures in the system, curves were taken from the Flood Handling Study (March 1989).

For the Lower Churchill developments, the data were taken from the Gull Island Power Development Study (October 1997). This study did not incorporate structure curves and assumed any flow not used to generate power would be spilled. This assumes that the spillway capacity would be adequately designed to pass any flows above the maximum power flow. For the purpose of this study, this assumption was taken to be adequate and to have no effect on the determination of energy generation. As can be seen in Table 4.7, a large arbitrary spillway capacity was given for Gull Island and Muskrat Falls to ensure that spillway capacity would not be limiting.

For the diversions, the data available was limited to the presentation notes. The maximum spill capacity of the Romaine structure provided in these notes was used as the maximum capacity of the Romaine spillway. This number on a monthly time step would not be exceeded; therefore, the spillway capacity was assumed to be adequate for the spill structure. A control structure located at Atikonak Lake would regulate the flow from the diversions to Ossokmanuan Reservoir.

Table 4.7 summarizes the structure curves used in the model for all the structures in the existing and proposed systems.

#### **4.3.4 System Operation**

The model maximizes firm energy production using the power plant characteristics as defined. However, to ensure maximum energy conversion at Churchill Falls, the new units are assumed to be loaded before the existing units. Also, when fishery demands are imposed on the system, as is required for the diversion, these demands are met before energy generation.

The definition of firm energy used for this study is the maximum average energy that can be produced during the most severe dry sequence of the hydrological record. The dry sequence begins after the last period when secondary energy was generated and ends when the reservoirs are just empty.

After fishery and power generation demands are satisfied, the remaining water in the system is either stored in the reservoirs, depending on operational rule curves, or spilled if all reservoirs are at maximum operating level and the plant is at maximum output.

The rule curve for Smallwood Reservoir was taken from the Gull Island Power Development Report (1997). For Ossokmanuan Reservoir and the forebays, rule curves were developed from actual water levels provided by CF(L)Co. The management rule curves of each of the reservoirs is described below.

- **Ossokmanuan Reservoir**

Reservoir drawdown begins in mid-February to allow for spring runoff. During spring runoff, the reservoir is allowed to fill. Excess water in Ossokmanuan Reservoir is passed to Smallwood Reservoir. If there is no storage available downstream, or if there is insufficient capacity at Gabbro, or if the plant is at maximum output, the excess water is spilled.

- **Smallwood Reservoir**

Smallwood Reservoir is operated to meet firm demand. If the reservoir is at the rule curve, excess water is used to generate secondary energy, up to the maximum plant output. Any additional water is spilled at Jacopie.

- **West Forebay**

During winter, the levels in the West Forebay are kept high and constant to maintain ice cover; otherwise, ice jamming could occur upstream of the Whitefish Falls control structure. During summer, the levels are kept low to allow for storage of excess flow.

- **East Forebay**

The East Forebay level is allowed to fluctuate depending on energy demands. There are no specific operational constraints on the East Forebay, except that full supply level is not exceeded.

Since the Lower Churchill developments are run-of-the-river, reservoir management is more straightforward than at the Upper Churchill development. Gull Island and Muskrat Falls headpond levels are kept constant (on a monthly time step) and any flow above maximum power flow is spilled.

The Romaine reservoir was assumed to be operated to provide water for firm energy if the Upper Churchill reservoirs are below their rule curves, water was also released to bring them to their rule curves. Water will also be released to generate secondary energy. If water levels in Romaine and St. Jean reservoirs are above the maximum allowable levels, and the Upper Churchill reservoirs are at

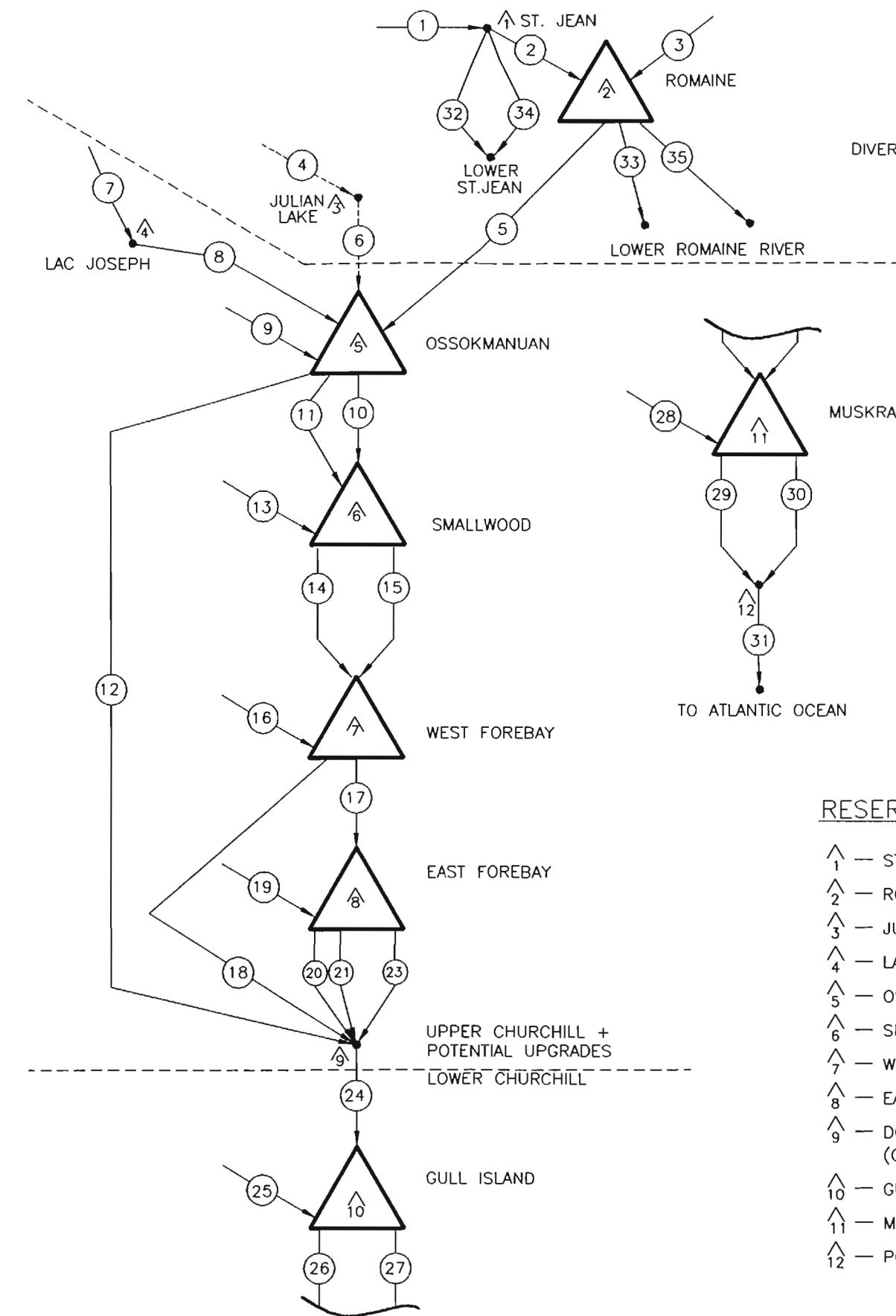
or above their rule curves, and the plant is generating at maximum output, excess flows from the Romaine and St. Jean reservoirs will be spilled.

For the fishery releases, ten percent of the mean local inflow to St. Jean and Romaine Rivers above the diversions is passed downstream. This demand must be met before any system demands or constraints are imposed. Table 4.8 summarizes the monthly fishery releases assumed for both the St. Jean and Romaine Rivers.

#### **4.4 Model Calibration with Existing Data 1995-1997**

In order to ensure that all the above physical characteristics represent the existing system, historical data were used to calibrate the model. For the period May 1995 to April 1997, the model was run to match the recorded power flow. Simulated water levels and generation were reviewed to ensure that the model accurately estimated operation and flow releases.

The initial model run slightly over-estimated the power generation of the system, and the plant efficiency in the model was reduced by 1.5 percent (the difference in historical and simulated energy). With this change in input data, results agreed with recorded data. This model setup of the existing Churchill Falls plant was used in all further runs for existing and proposed developments.



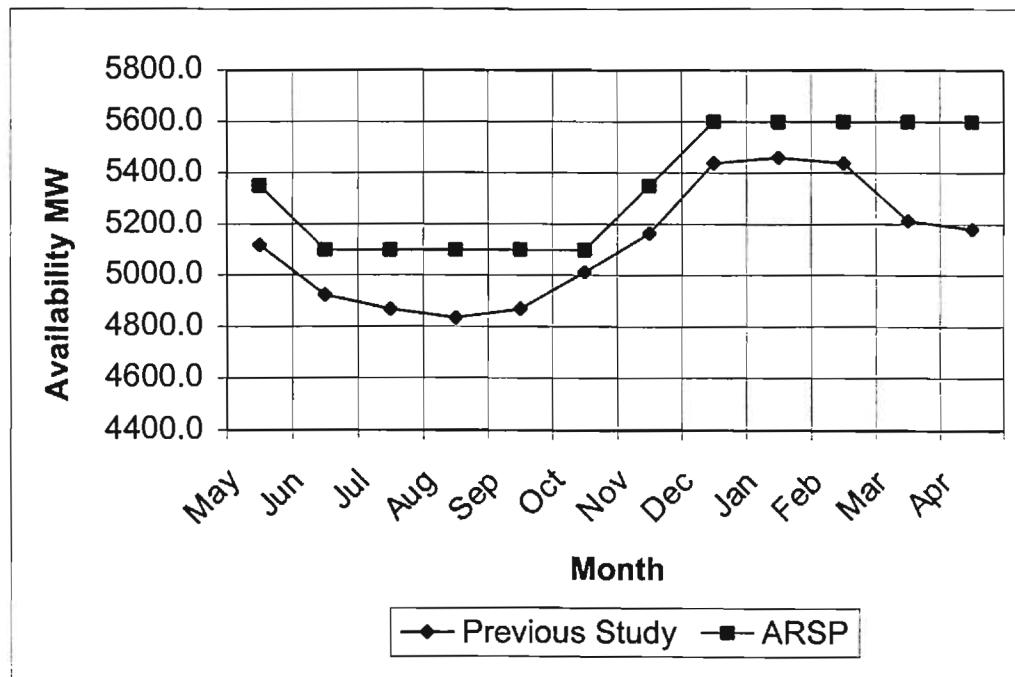
NOTE: JULIAN LAKE INCLUDED IN MODEL FOR POTENTIAL DEVELOPMENTS, NOT USED IN CURRENT MODEL SIMULATIONS.

FIG 4.1  
NEWFOUNDLAND AND LABRADOR HYDRO  
CHURCHILL RIVER COMPLEX  
POWER AND ENERGY MODELING

MODEL SCHEMATIC - CHURCHILL RIVER SYSTEM



Month	Availability	
	Previous Study	ARSP Model
May	5118.4	5350.0
Jun	4922.4	5100.0
Jul	4866.4	5100.0
Aug	4832.8	5100.0
Sep	4866.4	5100.0
Oct	5012.0	5100.0
Nov	5163.2	5350.0
Dec	5437.6	5600.0
Jan	5460.0	5600.0
Feb	5437.6	5600.0
Mar	5213.6	5600.0
Apr	5180.0	5600.0



**Table 4.1****Comparison with Previous Energy Results**

Case	Average Annual Energy		
	Previous Model (TWh/yr)	ARSP Model (TWh/yr)	Percent Difference (%)
1) Match Existing Churchill Falls			
-Churchill Falls	33.74	33.82	0.2
2) Match Existing Churchill Falls + Gull			
-Churchill Falls	33.56	33.59	0.1
-Gull Island	11.85	11.84	-0.1
-Total	45.41	45.43	0.0
3) Match Existing Churchill Falls + Gull + Muskrat			
-Churchill Falls	33.53	33.36	-0.5
-Gull Island	11.62	11.78	1.4
-Muskrat Falls	4.82	4.75	-1.4
-Total	49.97	49.89	-0.2

**Note:**

- Previous average annual energies were taken from the Gull Island Power Development Study (October 1997).

**Table 4.2****Key Reservoir Features**

<b>Basin</b>	<b>Reservoir/ Forebay</b>	<b>Full Supply Level (m)</b>	<b>Low Supply Level (m)</b>	<b>Live Storage Volume (*10^6 m^3)</b>
Diversions from the Province of Quebec	Romaine River Diversion Headpond	500.00	497.00	4000
Upper Churchill	Ossokmanuan Reservoir	479.15	475.03	2835
	Smallwood Reservoir	472.74	464.05	28946
	West Forebay	452.93	451.00	141
	East Forebay	448.51	447.60	121
Lower Churchill	*Gull Island Reservoir	125.00	122.00	550
	*Muskrat Falls Reservoir	39.00	39.00	0

Sources: Gull Island Power Development Report (October 1997)

CF(L)Co. Storage Curves (November 1996)

Hydro-Quebec Presentation Notes (February 1998)

Flood Handling Study Report (March 1989)

**Table 4.3****Reservoir Storage Curves**

<b>Ossokmanuan Reservoir</b>		<b>Smallwood Reservoir</b>	
<b>Elev. (m)</b>	<b>Storage (*10^6 m^3)</b>	<b>Elev. (m)</b>	<b>Storage (*10^6 m^3)</b>
475.03	0	464.05	0
476.00	586	467.10	2618
478.00	1923	469.00	10375
478.75	2490	470.50	17185
479.00	2701	471.50	22135
479.50	3176	472.50	27551
479.99	3734	473.04	30756

Source: CF(L)Co. (November 1996) Source: CF(L)Co. (November 1996)

<b>West Forebay</b>		<b>East Forebay</b>	
<b>Elev. (m)</b>	<b>Storage (*10^6 m^3)</b>	<b>Elev. (m)</b>	<b>Storage (*10^6 m^3)</b>
445.00	0	443.80	0
445.50	7	445.00	124
446.00	13	447.10	370
447.00	31	448.70	580
448.00	54	448.99	621
449.00	83		
450.00	120		
451.00	167		
452.00	231		
452.93	309		
452.99	315		

Source: CF(L)Co. (November 1996)

Source: CF(L)Co. (November 1996)

<b>Gull Island</b>		<b>Muskrat Falls</b>	
<b>Elev. (m)</b>	<b>Storage (*10^6 m^3)</b>	<b>Elev. (m)</b>	<b>Storage (*10^6 m^3)</b>
119.00	3200	39.00	0
122.00	3750	39.50	0
125.00	4300		

Source: Gull Island Power Development Report (October 1997)

<b>Romaine Headpond</b>	
<b>Elev. (m)</b>	<b>Storage (*10^6 m^3)</b>
497.00	0
500.00	4000

Source: Hydro-Quebec presentation Notes (February 1998)

**Table 4.4****Power Plant Characteristics**

Power Plant Characteristics	Stations				
	Lobstick	Churchill Falls	Churchill Falls New	Gull Island	Muskrat Falls
Installed Capacity (MW)	160	5600	1000	2264	824
Maximum Flow ( $m^3/s$ )	2020	1996	390	3055	2806
Best Efficiency Flow ( $m^3/s$ )	1618	1760	354	2752	2610
Efficiency @ Max Flow (%)	83.2	89.7	92.2	90.6	88.6
Efficiency @ Best Flow (%)	87.6	90.8	NR	92.2	90.9
Design Net Head (m)	9.7	312.4	312.4	85.6	34.4
Head Loss (m)	0.18	0.00	0.00	1.39	1.09

NR - Not Required (Unit Base loaded); See Section 4.3.2 for Sources of information

**Table 4.5****Tailwater Curves**

Lobstick Station		Churchill Falls and CF2 without Gull		Churchill Falls and CF2 with Gull	
Tailwater (m)	Discharge ( $m^3/s$ )	Tailwater (m)	Discharge ( $m^3/s$ )	Tailwater (m)	Discharge ( $m^3/s$ )
458.42	0	124.10	0	125.00	0
459.24	283	124.60	400	125.30	400
459.73	566	124.80	600	125.50	600
460.14	850	125.10	800	125.80	800
460.50	1133	125.50	1000	126.10	1000
460.82	1416	125.90	1200	126.40	1200
461.11	1700	126.70	1600	127.10	1600
461.38	1982	127.50	2000	127.80	2000
461.62	2265	129.10	2800	129.10	2800
462.09	2832				
463.69	5653				

Gull Island without Muskrat Falls		Gull Island with Muskrat Falls		Muskrat Falls	
Tailwater (m)	Discharge ( $m^3/s$ )	Tailwater (m)	Discharge ( $m^3/s$ )	Tailwater (m)	Discharge ( $m^3/s$ )
35.90	0	39.00	0	1.90	0
36.50	500	39.01	283	1.98	566
36.90	1000	39.03	566	3.44	2515
37.30	1500	39.07	850	3.80	3000
37.60	2000	39.09	1133		
37.90	2500	39.19	1699		
38.20	3000	39.32	2265		
38.80	4000	39.48	2832		
39.30	5000	40.37	5663		
39.80	6000				

Sources: Gull Island Power Development Report (October 1997)

and Churchill River Complex Energy Report (January 1991)

**Table 4.6****Monthly Demand Fraction**

Month	Demand Fraction	
	MW/MWc	GWh/GWh/yr
May	0.9073	0.0771
Jun.	0.8816	0.0725
Jul.	0.8767	0.0745
Aug.	0.8861	0.0753
Sep.	0.8828	0.0726
Oct.	0.9320	0.0792
Nov.	1.0458	0.0860
Dec.	1.1450	0.0973
Jan	1.2027	0.1022
Feb.	1.1687	0.0897
Mar	1.0838	0.0921
Apr.	0.9910	0.0815

Source: Gull Island Power Development Report (October 1997)

Note:

- ARSP model requires demand fraction with respect to power (MW/MWc). Therefore, numbers provided in Gull Island Power Development Report (GWh/GWh/yr) were converted.

**Table 4.7****Structure Discharge Curves**

Gabbro Control Structure		Lobstick Control Structure		Whitefish Control Structure	
Elev. (m)	Discharge (m^3/s)	Elev. (m)	Discharge (m^3/s)	Elev. (m)	Discharge (m^3/s)
472.90	0.00	457.20	0.00	448.00	0.00
473.35	169.90	463.30	2124.00	448.50	1077.00
473.96	339.80	466.34	3330.00	449.00	1518.00
474.88	566.30	469.39	4604.00	449.60	1905.00
476.40	1076.00	470.92	5326.00	451.10	2601.00
477.32	1415.80	472.44	6133.00	451.40	2718.00
478.54	1868.90	472.74	6329.00	451.70	2826.00
479.76	2491.90	473.96	7127.00	452.00	2937.00
				452.30	3045.00
				452.60	3153.00
				452.90	3258.00
				453.50	3459.00

Source: CF(L)Co.

**Table 4.7 (con't)****Structure Discharge Curves**

Flow Over Gabbro Control Structure*		Ossokmanuan Control Structure*		Jacopie Spillway*	
Elev. (m)	Discharge (m <sup>3</sup> /s)	Elev. (m)	Discharge (m <sup>3</sup> /s)	Elev. (m)	Discharge (m <sup>3</sup> /s)
472.90	0.0	474.20	0.0	440.90	0.0
479.76	0.0	475.50	311.0	445.00	1764.0
479.91	5.9	476.30	623.0	446.50	2307.0
480.06	16.8	477.00	962.0	448.10	2904.0
480.36	47.5	477.80	1472.0	449.60	3557.0
480.67	87.3	478.50	2066.0	451.10	4269.0
480.97	134.5	479.15	2348.0	452.63	5045.0
481.28	160.5	480.50	3679.0	454.15	5888.0
				455.00	6359.4

Gull Island Spillway**		Muskrat Falls Spillway**		Romaine Spillway***	
Elev. (m)	Discharge (m <sup>3</sup> /s)	Elev. (m)	Discharge (m <sup>3</sup> /s)	Elev. (m)	Discharge (m <sup>3</sup> /s)
115.00	10000.0	35.00	10000.0	485.30	2410.0
125.00	10000.0	45.00	10000.0	520.00	2410.0

East Forebay Spillway*		Atikonaak Control Structure***	
Elev. (m)	Discharge (m <sup>3</sup> /s)	Elev. (m)	Discharge (m <sup>3</sup> /s)
436.47	0.0	490.00	0.0
438.90	169.9	497.00	335.0
440.40	396.4	500.00	680.0
441.96	736.2		
443.50	1189.3		
445.00	1699.0		
446.50	2265.4		
448.06	2718.4		
448.67	2973.3		
449.28	3199.8		

Source: \*Flood Handling Study (March 1989)

\*\*Gull Island Power Development Report (October 1997)

\*\*\*Hydro-Quebec Presentation Notes (February 1998)

**Table 4.8****Monthly Fishery Releases**

Month	Monthly Fishery Release (m^3/s)	
	St. Jean River	Romaine River
May	4.6	29.4
Jun.	8.8	56.7
Jul.	4.8	30.6
Aug.	3.1	20.1
Sep.	2.8	18.1
Oct.	3.0	19.3
Nov.	2.3	14.8
Dec.	1.6	10.1
Jan.	1.1	7.0
Feb.	0.8	4.9
Mar.	0.8	4.9
Apr.	1.1	6.7
Average	2.9	18.6

Note:

- Fishery release equal to 10 percent mean monthly flow

## Model Results

## 5 Model Results

This section of the report presents the firm and average energy results of each model run for the existing and potential Churchill River developments. Detailed input and output for each of the model setups are provided in Volumes 2 and 3 as follows.

- **Volume 2:**

ARSP model input and output, including summary of system production and energy distribution, and available energy for sale at Québec-Labrador border for Run 1 to Run 4.

- **Volume 3:**

ARSP model input and output, including summary of system production and energy distribution, and available energy for sale at Québec-Labrador border for Run 5 to Run 8.

### 5.1 Required Model Setups

The following model setups defined by NLH were required for this study.

- Churchill Falls Existing (CF1) (Run 1)
- CF1 plus Gull Island (Run 2)
- CF1 plus Gull Island plus Muskrat Falls (Run 3)
- CF1 plus New Units at Churchill Falls (CF2) plus Diversions (New CF) (Run 4)
- New CF plus Gull Island (Run 5)
- New CF plus Gull Island plus Muskrat Falls (Run 6)
- New CF plus Gull Island plus Lobstick (Run 7)
- New CF plus Gull Island plus Lobstick plus Muskrat Falls (Run 8)

## 5.2 Results of Churchill River System Modeling

Table 5.1 summarizes the incremental average and firm energy for Runs 1 to 8. Model results for Runs 1 to 3 are summarized in Table 5.2 and model results for Runs 4 to 8 are summarized in Table 5.3.

## 5.3 Comparison with Previous Results

Table 5.4 compares the ARSP model results with previous energy results. There is good agreement between the total energy results of this model and the previous work. The differences are due to the inclusion of additional data provided by and agreed upon with NLH and CF(L)Co, as well as harmonized inflows.

## 5.4 Sensitivities

The following sensitivity runs were carried out to determine the effect of varying the following variables on energy output.

- Three additional installed capacities at Muskrat Falls.
- Maximizing firm energy.
- Maximizing average annual energy.
- No fishery release from Romaine.
- Reduced period of record for inflow sequences.
- Diversion inflow sequence.
- Romaine storage curve and Atikona Lake control structure.

Each of these is discussed below and the results of the analysis are summarized in Table 5.5, which also shows the base case results.

### Muskrat Falls Installed Capacity

In the original model runs which included Muskrat Falls, it was noticed that the spill from the plant was significantly larger than from Gull Island. The Muskrat Falls installed capacity was increased and the corresponding energy determined. For this sensitivity, the case including CF1, Gull Island, and Muskrat Falls (Run 3) was used for comparison. For the largest installed capacity, (950 MW) the average energy increased by approximately 0.2 percent over the base case.

### **Maximizing Firm Energy**

In order to maximize the firm energy of the existing system, each reservoir was kept at full supply level. Although this is not the normal operation of the system and would result in increased spill, it indicates the upper limit of firm energy available from the system. This was performed for only the existing Churchill River case (Run 1). The maximum firm energy of the system is approximately one percent higher over the base case firm energy.

### **Maximizing Average Annual Energy**

To maximize average annual energy, no firm energy requirement was imposed. The reservoirs in the system were kept low. This rule ensures that storage is not used to protect firm, and spill is minimized. The result indicates the upper limit of average annual energy available for the existing system. This was performed for only the existing Churchill River case (Run 1). The maximum average annual energy of the system is approximately 0.3 percent higher over the base case average annual energy.

### **No Fishery Release from Romaine**

To indicate the energy lost through the release of water to the Lower Romaine for fish, the model was run assuming no release of water to the Lower Romaine River. For this sensitivity, the case including CF1 and CF2 and the diversions (Run 4) was used for comparison. This resulted in the average annual energy being approximately one percent higher than the base case.

### **Reduced Period of Record for Inflow Sequences**

To determine the difference in energy of shortening the inflow sequence to start the same year that the hydrometric station located at Muskrat Falls on the Churchill River began recording continuous flow, the inflow sequences were reduced from 54 years to 43 years. A review of the hydrometric station data indicated that the gauge started recording continuous flow in 1954. Therefore, the model inflow sequence was changed to begin in May 1954. For this sensitivity, the case including CF1, Gull Island, and Muskrat Falls (Run 3) was used for comparison. This increased the average annual energy by approximately one percent over the base case.

### **Diversion Inflow Sequence**

As previously discussed in Section 3.2, for the diversions from Québec the Ossokmanuan inflow sequence was prorated based on average flow. Hydro-Québec provided an inflow sequence which included local inflow from St. Jean

and Romaine, and included fisheries releases. For this sensitivity, the case including CF1 and CF2, and the diversions (Run 4) was used for comparison. The average annual energy was increased by approximately 0.2 percent over the base case.

#### **Romaine Storage Curve and Atikonak Lake Control Structure**

Hydro-Québec provided the Romaine headpond storage curve and Atikonak Lake, which were values not available during model setup and runs. To determine the effect of these changes on the results, the case including CF1, CF2, and the diversions (Run 4) was used for comparison. The average annual energy was decreased by approximately 0.1 percent over the base case.

**Table 5.1****Incremental Average and Firm Energy Above Existing Case (Run 1)**

<b>Model Setups</b>	<b>Installed Capacity (MW)</b>	<b>Firm Energy (TWh/yr)</b>	<b>Average Energy (TWh/yr)</b>	<b>Incremental Firm Energy (TWh/yr)</b>	<b>Incremental Avg Energy (TWh/yr)</b>
Existing (CF1) (Run 1)	5600	31.37	34.50	-	-
CF1 + Gull (Run 2)	7864	42.16	46.28	10.79	11.78
CF1 + Gull + Muskrat (Run 3)	8688	46.24	50.69	14.87	16.19
Diversions + CF1 + CF2 (New CF) (Run 4)	6600	36.00	39.42	4.63	4.92
New CF + Gull (Run 5)	8864	47.91	52.42	16.54	17.92
New CF + Gull + Muskrat (Run 6)	9688	52.40	57.19	21.03	22.69
New CF + Gull + Lobstick (Run 7)	9024	48.80	53.50	17.43	19.00
New CF + Gull + Lobstick + Muskrat (Run 8)	9848	53.29	58.28	21.92	23.78

**Table 5.2****Model Results - Run 1 to Run 3**

<b>Model Setups</b>	<b>Installed Capacity (MW)</b>	<b>Firm Energy (TWh/yr)</b>	<b>Average Energy (TWh/yr)</b>	<b>Incremental Avg Energy (TWh/yr)</b>	<b>Spill (m^3/s)</b>	<b>Incremental Spill (m^3/s)</b>	<b>Energy Eqv. of Spill (GWh/yr)</b>
Existing (CF1) (Run1)							
-CF1	5600	31.37	34.50	-	15.8	-	397.2
CF1 + Gull (Run2)							
-CF1	5600		34.30	-0.19	21.8	6.0	546.9
-Gull Island	2264		11.98	-	14.7	-	100.1
-Total	7864	42.16	46.28	11.78	36.5	20.7	647.0
CF1 + Gull + Muskrat (Run3)							
-CF1	5600	now 2264 824	34.24	-0.07	24.4	2.5	610.5
-Gull Island	2264		11.54	-0.44	13.4	-1.2	88.3
-Muskrat Falls	824		4.91	-	31.9	-	86.8
-Total	8688		50.69	16.19	69.7	53.8	785.6

Note:

- For total average energy, incremental average energy is the difference over the existing case (Run 1).
- For individual plant energy, incremental average energy is the difference over the previous run.
- Incremental spill is calculated the same as incremental average energy.
- Energy generation is energy at bus before losses and load demands.

**Table 5.3****Model Results - Run 4 to Run 8**

Model Setups	Installed Capacity (MW)	Firm Energy (TWh/yr)	Average Energy (TWh/yr)	Incremental Avg Energy (TWh/yr)	Spill (m^3/s)	Incremental Spill (m^3/s)	Energy Eqv. of Spill (GWh/yr)
Diversions + CF1 + CF2 (New CF) (Run 4)							
-CF1	5600		31.02	-	16.5	-	413.2
-CF2	1000		8.40	-	-	-	-
-Total	6600	36.00	39.42	-	16.5	-	413.2
New CF + Gull (Run 5)							
-CF1	5600		30.81	-0.21	13.3	-3.2	332.7
-CF2	1000		8.40	0.00	-	0.0	-
-Gull Island	2264		13.21	-	14.9	-	101.6
-Total	8864	47.91	52.42	13.00	28.2	11.7	434.2
New CF + Gull + Muskrat (Run 6)							
-CF1	5600		30.71	-0.10	13.8	0.5	346.3
-CF2	1000		8.40	0.00	-	0.0	-
-Gull Island	2264		12.72	-0.49	12.9	-2.0	84.9
-Muskrat Falls	824		5.36	-	39.5	-	107.4
-Total	9688	52.40	57.19	17.77	66.3	49.8	538.6
New CF + Gull + Lobstick (Run 7)							
-Lobstick	160		1.09	-	78.6	-	58.6
-CF1	5600		30.80	0.09	13.4	-0.4	335.2
-CF2	1000		8.40	0.00	-	0.0	-
-Gull Island	2264		13.21	0.49	15.1	2.1	102.7
-Total	9024	48.80	53.50	14.08	107.1	90.6	496.5
New CF + Gull + Lobstick + Muskrat (Run 8)							
-Lobstick	160		1.09	0.00	81.1	2.5	60.6
-CF1	5600		30.71	-0.09	13.8	0.4	345.8
-CF2	1000		8.40	0.00	-	0.0	-
-Gull Island	2264		12.72	-0.49	12.9	-2.1	84.9
-Muskrat Falls	824		5.36	-	39.8	-	108.2
-Total	9848	53.29	58.28	18.86	147.7	131.2	599.6

Note: - Notes as per Table 5.2, exceptions follow.  
 - For total average energy, incremental average energy is the difference over Run 4.  
 - Energy generation is energy at bus before losses and load demands.

**Table 5.4****Comparison of Model Results**

<b>Model Setups</b>	<b>1997 Estimated Energy (TWh/yr)</b>	<b>1998 Estimated Energy (TWh/yr)</b>	<b>Percent Difference (%)</b>
Existing (CF1) (Run 1)			
-CF1	33.74 *	34.50	2.3
CF1 + Gull (Run 2)			
-CF1	33.56 *	34.30	2.2
-Gull Island	11.85 *	11.98	1.1
-Total	45.41 *	46.28	1.9
CF1 + Gull + Muskrat (Run 3)			
-CF1	33.53 *	34.24	2.1
-Gull Island	11.62 *	11.54	-0.6
-Muskrat Falls	4.82 *	4.91	1.8
-Total	49.97 *	50.69	1.4
Diversions + CF1 + CF2 (New CF) (Run 4)			
-CF1	-	31.02	-
-CF2	-	8.40	-
-Total	38.83 **	39.42	1.5
New CF + Gull (Run 5)			
-CF1+CF2	38.76 **	39.21	1.2
-Gull Island	12.92 **	13.21	2.2
- Total	51.68 **	52.42	1.4

\* Gull Island Power Development Report (October 1997)

\*\* Hydro-Quebec Presentation Notes (February 1998)

**Table 5.5****Results of Sensitivities**

Sensitivity	Installed Capacity (MW)	Firm Energy (TWh/yr)	Average Annual Energy		Difference in Energy (TWh/yr)
			Sensitivity (TWh/yr)	*Base Case (TWh/yr)	
Sensitivity to Muskrat IC					
-CF1	5600		34.24	34.24	0.00
-Gull Island	2264		11.54	11.54	0.00
-Muskrat Falls	830		4.91	4.91	0.00
-Total	8694	46.24	50.69	50.69	0.00
Sensitivity to Muskrat IC					
-CF1	5600		34.24	34.24	0.00
-Gull Island	2264		11.54	11.54	0.00
-Muskrat Falls	850		4.92	4.91	0.01
-Total	8714	46.24	50.71	50.69	0.02
Sensitivity to Muskrat IC					
-CF1	5600		34.29	34.24	0.05
-Gull Island	2264		11.55	11.54	0.01
-Muskrat Falls	950		4.96	4.91	0.05
-Total	8814	46.24	50.80	50.69	0.11
Sensitivity to Average Annual Energy					
-CF1	5600	-	34.61	34.50	0.11
Maximize Average Annual Energy					
Sensitivity to Firm Energy					
-CF1	5600	31.69	33.72	34.50	-0.78
Maximize Firm Energy					
Sensitivity to Romaine Fishery Release					
-CF1	5600		31.44	31.02	0.42
-CF2	1000		8.40	8.40	0.00
- Total	6600	36.50	39.84	39.42	0.42
Sensitivity to Length of Inf. Sequence					
-CF1	5600		34.60	34.24	0.36
-Gull Island	2264		11.67	11.54	0.13
-Muskrat Falls	824		4.96	4.91	0.05
-Total	8688	46.24	51.23	50.69	0.54
Sensitivity to Diversion Inf. Sequence					
-CF1	5600		31.08	31.02	0.06
-CF2	1000		8.4	8.40	0.00
- Total	6600	35.64	39.48	39.42	0.06
Sensitivity to Romaine Storage and Atikonak Lake Structure Curve					
-CF1	5600		30.99	31.02	-0.03
-CF2	1000		8.4	8.40	0.00
- Total	6600	35.94	39.39	39.42	-0.03

\* Base Case results refer to model setups Run 1 to Run 8.

**Energy Available for Sale  
at Québec-Labrador Border**

## 6 Energy Available for Sale at Québec-Labrador Border

Energy generated at the existing and proposed Churchill River developments, once losses and demands including infeed are removed, will be transmitted to the province of Québec for sale to energy markets. In order to determine the amount of energy available, a post-processor was developed to carry out the required calculations using the ARSP output. Appendix G presents the detailed calculations for Run 1. Summary of system production and energy distribution, and results for the energy available for sale at the Québec-Labrador border for all runs are provided in Volumes 2 and 3 of this report.

### 6.1 Transmission Layout

The transmission layout presented in Figure 6.1 was assumed for the Churchill River system, as provided by NLH. Information on line and generator losses used to determine the available energy for sale at the Québec-Labrador border were provided by NLH (Appendix H). This table was updated in discussions with NLH to take account of variations in installed capacities and maximum loads at the bus. These loss numbers and transmission line losses are summarized in Table 6.1.

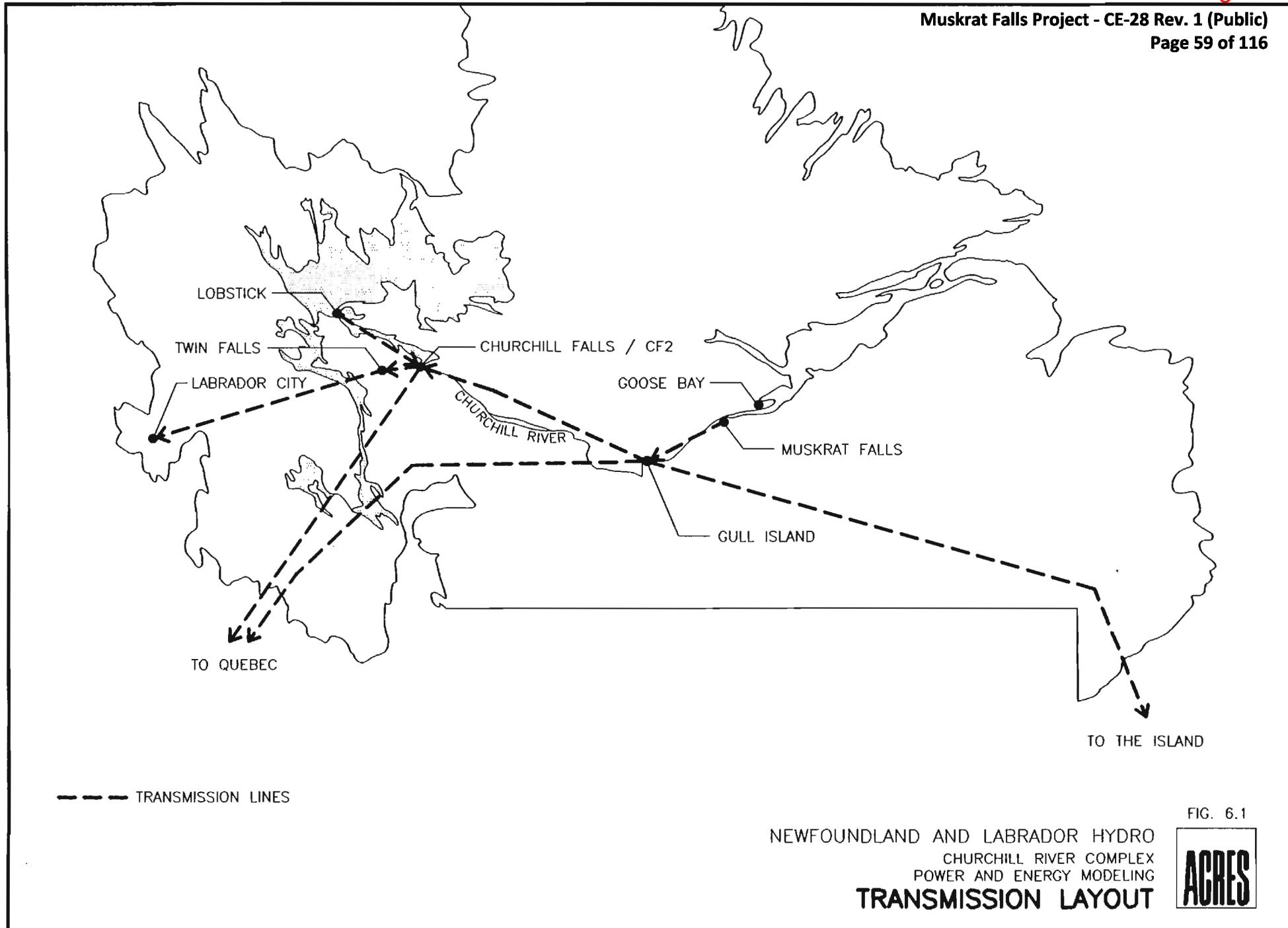
The procedure used to calculate energy available at the Québec-Labrador border is as follows.

- 1) Calculate the total system energy using ARSP.
- 2) Calculate net total system energy by removing the generator transformer losses from total system energy.
- 3) Subtract infeed to the Island (except for Run 1 and Run 4), Labrador loads, and station services/Twin Falls loads (Twinco Block) from the net total system energy to determine the energy available for sale at the Québec-Labrador border at the sending end. The Labrador and Island loads used in the calculations are presented in Appendix E.
- 4) Determine the energy available for sale at the Québec-Labrador border by subtracting the line losses from the energy available at the sending end.

It was noticed that the maximum load at 230 kV values are exceeded for the energy available at the Québec-Labrador border at the sending end for some months in some runs. This has to do with the calculation of maximum load at the bus. This affects the loss at maximum load. It was determined that the adjustment in losses at maximum load would not affect the results.

## 6.2 Energy at Québec-Labrador Border

Values of average annual and monthly energy available for sale at the Québec-Labrador border (TWh) are presented in Table 6.2. Total and incremental average energy available for sale at the Québec-Labrador border (TWh) is presented in Table 6.3.



**Table 6.1****Summary of Transmission System Losses**

<b>Run No.</b>	<b>Max. Total Generation (1) (MW)</b>	<b>Max. Generator Transformer (2) Losses (MW)</b>	<b>Maximum 230kV Bus Load (3) (MW)</b>	<b>Max Load at 230kV Sending End (MW) (4)</b>	<b>Losses at Max. Load (MW) (5)</b>
1	5600	15.6	377.1	5207.3	52.1
2	7864	22.8	1092.4	6748.8	71.7
3	8688	24.8	1092.4	7570.8	105.9
4	6600	18.4	377.1	6204.5	70.1
5	8864	25.4	1092.4	7746.2	90.5
6	9688	27.4	1092.4	8568.2	126.0
7	9024	26.0	1092.4	7905.6	98.5
8	9848	28.0	1092.4	8727.6	133.9

- Notes:
1. Maximum Total Generation is the gross generation output less unit service, excitation system, and isophase bus losses. This yields the generation at the low voltage bushing of the generator step up transformer.
  2. The 15/230 kV and 13.8/230 kV generator step up transformer losses.
  3. 230 kV bus load includes Labrador Loads, Station Service/Twin Falls Loads and HVDC Loads at Gull Island where appropriate.
  4. This is the available generation for the 735 kV network and is calculated as Total Generation less generator transformer losses and 230 kV bus loads. Churchill Falls 230 kV cable losses are ignored.
  5. This is the 230/735 kV autotransformer and 735 kV transmission line losses to the border. 735 kV shunt reactor losses are ignored.

For total generator output levels other than those given in the table, losses are approximated as follows for each generation scenario:

$$\text{Generator Transformer Losses (MW)} = (0.15 * \text{TLF} + 0.85 * \text{TLF}^2) * (\text{Max. Generator Trans. Losses})$$

$$\text{TLF} = \frac{(\text{Current Total Generation})}{(\text{Maximum Total Generation})}$$

$$\text{Transmission System Losses (MW)} = (0.15 * \text{LF} + 0.85 * \text{LF}^2) * (\text{Losses at Maximum Load})$$

$$\text{LF} = \frac{(\text{Current Load at 230kV Bus})}{(\text{Maximum Load at 230kV Bus})}$$

$$\text{Current Load at Sending End} = \text{Current Total Generation} - \text{Generation Transformer Losses} \\ - 230\text{kV Bus Load}$$

$$230\text{kV Bus Load} = \text{HVDC Infeed Load} + \text{Station Service/Twin Falls (Twinco Block) Load} + \text{Labrador Load}$$

**Table 6.2**

**Average Annual and Monthly Energy Available for Sale at  
Quebec-Labrador Border (TWh)**

<b>Run No.</b>	<b>May</b>	<b>Jun</b>	<b>Jul</b>	<b>Aug</b>	<b>Sep</b>	<b>Oct</b>	<b>Nov</b>	<b>Dec</b>	<b>Jan</b>	<b>Feb</b>	<b>Mar</b>	<b>Apr</b>	<b>Total</b>
1	2.21	2.22	2.62	2.55	2.35	2.52	2.46	2.75	2.95	2.71	2.98	2.86	31.18
2	2.72	2.81	3.45	3.33	3.13	3.23	3.04	3.32	3.56	3.19	3.54	3.52	38.84
3	2.99	3.11	3.81	3.71	3.49	3.61	3.39	3.71	3.96	3.55	3.90	3.87	43.10
4	2.57	2.45	3.02	2.92	2.75	2.89	2.83	3.19	3.49	3.30	3.40	3.21	36.02
5	3.14	3.16	3.89	3.78	3.60	3.71	3.53	3.87	4.21	3.91	4.11	3.97	44.88
6	3.45	3.46	4.25	4.21	3.96	4.09	3.93	4.30	4.65	4.30	4.52	4.37	49.49
7	3.20	3.23	3.97	3.87	3.68	3.79	3.60	3.96	4.31	4.02	4.20	4.08	45.91
8	3.52	3.53	4.34	4.29	4.04	4.17	4.01	4.38	4.75	4.40	4.61	4.49	50.53

**Table 6.3**

**Total and Incremental Average Annual Energy Available for Sale at Quebec-Labrador Border (TWh)**

Run No.	Available Energy for Sale at Quebec- Labrador Border	
	Total (TWh)	Incremental (TWh)
1	31.18	-
2	38.84	7.66
3	43.10	11.92
4	36.02	4.84
5	44.88	13.70
6	49.49	18.31
7	45.91	14.73
8	50.53	19.35

## **Conclusions and Recommendations**

## 7 Conclusions and Recommendations

### 7.1 Conclusions

The conclusions of the study are as follows.

1. The model of the existing Churchill River system, as set up in this study, gives similar results when compared with recorded data and previous studies.
2. The model was used to estimate firm and average annual energy for the existing and proposed developments in the Churchill River basin, and can be used to assess other arrangements.
3. The post-processor developed for this study is a useful tool in determining available energy for sale at the Québec-Labrador border from model results.
4. The Lower Churchill River hydrology may slightly underestimate flows. It could be reviewed using data from Environment Canada hydrometric stations in and around the basin.

### 7.2 Recommendations

The recommendations of the study are as follows.

1. As more information on diversions from Québec becomes available, the model setups which include the diversions should be updated.
2. The hydrology of the St. Jean River and Romaine River should be further investigated to develop more detailed inflow sequences for the rivers.

**Appendix A  
Available Information**

**Table A.1****Available Information**

Number	Description
1	Newfoundland and Labrador Hydro (October 1997). <i>Gull Island Power Development: Review of Engineering and Capital Cost Estimate Final Report; Volume 1</i> . Prepared by SNC-Agra. Excerpts.
2	Newfoundland and Labrador Hydro (October 1997). <i>Gull Island Power Development: Review of Engineering and Capital Cost Estimate Final Report; Volume 2 - Detailed Calculation of Energy Simulation</i> . Prepared by SNC-Agra.
3	Hydro-Quebec (October 1997). <i>Churchill Falls Inflows Harmonization of Hydro-Quebec and CF(L)Co. Data Bases</i> . Preliminary*
4	Hydro-Quebec (February 1998). <i>Partial Diversions of Upper St. Jean and Romaine Rivers - Preliminary Studies</i> . Hydro-Quebec Presentation Notes. Prepared by Hydro-Quebec.
5	Hydro-Quebec (September 1997). <i>A Development Scenario for Upper Churchill Watershed</i> . Hydro-Quebec Presentation Notes.
6	Newfoundland and Labrador Hydro (January 1991). <i>Churchill River Complex Energy Studies Final Report; Volume 1</i> . Prepared by SNC.
7	Newfoundland and Labrador Hydro (January 1991). <i>Churchill River Complex Energy Studies Final Report; Volume 2 (Annex)</i> . Prepared by SNC.
8	Hydro-Quebec and Churchill Falls (Labrador) Corporation Limited (May 1979) <i>Determination and Adjustments of Technical Operational Characteristics related to the application of the Power Contract of May 12, 1969 between Hydro-Quebec and Churchill Falls (Labrador) Corporation Limited</i> .

**Table A.1 (cont.)****Available Information**

<b>Number</b>	<b>Description</b>
9	Churchill Falls (Labrador) Corporation Limited (March 1989). <i>Flood Handling Study of the Churchill Falls System Main Report</i> . Prepared by Acres International Limited.
10	Churchill Falls (Labrador) Corporation Limited. <i>Churchill Falls Reservoir Storage Curves and Volume in International Units</i> .
11	Acres Canadian Bechtel of Churchill Falls (June 1973). <i>Rules of Operation for Churchill Falls Reservoir System</i> . Prepared by Acres Consulting Services Limited.
12	Churchill Falls (Labrador) Corporation Limited. <i>Storage Curves (November 1996), Structure Curves, and recorded site data (May 1995 to April 1997)</i> . provided by CF(L)Co.

\*Note: A comparison with the final report (April 1998) showed no difference in inflows.

**Appendix B  
Inflow Sequences**

**Diversions  
Inflow Sequences**





## **Upper Churchill River Inflow Sequences**











## **Lower Churchill River Inflow Sequences**





**Appendix C  
Description of ARSP Model**

ARSP is a general reservoir simulation program that is capable of simulating a wide range of operating policies in multipurpose, multi reservoir systems. Water resource allocation problems involving energy production, flood control, water supply, irrigation, low-flow augmentation, diversion, navigation, environmental, and many other requirements can be modeled. The model takes natural inflows, precipitation, evaporation and evapotranspiration data as input.

A major advantage of ARSP is its flexibility in allowing the user to make structural or operating policy changes by modifying the input data rather than by changing the computer program itself. Furthermore, the operating policies are modeled separately from the physical system. In this way, a unique and powerful division in representation of a water resource network is realized and is responsible, in large part, for the flexibility and general applicability of the model. This approach allows alternative water resource policies to be investigated by superimposing new penalty structures on the existing network. The penalty structure defines the relative priorities of conflicting water uses under various hydrologic conditions, and at various times of the year. The priorities are specified by the user, and are not dependent on the system configuration.

Operational features that can be represented include storage and release of water by reservoirs, physical discharge controls at reservoir outlets, water flow in channels (e.g., streams, power channels, diversion or irrigation canals), consumptive demands (e.g., agricultural, industrial or municipal), hydropower releases, head losses in channels, water losses in channels, hydraulic routing through channels and reservoirs, and inflow forecasts. Flow and water level constraints may be absolute, or they may be relative to the flow or level in a previous time step.

ARSP is based on the premise that a water resource system can be represented by a flow network and that an optimal operating decision for the upcoming time period can be made given the initial state of the system and estimates of net inflows during the period. It is a steady-state model since the system configuration and the penalty structure do not change with time. It is not an “optimization model”, but it does use a solution algorithm that is based on optimization principles. It is known as the “out of kilter” algorithm.

In the model, a physical water resource system is described as a network consisting of discrete components, each of which is defined separately. Junctions and control points, such as reservoirs, are represented as nodes, while natural or man-made flow paths that connect junctions are referred to as channels. The network solution technique allocates water in such a way that the total penalties for demand and reservoir storage are minimized for a given time step, e.g., the model might determine if it is preferable to draw a reservoir down to maintain a minimum flow in a channel or to keep the water in storage and allow the channel flow to fall below the desired value.

**Appendix D  
Storage Curves**

## EMMAGASINEMENT A Ossokmanuan

VOLUME EN MILLIONS DE METRES CUBES EN FONCTION DU NIVEAU EN METRES

NIVEAU	0	1	2	3	4	5	6	7	8	9
471.8				0.00	0.00	0.00	0.00	0.00	0.00	0.00
471.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
472.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
472.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
472.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
472.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
472.4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
472.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
472.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
472.7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
472.8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
472.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
473.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
473.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
473.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
473.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
473.4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
473.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
473.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
473.7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
473.8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
473.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
474.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
474.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
474.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
474.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
474.4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
474.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
474.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
474.7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
474.8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
474.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
475.0	0.00	0.00	0.00	0.00	2.34	7.89	13.45	19.02	24.61	30.22
475.1	35.84	41.48	47.13	52.80	58.40	64.18	69.89	75.61	81.35	87.10
475.2	92.87	98.65	104.44	110.24	116.06	121.89	127.60	133.45	139.32	145.20
475.3	151.10	157.00	162.92	168.85	174.79	180.74	186.70	192.68	198.66	204.66
475.4	210.67	216.68	222.71	228.75	234.80	240.86	246.93	253.00	259.09	265.19
475.5	271.30	277.26	283.39	289.52	295.67	301.82	307.98	314.15	320.32	326.51
475.6	332.70	338.91	345.12	351.34	357.56	363.80	370.04	376.28	382.54	388.80
475.7	395.07	401.35	407.63	413.93	420.22	426.53	432.88	439.00	445.32	451.65
475.8	457.99	464.33	470.68	477.03	483.39	489.75	496.12	502.50	508.88	515.26
475.9	521.66	528.05	534.45	540.86	547.27	553.69	560.11	566.53	572.96	579.39

## E M M A G A S I N E M E N T A O s s o k m a n u a n

VOLUME EN MILLIONS DE METRES CUBES EN fonction DU NIVEAU EN METRES

NIVEAU	0	1	2	3	4	5	6	7	8	9
476.0	585.83	592.12	598.56	605.02	611.47	617.93	624.39	630.86	637.33	643.80
476.1	650.20	656.76	663.25	669.73	676.23	682.72	689.22	695.72	702.23	708.73
476.2	715.24	721.76	728.27	734.79	741.32	747.84	754.21	760.74	767.27	773.81
476.3	780.35	786.89	793.43	799.97	806.52	813.07	819.62	826.18	832.73	839.29
476.4	845.85	852.41	850.98	865.55	872.11	878.68	885.26	891.83	898.41	904.98
476.5	911.56	917.98	924.57	931.15	937.74	944.33	950.92	957.51	964.10	970.69
476.6	977.29	983.89	990.49	997.09	1003.69	1010.29	1016.90	1023.50	1030.11	1036.72
476.7	1043.33	1049.94	1056.55	1063.17	1069.78	1076.40	1082.86	1089.48	1096.10	1102.72
476.8	1109.35	1115.97	1122.60	1129.23	1135.86	1142.49	1149.12	1155.76	1162.39	1169.03
476.9	1175.67	1182.31	1188.95	1195.59	1202.23	1208.88	1215.53	1222.18	1228.83	1235.48
477.0	1242.13	1248.63	1255.29	1261.94	1268.60	1275.27	1281.93	1288.60	1295.27	1301.93
477.1	1308.61	1315.28	1321.95	1328.63	1335.31	1341.99	1348.68	1355.36	1362.05	1368.74
477.2	1375.43	1382.13	1388.82	1395.52	1402.23	1408.93	1415.47	1422.19	1428.89	1435.61
477.3	1442.33	1449.05	1455.77	1462.50	1469.23	1475.96	1482.69	1489.43	1496.17	1502.92
477.4	1509.67	1516.42	1523.17	1529.93	1536.69	1543.46	1550.22	1557.00	1563.78	1570.56
477.5	1577.34	1583.96	1590.76	1597.55	1604.35	1611.16	1617.97	1624.78	1631.60	1638.42
477.6	1645.25	1652.09	1658.92	1665.76	1672.61	1679.47	1686.32	1693.19	1700.06	1706.93
477.7	1713.81	1720.70	1727.59	1734.49	1741.39	1748.30	1755.05	1761.97	1768.89	1775.83
477.8	1782.77	1789.72	1796.67	1803.63	1810.60	1817.58	1824.56	1831.55	1838.55	1845.55
477.9	1852.56	1859.50	1866.41	1873.65	1880.69	1887.74	1894.80	1901.87	1908.95	1916.03
478.0	1923.13	1930.06	1937.17	1944.29	1951.42	1958.56	1965.71	1972.87	1980.04	1987.22
478.1	1994.40	2001.60	2008.81	2016.01	2023.26	2030.50	2037.75	2045.02	2052.29	2059.57
478.2	2066.87	2074.18	2081.50	2088.83	2096.17	2103.53	2110.71	2118.09	2125.49	2132.89
478.3	2140.31	2147.74	2155.18	2162.64	2170.11	2177.59	2185.09	2192.60	2200.13	2207.67
478.4	2215.22	2222.79	2230.37	2237.97	2245.59	2253.21	2260.86	2268.52	2276.19	2283.88
478.5	2291.59	2299.13	2306.86	2314.62	2322.39	2330.18	2337.99	2345.81	2353.65	2361.51
478.6	2369.39	2377.28	2385.19	2393.12	2401.07	2409.04	2417.03	2425.03	2433.06	2441.10
478.7	2449.17	2457.25	2465.35	2473.48	2481.62	2489.79	2497.77	2505.98	2514.21	2522.46
478.8	2530.73	2539.02	2547.33	2555.67	2564.03	2572.41	2580.81	2589.24	2597.69	2606.16
478.9	2614.66	2623.18	2631.73	2640.30	2648.89	2657.51	2666.15	2674.82	2683.51	2692.23
479.0	2700.98	2709.54	2718.33	2727.15	2736.00	2744.88	2753.78	2762.72	2771.67	2780.66
479.1	2789.67	2798.72	2807.79	2816.89	2826.01	2835.17	2844.36	2853.57	2862.82	2872.10
479.2	2881.41	2890.74	2900.11	2909.51	2918.94	2928.40	2937.66	2947.19	2956.75	2966.34
479.3	2975.96	2985.62	2995.30	3005.03	3014.78	3024.58	3034.40	3044.26	3054.15	3064.08
479.4	3074.05	3084.05	3094.08	3104.16	3114.26	3124.41	3134.59	3144.81	3155.06	3165.36
479.5	3175.69	3185.81	3196.21	3206.66	3217.15	3227.67	3238.24	3248.04	3259.48	3270.17
479.6	3280.89	3291.66	3302.47	3313.32	3324.21	3335.14	3346.12	3357.13	3368.19	3379.30
479.7	3390.45	3401.64	3412.87	3424.15	3435.48	3446.85	3457.98	3469.44	3480.95	3492.50
479.8	3504.10	3515.74	3527.44	3539.17	3550.96	3562.79	3574.68	3586.61	3598.59	3610.62
479.9	3622.70	3634.83	3647.01	3659.23	3671.52	3683.85	3696.23	3708.66	3721.15	3733.69

## E M M A G A S I N E M E N T A S m a l l w o o d

## VOLUME EN MILLIONS DE METRES CUBES EN FONCTION DU NIVEAU EN METRES

NIVEAU	0	1	2	3	4	5	6	7	8	9
463.9	-98.51	-92.38	-86.24	-80.08	-73.91	-67.72	-61.52	-55.30	-49.07	-42.82
464.0	-36.56	-30.44	-24.15	-17.84	-11.52	-5.19	1.15	7.52	13.90	20.29
464.1	26.70	33.12	39.56	46.02	52.40	58.97	65.46	71.98	78.50	85.05
464.2	91.60	98.17	104.76	111.36	117.98	124.61	131.09	137.75	144.43	151.12
464.3	157.82	164.54	171.27	178.02	184.79	191.56	198.36	205.16	211.99	218.82
464.4	225.68	232.54	239.43	246.32	253.23	260.16	267.10	274.06	281.03	288.01
464.5	295.01	301.05	308.00	315.93	322.99	330.06	337.15	344.25	351.37	358.50
464.6	365.65	372.81	379.99	387.18	394.39	401.61	408.84	416.10	423.36	430.64
464.7	437.94	445.25	452.57	459.91	467.27	474.63	481.04	488.24	496.65	504.08
464.8	511.52	518.98	526.45	533.94	541.44	548.95	556.48	564.03	571.59	579.17
464.9	586.76	594.36	601.98	609.62	617.27	624.93	632.61	640.30	648.01	655.73
465.0	663.47	671.03	678.00	686.58	694.38	702.19	710.02	717.86	725.71	733.58
465.1	741.47	749.17	757.20	765.21	773.16	781.12	789.09	797.08	805.00	813.10
465.2	821.13	829.18	837.24	845.32	853.41	861.52	869.44	877.50	885.73	893.99
465.3	902.07	910.27	918.48	926.70	934.94	943.19	951.46	959.75	968.04	976.36
465.4	984.68	993.03	1001.39	1009.75	1018.14	1026.54	1034.96	1043.39	1051.83	1060.29
465.5	1068.77	1077.05	1085.55	1094.08	1102.61	1111.16	1119.72	1128.30	1136.89	1145.50
465.6	1154.12	1162.76	1171.41	1180.07	1188.76	1197.45	1206.16	1214.89	1223.63	1232.38
465.7	1241.15	1249.93	1258.73	1267.55	1276.38	1285.22	1293.86	1302.73	1311.62	1320.52
465.8	1329.44	1338.37	1347.32	1356.28	1365.25	1374.24	1383.25	1392.27	1401.30	1410.35
465.9	1419.42	1428.49	1437.59	1446.70	1455.02	1464.96	1474.11	1483.20	1492.46	1501.65
466.0	1510.87	1519.87	1529.11	1538.36	1547.63	1556.92	1566.22	1575.53	1584.86	1594.20
466.1	1603.56	1612.93	1622.32	1631.72	1641.14	1650.57	1660.02	1669.48	1678.96	1688.45
466.2	1697.95	1707.47	1717.01	1726.56	1736.12	1745.70	1755.06	1764.67	1774.29	1783.93
466.3	1793.58	1803.25	1812.93	1822.63	1832.34	1842.07	1851.81	1861.56	1871.33	1881.12
466.4	1890.92	1900.73	1910.56	1920.40	1930.26	1940.13	1950.02	1959.93	1969.84	1979.77
466.5	1989.72	1999.44	2009.42	2019.41	2029.41	2039.43	2049.47	2059.52	2069.58	2079.66
466.6	2089.75	2099.86	2109.98	2120.12	2130.27	2140.44	2150.62	2160.82	2171.03	2181.26
466.7	2191.50	2201.75	2212.02	2222.31	2232.61	2243.92	2253.00	2263.34	2273.70	2284.07
466.8	2294.46	2304.06	2315.20	2325.71	2336.15	2346.62	2357.09	2367.58	2378.09	2388.61
466.9	2399.14	2409.69	2420.25	2430.83	2441.43	2452.03	2462.66	2473.29	2483.95	2494.61
467.0	2505.29	2515.73	2526.44	2537.17	2547.91	2558.66	2569.43	2580.21	2591.01	2601.83
467.1	2612.65	2633.78	2670.59	2707.46	2744.37	2781.35	2818.38	2855.47	2892.61	2929.80
467.2	2967.05	3004.35	3041.71	3079.12	3116.58	3154.10	3190.75	3228.38	3266.05	3303.78
467.3	3341.56	3379.39	3417.28	3455.22	3493.21	3531.25	3569.34	3607.48	3645.68	3683.92
467.4	3722.22	3760.56	3798.96	3837.41	3875.90	3914.45	3953.05	3991.69	4030.39	4069.13
467.5	4107.92	4145.82	4184.71	4223.64	4262.63	4301.66	4340.74	4379.87	4419.05	4458.27
467.6	4497.54	4536.86	4576.22	4615.64	4655.09	4694.59	4734.14	4773.74	4813.38	4853.06
467.7	4892.80	4932.57	4972.39	5012.26	5052.17	5092.12	5131.14	5171.19	5211.27	5251.40
467.8	5291.57	5331.79	5372.05	5412.35	5452.69	5493.08	5533.51	5573.98	5614.50	5655.05
467.9	5695.64	5736.20	5776.96	5817.68	5858.44	5899.25	5940.09	5980.97	6021.89	6062.86



## E M M A G A S I N E M E N T A S m a l l w o o d

VOLUME EN MILLIONS DE METRIQUES CUBIQUES EN FONCTION DU NIVEAU EN METRES

NIVEAU	0	1	2	3	4	5	6	7	8	9
473.0	30505.53	30565.47	30627.01	30688.64	30750.38					

## EMMAGASINEMENT A BIEF amont ouest

VOLUME EN MILLIONS DE METRES CUBES EN FONCTION DU NIVEAU EN METRES

NIVEAU	0	1	2	3	4	5	6	7	8	9
445.0		1.34	1.43	1.52	1.61	1.70	1.80	1.89	1.98	2.08
445.1	2.17	2.27	2.36	2.46	2.56	2.66	2.76	2.86	2.96	3.06
445.2	3.16	3.26	3.37	3.47	3.57	3.68	3.78	3.89	4.00	4.10
445.3	4.21	4.32	4.43	4.54	4.65	4.77	4.88	4.99	5.11	5.22
445.4	5.34	5.45	5.57	5.69	5.80	5.92	6.04	6.16	6.28	6.40
445.5	6.52	6.64	6.76	6.89	7.01	7.14	7.26	7.39	7.51	7.64
445.6	7.77	7.90	8.03	8.16	8.29	8.42	8.55	8.68	8.81	8.95
445.7	9.08	9.21	9.35	9.49	9.62	9.76	9.89	10.03	10.17	10.31
445.8	10.45	10.59	10.73	10.87	11.01	11.15	11.30	11.44	11.58	11.73
445.9	11.87	12.02	12.17	12.31	12.46	12.61	12.76	12.91	13.06	13.21
446.0	13.36	13.51	13.66	13.81	13.96	14.12	14.27	14.43	14.58	14.74
446.1	14.89	15.05	15.21	15.37	15.53	15.69	15.85	16.01	16.17	16.33
446.2	16.49	16.65	16.81	16.98	17.14	17.31	17.47	17.63	17.80	17.97
446.3	18.13	18.30	18.47	18.64	18.81	18.98	19.15	19.32	19.49	19.66
446.4	19.83	20.01	20.18	20.35	20.53	20.70	20.88	21.06	21.23	21.41
446.5	21.59	21.76	21.94	22.12	22.30	22.48	22.66	22.84	23.02	23.20
446.6	23.39	23.57	23.75	23.94	24.12	24.31	24.49	24.68	24.87	25.06
446.7	25.24	25.43	25.62	25.81	26.00	26.19	26.38	26.57	26.76	26.95
446.8	27.15	27.34	27.53	27.73	27.92	28.12	28.31	28.51	28.71	28.90
446.9	29.10	29.30	29.50	29.70	29.90	30.10	30.30	30.50	30.70	30.91
447.0	31.11	31.31	31.51	31.72	31.92	32.13	32.33	32.54	32.75	32.96
447.1	33.16	33.37	33.58	33.79	34.00	34.21	34.42	34.63	34.85	35.06
447.2	35.27	35.49	35.70	35.92	36.13	36.35	36.56	36.77	36.99	37.21
447.3	37.43	37.65	37.87	38.09	38.31	38.53	38.75	38.97	39.19	39.42
447.4	39.64	39.86	40.09	40.31	40.54	40.77	40.99	41.22	41.45	41.68
447.5	41.90	42.13	42.36	42.59	42.82	43.05	43.28	43.51	43.75	43.98
447.6	44.22	44.45	44.69	44.92	45.16	45.39	45.63	45.87	46.11	46.35
447.7	46.59	46.83	47.07	47.31	47.55	47.79	48.03	48.27	48.52	48.76
447.8	49.01	49.25	49.50	49.74	49.99	50.24	50.49	50.74	50.99	51.24
447.9	51.49	51.74	51.99	52.24	52.49	52.75	53.00	53.26	53.51	53.77
448.0	54.02	54.27	54.53	54.79	55.05	55.31	55.57	55.83	56.09	56.35
448.1	56.61	56.88	57.14	57.40	57.67	57.93	58.20	58.47	58.73	59.00
448.2	59.27	59.54	59.81	60.08	60.35	60.62	60.89	61.16	61.43	61.70
448.3	61.98	62.25	62.53	62.81	63.08	63.36	63.64	63.92	64.20	64.48
448.4	64.76	65.04	65.32	65.61	65.89	66.17	66.46	66.74	67.03	67.32
448.5	67.60	67.88	68.17	68.46	68.75	69.04	69.33	69.63	69.92	70.21
448.6	70.51	70.80	71.10	71.39	71.69	71.99	72.29	72.58	72.88	73.18
448.7	73.49	73.79	74.09	74.39	74.70	75.00	75.30	75.61	75.91	76.22
448.8	76.53	76.84	77.15	77.46	77.77	78.08	78.39	78.71	79.02	79.34
448.9	79.65	79.97	80.28	80.60	80.92	81.24	81.56	81.88	82.20	82.53
449.0	82.85	83.17	83.49	83.82	84.14	84.47	84.80	85.13	85.46	85.79
449.1	86.12	86.45	86.78	87.12	87.45	87.79	88.12	88.46	88.80	89.14
449.2	89.48	89.82	90.16	90.50	90.84	91.18	91.52	91.87	92.21	92.56
449.3	92.91	93.26	93.61	93.96	94.31	94.66	95.01	95.37	95.72	96.08
449.4	96.43	96.79	97.15	97.51	97.87	98.23	98.59	98.96	99.32	99.69
449.5	100.05	100.41	100.78	101.14	101.51	101.88	102.26	102.63	103.00	103.38
449.6	103.75	104.13	104.50	104.88	105.26	105.64	106.02	106.40	106.79	107.17
449.7	107.56	107.94	108.33	108.72	109.11	109.50	109.88	110.27	110.66	111.06
449.8	111.45	111.85	112.24	112.64	113.04	113.44	113.84	114.24	114.65	115.05
449.9	115.46	115.86	116.27	116.68	117.09	117.50	117.91	118.33	118.74	119.15

## E M M A G A S I N E M E N T A B i e f a m o n t o u e s t

VOLUME EN MILLIONS DE METRES CUBES EN FONCTION DU NIVEAU EN METRES

NIVEAU	0	1	2	3	4	5	6	7	8	9
450.0	119.57	119.98	120.40	120.82	121.24	121.66	122.08	122.51	122.93	123.36
450.1	123.78	124.21	124.64	125.07	125.51	125.94	126.37	126.81	127.24	127.68
450.2	128.12	128.56	129.00	129.45	129.89	130.33	130.77	131.22	131.67	132.12
450.3	132.57	133.02	133.47	133.93	134.38	134.84	135.30	135.76	136.22	136.68
450.4	137.14	137.61	138.08	138.54	139.01	139.48	139.95	140.42	140.90	141.37
450.5	141.85	142.32	142.79	143.27	143.76	144.24	144.72	145.21	145.70	146.18
450.6	146.67	147.16	147.66	148.15	148.65	149.14	149.64	150.14	150.64	151.14
450.7	151.64	152.15	152.66	153.16	153.67	154.18	154.68	155.20	155.71	156.23
450.8	156.74	157.26	157.78	158.31	158.83	159.35	159.88	160.41	160.94	161.47
450.9	162.00	162.53	163.07	163.61	164.14	164.68	165.23	165.77	166.31	166.86
451.0	167.41	167.94	168.49	169.04	169.60	170.15	170.71	171.27	171.83	172.39
451.1	172.95	173.52	174.09	174.65	175.22	175.79	176.37	176.94	177.52	178.10
451.2	178.67	179.26	179.84	180.42	181.01	181.60	182.17	182.76	183.36	183.95
451.3	184.55	185.14	185.74	186.35	186.95	187.55	188.16	188.77	189.38	189.99
451.4	190.60	191.22	191.84	192.45	193.07	193.70	194.32	194.95	195.58	196.20
451.5	196.84	197.45	198.09	198.73	199.36	200.00	200.65	201.29	201.94	202.59
451.6	203.24	203.89	204.54	205.20	205.85	206.51	207.17	207.84	208.50	209.17
451.7	209.94	210.51	211.18	211.86	212.53	213.21	213.87	214.56	215.24	215.93
451.8	216.62	217.31	218.00	218.69	219.39	220.09	220.79	221.49	222.20	222.90
451.9	223.61	224.32	225.03	225.75	226.47	227.19	227.91	228.63	229.35	230.08
452.0	230.81	231.53	232.26	233.00	233.73	234.47	235.22	235.96	236.71	237.46
452.1	238.21	238.96	239.71	240.47	241.23	241.99	242.76	243.52	244.29	245.06
452.2	245.84	246.61	247.39	248.17	248.95	249.74	250.50	251.29	252.08	252.88
452.3	253.67	254.47	255.27	256.07	256.88	257.69	258.50	259.31	260.12	260.94
452.4	261.76	262.58	263.40	264.23	265.06	265.89	266.72	267.56	268.40	269.24
452.5	270.09	270.91	271.76	272.61	273.46	274.32	275.17	276.03	276.90	277.76
452.6	278.63	279.50	280.37	281.25	282.13	283.01	283.89	284.78	285.67	286.56
452.7	287.45	288.35	289.25	290.15	291.05	291.96	292.85	293.76	294.67	295.59
452.8	296.51	297.43	298.36	299.29	300.22	301.15	302.09	303.02	303.97	304.91
452.9	305.06	306.01	307.76	308.71	309.67	310.63	311.60	312.56	313.53	314.50

## É M M A G A S I N E M E N T   A   B . - e s t , C h u r c h .   F a l l s

VOLUME EN MILLIONS DE MÈTRES CUBES EN FONCTION DU NIVEAU EN MÈTRES

NIVEAU	0	1	2	3	4	5	6	7	8	9
443.7									-1.34	-0.35
443.8	0.63	1.62	2.61	3.60	4.60	5.59	6.59	7.58	8.58	9.57
443.9	10.57	11.57	12.57	13.57	14.57	15.57	16.58	17.58	18.59	19.59
444.0	20.60	21.58	22.59	23.60	24.60	25.61	26.63	27.64	28.65	29.66
444.1	30.68	31.69	32.71	33.72	34.74	35.76	36.78	37.80	38.82	39.84
444.2	40.86	41.88	42.91	43.93	44.96	45.98	46.98	48.01	49.04	50.07
444.3	51.10	52.13	53.16	54.19	55.23	56.26	57.29	58.33	59.37	60.40
444.4	61.44	62.48	63.52	64.56	65.60	66.64	67.68	68.73	69.77	70.82
444.5	71.86	72.08	73.93	74.90	76.01	77.08	78.13	79.18	80.23	81.28
444.6	82.34	83.39	84.45	85.50	86.56	87.62	88.68	89.74	90.80	91.86
444.7	92.92	93.98	95.04	96.11	97.17	98.24	99.28	100.35	101.41	102.48
444.8	103.55	104.62	105.69	106.77	107.84	108.91	109.99	111.06	112.14	113.22
444.9	114.29	115.37	116.45	117.53	118.61	119.69	120.77	121.86	122.94	124.03
445.0	125.11	126.17	127.26	128.35	129.44	130.53	131.62	132.71	133.80	134.89
445.1	135.90	137.08	138.17	139.27	140.37	141.46	142.56	143.66	144.76	145.86
445.2	146.96	148.06	149.17	150.27	151.38	152.48	153.56	154.67	155.78	156.88
445.3	157.99	159.10	160.21	161.33	162.44	163.55	164.67	165.78	166.90	168.01
445.4	169.13	170.25	171.37	172.49	173.61	174.73	175.85	176.97	178.10	179.22
445.5	180.35	181.45	182.57	183.70	184.83	185.96	187.09	188.22	189.35	190.48
445.6	191.62	192.75	193.89	195.02	196.16	197.29	198.43	199.57	200.71	201.85
445.7	202.99	204.13	205.28	206.42	207.56	208.71	209.83	210.97	212.12	213.27
445.8	214.42	215.57	216.72	217.87	219.02	220.16	221.33	222.49	223.64	224.80
445.9	225.95	227.11	228.27	229.43	230.59	231.75	232.91	234.08	235.24	236.40
446.0	237.57	238.71	239.87	241.04	242.21	243.38	244.55	245.72	246.89	248.06
446.1	249.23	250.41	251.58	252.76	253.93	255.11	256.29	257.47	258.65	259.83
446.2	261.01	262.19	263.37	264.55	265.74	266.92	268.08	269.27	270.45	271.64
446.3	272.83	274.02	275.21	276.40	277.59	278.79	279.98	281.17	282.37	283.57
446.4	284.76	285.96	287.16	288.36	289.56	290.76	291.96	293.16	294.37	295.57
446.5	296.77	297.95	299.16	300.36	301.57	302.78	303.99	305.20	306.41	307.62
446.6	308.84	310.05	311.26	312.48	313.69	314.91	316.13	317.35	318.57	319.79
446.7	321.01	322.23	323.45	324.67	325.90	327.12	328.32	329.54	330.77	332.00
446.8	333.23	334.46	335.69	336.92	338.15	339.38	340.62	341.85	343.08	344.32
446.9	345.56	346.79	348.03	349.27	350.51	351.75	352.99	354.23	355.48	356.72
447.0	357.97	359.18	360.43	361.67	362.92	364.17	365.42	366.67	367.92	369.17
447.1	370.42	371.68	372.93	374.19	375.44	376.70	377.96	379.21	380.47	381.73
447.2	382.99	384.25	385.52	386.78	388.04	389.31	390.54	391.81	393.07	394.34
447.3	395.61	396.88	398.15	399.42	400.69	401.96	403.24	404.51	405.78	407.06
447.4	408.34	409.61	410.89	412.17	413.45	414.73	416.01	417.29	418.57	419.86
447.5	421.14	422.40	423.68	424.97	426.26	427.54	428.83	430.12	431.41	432.70
447.6	434.00	435.29	436.58	437.88	439.17	440.47	441.77	443.06	444.36	445.66
447.7	446.96	448.26	449.57	450.87	452.17	453.48	454.75	456.05	457.36	458.67
447.8	459.98	461.28	462.59	463.90	465.22	466.53	467.84	469.15	470.47	471.78
447.9	473.10	474.42	475.73	477.05	478.37	479.69	481.01	482.33	483.66	484.98

## E M M A G A S I N E M E N T A B . - e s t , C h u r c h . F a l l s

VOLUME EN MILLIONS DE METRES CUBES EN FONCTION DU NIVEAU EN METRES

NIVEAU	0	1	2	3	4	5	6	7	8	9
448.0	486.30	487.60	488.92	490.25	491.58	492.90	494.23	495.56	496.89	498.22
448.1	499.56	500.89	502.22	503.56	504.89	506.23	507.56	508.90	510.24	511.58
448.2	512.92	514.26	515.60	516.94	518.29	519.63	520.94	522.29	523.63	524.98
448.3	526.33	527.68	529.03	530.38	531.73	533.08	534.43	535.79	537.14	538.49
448.4	539.85	541.21	542.56	543.92	545.28	546.64	548.00	549.36	550.72	552.09
448.5	553.45	554.78	556.15	557.51	558.88	560.25	561.62	562.99	564.36	565.73
448.6	567.10	568.47	569.84	571.22	572.59	573.97	575.35	576.72	578.10	579.48
448.7	580.86	582.24	583.62	585.00	586.39	587.77	589.12	590.51	591.89	593.28
448.8	594.67	596.05	597.44	598.83	600.22	601.62	603.01	604.40	605.79	607.19
448.9	608.59	609.98	611.38	612.78	614.18	615.57	616.97	618.38	619.78	621.18

**Appendix E  
Load Demands**

**Table E.1****Load Demands**

<b>Month</b>	<b>*Infeed to Newfoundland (GWh)</b>	<b>Labrador (GWh)</b>	<b>Site Services Twin Falls (GWh)</b>
Jan	478.0	110.0	170.6
Feb	481.0	99.0	154.1
Mar	419.0	90.0	170.6
Apr	343.0	87.0	165.1
May	299.0	79.0	170.6
Jun	257.0	53.0	165.1
Jul	257.0	64.0	170.6
Aug	265.0	67.0	170.6
Sep	173.0	71.0	165.1
Oct	244.0	82.0	170.6
Nov	354.0	92.0	165.1
Dec	469.0	105.0	170.6
Total	4039	999	2008.7

\*Sending End

**Appendix F**  
**Structure Curves and Tables**

## LOBSTICK CONTROL STRUCTURE

Page

Rating table for one gate fully open .

H: Main reservoir level upstream of the structure      Q: discharge in cfs

H	Q
1515.0	17,400
1515.5	18,300
1516.0	19,000
1516.5	19,800
1517.0	20,600
1517.5	21,300
1518.0	22,100
1518.5	22,800
1519.0	23,600
1519.5	24,300
1520.0	25,000
1520.5	25,800
1521.0	26,500
1521.5	27,200
1522.0	27,900
1522.5	28,700
1523.0	29,400
1523.5	30,100
1524.0	30,800
1524.5	31,500
1525.0	32,200

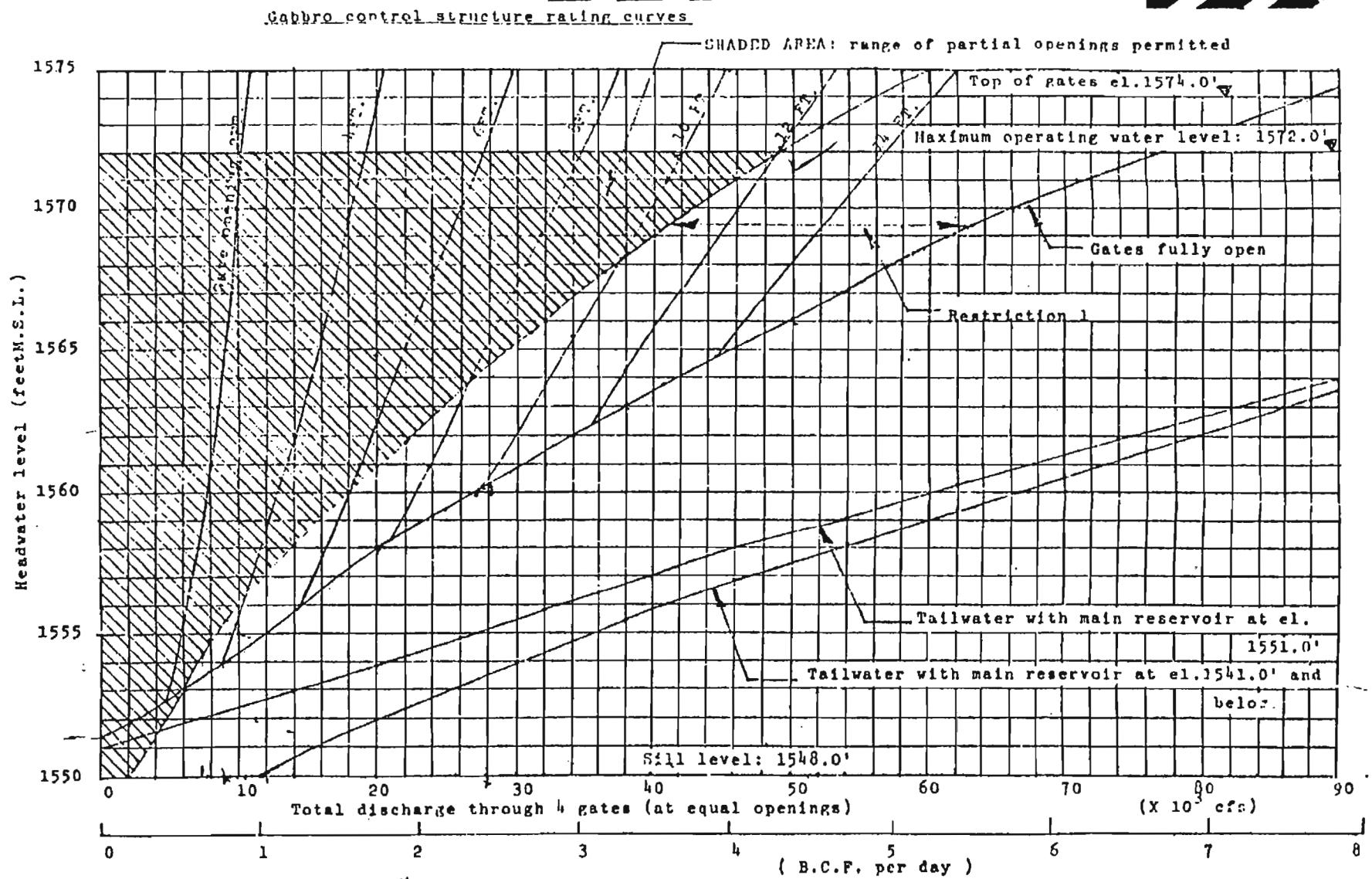
H	Q
1525.5	32,900
1526.0	33,600
1526.5	34,300
1527.0	35,000
1527.5	35,700
1528.0	36,400
1528.5	37,100
1529.0	37,800
1529.5	38,500
1530.0	39,200
1530.5	39,900
1531.0	40,600
1531.5	41,300
1532.0	42,000
1532.5	42,700
1533.0	43,400
1533.5	44,200
1534.0	44,900
1534.5	45,600
1535.0	46,400

H	Q
1535.5	47,200
1536.0	47,900
1536.5	48,700
1537.0	49,500
1537.5	50,200
1538.0	51,000
1538.5	51,800
1539.0	52,600
1539.5	53,400
1540.0	54,200
1540.5	55,000
1541.0	55,800
1541.5	56,700
1542.0	57,500
1542.5	58,400
1543.0	59,200
1543.5	60,100
1544.0	60,900
1544.5	61,800
1545.0	62,700

H	Q
1545.5	63,600
1546.0	64,500
1546.5	65,400
1547.0	66,400
1547.5	67,300
1548.0	68,200
1548.5	69,200
1549.0	70,100
1549.5	71,100
1550.0	72,200
1550.5	73,300
1551.0	74,500
1551.5	75,600
1552.0	76,700
1552.5	77,900
1553.0	79,100
1553.5	80,300
1554.0	81,500
1554.5	82,700
1555.0	83,900

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Gabbro Control Structure.....Rating table for one gate fully open.  
H: Ossokmaruan reservoir level, upstream of the structure.

H	Q	H	Q	H	Q	H	Q	H	Q	H	Q
1555.0	2050	1558.4	5370	1561.8	8270	1565.2	11500	1568.6	14900	1572.0	18500
.1	2925	.5	5450	.9	8360	.3	11600	.7	15000	.1	18610
.2	3000	.6	5530	.1	8450	.4	11700	.8	15100	.2	18720
.3	3075	.7	5610	.2	8545	.5	11800	.9	15200	.3	18830
.4	3150	.8	5690	.3	8640	.6	11900	1569.0	15300	.4	18940
.5	3225	.9	5770	.4	8735	.7	12000	.1	15405	.5	19050
.6	3300	1559.0	5850	.5	8830	.8	12100	.2	15510	.6	19160
.7	3375	.1	5930	.6	8925	.9	12200	.3	15615	.7	19270
.8	3450	.2	6010	.7	9020	1566.0	12300	.4	15720	.8	19380
.9	3525	.3	6090	.8	9115	.1	12400	.5	15825	.9	19490
1556.0	3600	.4	6170	.9	9210	.2	12500	.6	15930	1573.0	19600
.1	3670	.5	6250	.9	9305	.3	12600	.7	16035	.1	19715
.2	3740	.6	6330	1563.0	9400	.4	12700	.8	16140	.2	19830
.3	3810	.7	6410	.1	9495	.5	12800	.9	16245	.3	19945
.4	3880	.8	6490	.2	9590	.6	12900	1570.0	16350	.4	20060
.5	3950	.9	6570	.3	9685	.7	13000	.1	16455	.5	20175
.6	4020	1560.0	6650	.4	9780	.8	13100	.2	16560	.6	20290
.7	4090	.1	6740	.5	9875	.9	13200	.3	16665	.7	20405
.8	4160	.2	6830	.6	9970	1567.0	13300	.4	16770	.8	20520
.9	4230	.3	6920	.7	10065	.1	13400	.5	16875	.9	20635
1557.0	4300	.4	7010	.8	10160	.2	13500	.6	16980	1574.0	20750
.1	4375	.5	7100	.9	10255	.3	13600	.7	17085	.1	20860
.2	4450	.6	7190	1564.0	10350	.4	13700	.8	17190	.2	20970
.3	4525	.7	7280	.1	10445	.5	13800	.9	17295	.3	21080
.4	4600	.8	7370	.2	10540	.6	13900	1571.0	17400	.4	21190
.5	4675	.9	7460	.3	10635	.7	14000	.1	17510	.5	21300
.6	4750	1561.0	7550	.4	10730	.8	14100	.2	17620	.6	21410
.7	4825	.1	7640	.5	10825	.9	14200	.3	17730	.7	21520
.8	4900	.2	7730	.6	10920	1568.0	14300	.4	17840	.8	21630
.9	4975	.3	7820	.7	11015	.1	14400	.5	17950	.9	21740
1558.0	5050	.4	7910	.8	11110	.2	14500	.6	18060	1575.0	21850
.1	5130	.5	8000	.9	11205	.3	14600	.7	18170		
.2	5210	.6	8090	1565.0	11300	.4	14700	.8	18280		
.3	5290	.7	8180	.1	11400	.5	14800	.9	18390		

WHEN USING THIS CHART ADD. (0.2) TO GET TRUE FLOW

## Ossokmanuan Reservoir Storage

H: Upstream elevation at Gabbro structure

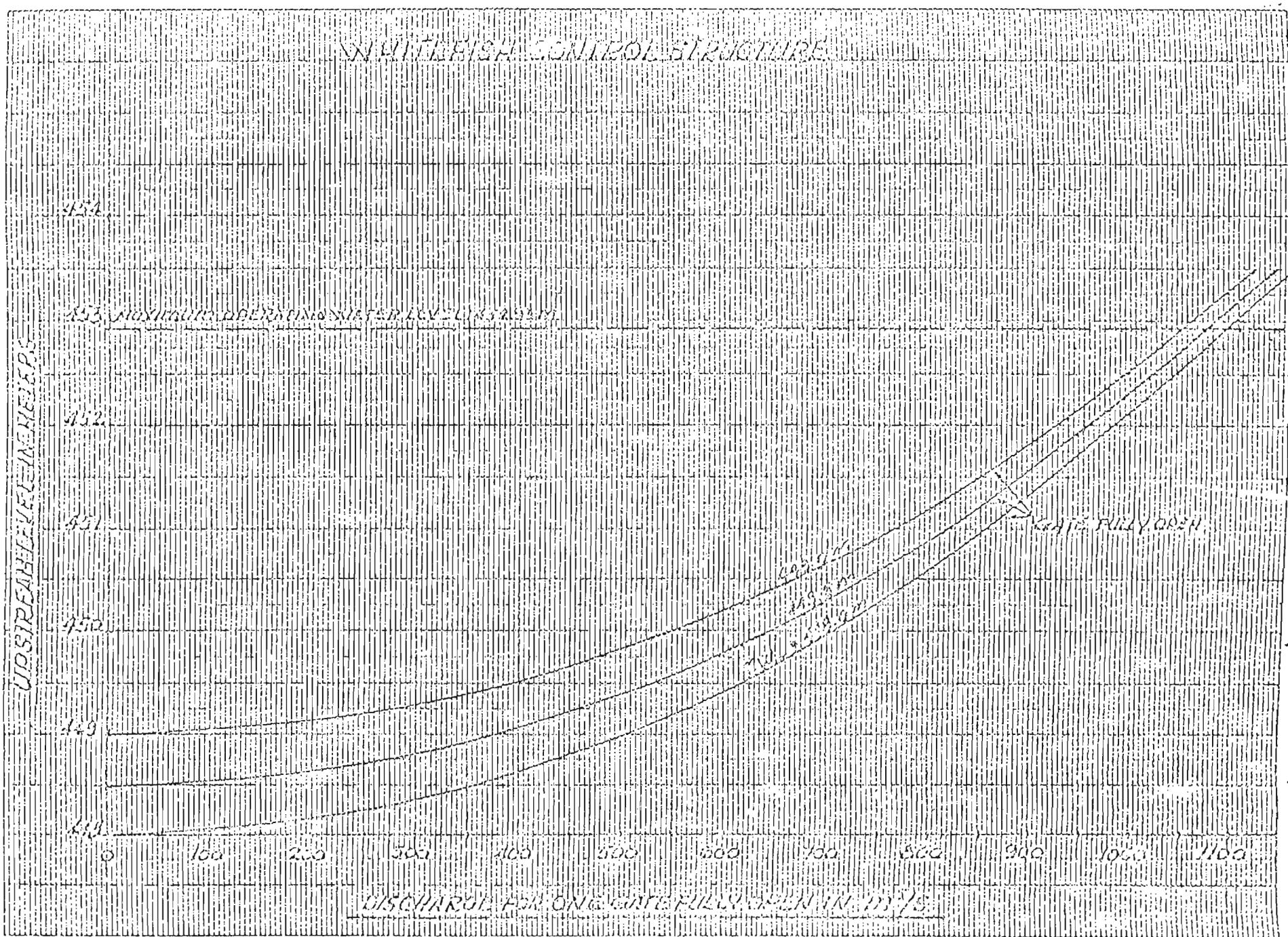
H	Q	S
1565.0	510,000	44.064
.1	519,357	44.872
.2	528,714	45.681
.3	538,071	46.490
.4	547,428	47.298
.5	556,785	48.106
.6	566,142	48.915
.7	575,499	49.718
.8	584,856	50.526
.9	594,213	51.334
1566.0	603,570	52.142
.1	612,921	52.950
.2	622,284	53.758
.3	631,641	54.566
.4	640,998	55.374
.5	650,355	56.182
.6	659,712	56.990
.7	669,069	57.798
.8	678,426	58.606
.9	687,783	59.414
1567.0	697,140	60.222
.1	706,497	61.030
.2	715,854	61.838
.3	725,211	62.646
.4	734,568	63.454
.5	743,925	64.262
.6	753,282	65.070
.7	762,639	65.878
.8	771,996	66.686
.9	781,353	67.494

Q: CFS/days

H	Q	S
1568.0	790,710	68.302
.1	800,067	69.110
.2	809,424	69.918
.3	818,781	70.726
.4	828,138	71.534
.5	837,495	72.342
.6	846,852	73.150
.7	856,209	73.958
.8	865,566	74.766
.9	874,923	75.574
1569.0	884,280	76.382
.1	893,637	77.190
.2	902,994	77.998
.3	912,351	78.806
.4	921,708	79.614
.5	931,065	80.422
.6	940,422	81.230
.7	949,779	82.038
.8	959,136	82.846
.9	968,493	83.654
1570.0	977,850	84.462
.1	987,207	85.270
.2	996,564	86.078
.3	1,005,921	86.886
.4	1,015,278	87.694
.5	1,024,635	88.502
.6	1,033,992	89.310
.7	1,043,349	90.118
.8	1,052,706	90.926
.9	1,062,063	91.734

S: Billion cubic feet (BCF)

H	Q	S
1571.0	1,071,420	92.542
.1	1,080,777	93.350
.2	1,090,134	94.158
.3	1,099,491	94.966
.4	1,108,848	95.774
.5	1,118,205	96.582
.6	1,127,562	97.390
.7	1,136,919	98.198
.8	1,146,276	99.006
.9	1,155,633	99.814
1572.0	1,164,990	100.622
.1	1,174,347	101.464
.2	1,183,704	102.272
.3	1,193,061	103.081



## RATING TABLE OF DISCHARGES (IN CMS) FOR ONE GATE FULLY OPEN

UPSTREAM LEVEL METERS	EAST FOREBAY LEVEL (IN METERS) DOWNSTREAM OF THE STRUCTURE								
	447.8	447.9	448.0	448.1	448.2	448.3	448.4	448.5	448.6
448.0	224	160	0	0	0	0	0	0	0
448.1	274	226	161	0	0	0	0	0	0
448.2	316	276	228	163	0	0	0	0	0
448.3	353	319	279	230	164	0	0	0	0
448.4	386	356	322	281	232	166	0	0	0
448.5	417	390	359	325	284	234	187	0	0
448.6	445	421	393	363	328	286	236	169	0
448.7	472	449	424	397	366	330	289	238	0
448.8	497	476	453	428	400	369	333	292	0
448.9	520	501	480	457	432	404	372	336	0
449.0	543	525	506	485	461	436	407	376	0
449.1	565	548	530	510	489	465	440	411	0
449.2	585	570	553	534	515	493	469	443	0
449.3	605	590	575	558	539	519	497	474	0
449.4	624	610	596	580	562	544	524	502	0
449.5	643	630	616	601	585	567	548	528	0
449.6	661	648	635	621	606	590	572	553	0
449.7	678	666	654	641	626	611	595	577	0
449.8	695	684	672	659	646	632	616	600	0
449.9	711	701	689	678	665	651	637	621	0
450.0	727	717	706	695	683	671	657	642	0
450.1	742	733	723	712	701	689	676	662	0
450.2	757	748	739	729	718	707	695	682	0
450.3	772	764	755	745	735	724	713	700	0
450.4	786	773	770	761	751	741	730	718	0
450.5	800	793	785	776	767	757	747	735	0
450.6	814	807	799	791	782	773	763	753	0
450.7	828	821	813	806	797	789	779	770	0
450.8	841	834	827	820	812	804	795	786	0
450.9	854	848	841	834	827	819	810	801	0
451.0	867	861	854	848	841	833	825	817	0
451.1	879	874	867	861	854	847	840	832	0
451.2	892	886	880	874	868	861	854	846	0
451.3	904	899	893	887	881	875	868	860	0
451.4	916	911	906	900	894	888	881	874	0
451.5	928	923	918	913	907	901	895	888	0
451.6	940	935	930	925	920	914	908	902	0
451.7	952	947	942	937	932	927	921	915	0
451.8	964	959	954	950	945	939	934	928	0
451.9	976	971	966	962	957	952	946	941	0

**Muskrat Falls Project - CE-28 Rev. 1 (Public)**  
**WHITEFISH, CONTROL STRUCTURE**  
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RATING TABLE OF DISCHARGES (IN CMS) FOR ONE GATE FULLY OPEN

UPSTREAM LEVEL METERS	EAST FOREBAY LEVEL (IN METERS) DOWNSTREAM OF THE STRUCTURE								
	447.8	447.9	448.0	448.1	448.2	448.3	448.4	448.5	448.6
452.0	988	984	979	974	969	964	959	954	950
452.1	1000	996	991	986	981	976	971	966	962
452.2	1012	1008	1003	998	993	988	983	978	974
452.3	1024	1020	1015	1011	1006	1001	996	991	987
452.4	1035	1031	1027	1023	1018	1013	1008	1003	999
452.5	1047	1043	1039	1035	1030	1026	1021	1016	1012
452.6	1059	1055	1051	1047	1042	1038	1033	1028	1024
452.7	1070	1066	1062	1059	1054	1050	1045	1041	1037
452.8	1081	1078	1074	1070	1066	1062	1058	1053	1049
452.9	1093	1089	1086	1082	1078	1074	1070	1065	1061
453.0	1104	1100	1097	1093	1090	1086	1082	1077	1073
453.1	1115	1112	1108	1105	1101	1097	1093	1089	1085
453.2	1126	1123	1120	1116	1113	1109	1105	1101	1097
453.3	1137	1134	1131	1128	1124	1121	1117	1113	1109
453.4	1148	1145	1142	1139	1135	1132	1128	1125	1121
453.5	1159	1156	1153	1150	1147	1143	1140	1136	1132

## RATING TABLE OF DISCHARGES (IN CMS) FOR ONE GATE FULLY OPEN

UPSTREAM LEVEL METERS	EAST FOREBAY LEVEL (IN METERS) DOWNSTREAM OF THE STRUCTURE			
	448.7	448.8	448.9	449.0
448.0	0	0	0	0
448.1	0	0	0	0
448.2	0	0	0	0
448.3	0	0	0	0
448.4	0	0	0	0
448.5	0	0	0	0
448.6	0	0	0	0
448.7	0	0	0	0
448.8	171	0	0	0
448.9	242	172	0	0
449.0	296	244	174	0
449.1	342	299	246	175
449.2	382	345	301	248
449.3	418	385	348	304
449.4	451	421	388	351
449.5	481	455	425	392
449.6	510	485	458	428
449.7	537	514	489	462
449.8	562	541	518	493
449.9	586	567	546	523
450.0	609	591	571	550
450.1	631	614	596	576
450.2	653	637	619	601
450.3	673	658	642	624
450.4	693	678	663	647
450.5	712	698	684	668
450.6	730	717	704	689
450.7	748	736	723	709
450.8	765	754	741	729
450.9	782	771	759	747
451.0	798	788	777	765
451.1	814	804	794	783
451.2	829	820	810	800
451.3	844	835	826	817
451.4	859	851	842	833
451.5	874	866	857	848
451.6	888	880	872	864
451.7	902	894	887	879
451.8	915	908	901	893
451.9	929	922	915	908

## RATING TABLE OF DISCHARGES (IN CMS) FOR ONE GATE FULLY OPEN

UPSTREAM LEVEL METERS	EAST FOREBAY LEVEL (IN METERS) DOWNSTREAM OF THE STRUCTURE			
	448.7	448.8	448.9	449.0
452.0	942	936	929	922
452.1	955	949	942	936
452.2	968	962	956	949
452.3	980	975	969	963
452.4	993	987	982	976
452.5	1005	1000	995	989
452.6	1017	1012	1007	1002
452.7	1030	1025	1020	1014
452.8	1043	1038	1032	1027
452.9	1055	1050	1045	1039
453.0	1068	1063	1058	1052
453.1	1080	1075	1070	1065
453.2	1092	1088	1083	1078
453.3	1104	1100	1095	1090
453.4	1116	1112	1108	1103
453.5	1128	1124	1120	1115

**Appendix G**  
**Post-Processor Sample Output**

**TABLE OF RESULTS FOR RUN #1**

Churchill Falls Existing (CF1)

**Muskrat Falls Project - CE-28 Rev. 1 (Public)****Page 107 of 116****System Production and Energy Distribution (MWc)**

	<b>May</b>	<b>Jun</b>	<b>Jul</b>	<b>Aug</b>	<b>Sep</b>	<b>Oct</b>	<b>Nov</b>	<b>Dec</b>	<b>Jan</b>	<b>Feb</b>	<b>Mar</b>	<b>Apr</b>	<b>Average</b>
Total Hydro Production	3329.0	3410.7	3876.0	3777.8	3625.5	3757.2	3800.6	4103.0	4388.7	4457.4	4392.6	4372.3	3938.2
Energy Sent to Island	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Energy Sent to Labrador	106.2	73.6	86.0	90.1	98.6	110.2	127.8	141.1	147.8	147.3	121.0	120.8	114.0
Energy Sent to Station Service/ Twin Falls (Twinco Block)	229.3	229.3	229.3	229.3	229.3	229.3	229.3	229.3	229.3	229.3	229.3	229.3	229.3
Energy Received at Quebec-Labrador Border	2968.0	3080.2	3525.1	3424.8	3266.7	3385.1	3411.3	3695.5	3969.3	4036.7	3998.7	3978.0	3559.1
Total Losses	25.5	27.6	35.6	33.6	30.9	32.5	32.2	37.1	42.3	44.0	43.7	44.2	35.7

**System Production and Energy Distribution (GWh)**

	<b>May</b>	<b>Jun</b>	<b>Jul</b>	<b>Aug</b>	<b>Sep</b>	<b>Oct</b>	<b>Nov</b>	<b>Dec</b>	<b>Jan</b>	<b>Feb</b>	<b>Mar</b>	<b>Apr</b>	<b>Total</b>
Total Hydro Production	2476.7	2455.7	2883.8	2810.7	2610.4	2795.3	2736.4	3052.6	3265.2	2995.4	3268.1	3148.0	34498.4
Energy Sent to Island	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Energy Sent to Labrador	79.0	53.0	64.0	67.0	71.0	82.0	92.0	105.0	110.0	99.0	90.0	87.0	999.0
Energy Sent to Station Service/ Twin Falls (Twinco Block)	170.6	165.1	170.6	170.6	165.1	170.6	165.1	170.6	170.6	154.1	170.6	165.1	2008.7
Energy Received at Quebec-Labrador Border	2208.2	2217.8	2622.6	2548.1	2352.0	2518.5	2456.1	2749.4	2953.2	2712.7	2975.0	2864.2	31177.9
Total Losses	18.9	19.9	26.5	25.0	22.2	24.2	23.2	27.6	31.5	29.6	32.5	31.8	312.8

- Enter the following parameters for the current run:

Maximum Total Generation (MW)	Maximum Generator Transformer Losses (MW)	Maximum Load at 230kV Sending End (MW)	Losses at Maximum Load (MW)
5600	15.6	5207.3	52.1

- Enter the Following Parameters (GWh):

Month	Infeed Load (If Used)	Labrador Load	Station Service/ Twin Falls Load
May	0	79	170.6
Jun	0	53	165.1
Jul	0	64	170.6
Aug	0	67	170.6
Sep	0	71	165.1
Oct	0	82	170.6
Nov	0	92	165.1
Dec	0	105	170.6
Jan	0	110	170.6
Feb	0	99	154.1
Mar	0	90	170.6
Apr	0	87	165.1

- Go to the sheet entitled Total Integrated Power, and paste the ARSP Total Integrated Power output for the current Run. This should be done such that the input for May 1943 is entered into cell D10.
- To view results, go to the sheet entitled "RESULTS". Edit the title on the results sheet as appropriate.

Month	Infeed Load	Labrador Load	Station Service/Twin Falls Load
May	0.0	79.0	170.6
Jun	0.0	53.0	165.1
Jul	0.0	64.0	170.6
Aug	0.0	67.0	170.6
Sep	0.0	71.0	165.1
Oct	0.0	82.0	170.6
Nov	0.0	92.0	165.1
Dec	0.0	105.0	170.6
Jan	0.0	110.0	170.6
Feb	0.0	99.0	154.1
Mar	0.0	90.0	170.6
Apr	0.0	87.0	165.1

**MWc**

Month	Infeed Load	Labrador Load	Station Service/Twin Falls Load
May	0.0	106.2	229.3
Jun	0.0	73.6	229.3
Jul	0.0	86.0	229.3
Aug	0.0	90.1	229.3
Sep	0.0	98.6	229.3
Oct	0.0	110.2	229.3
Nov	0.0	127.8	229.3
Dec	0.0	141.1	229.3
Jan	0.0	147.8	229.3
Feb	0.0	147.3	229.3
Mar	0.0	121.0	229.3
Apr	0.0	120.8	229.3











**Appendix H  
Summary of Transmission  
Losses**

**Churchill River Project**  
**Summary of Transmission Losses to Border**

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Scenao	Maximum Total Generation (MW)	Maximum Generator Transformer Losses (MW)	Maximum 230 kV Bus Load (MW)	Maximum Load at 230 kV Sending End (MW)	Losses at Maximum Load (MW)
Existing	5560	15.4	460.8	5083.8	49.8
CF + GI	7824	22.6	1460.2	6341.0	63.9
CF + CF2	6560	18.2	460.8	6081.0	67.5
CF + GI + CF2	8824	25.2	1460.4	7338.4	81.9
CF + GI + MF	8648	24.6	1460.4	7163.0	95.6
CF + GI + CF2 + MF	9648	27.2	1460.4	8160.4	115.1
CF + GI + MF + LOB	8808	25.1	1460.4	7322.5	102.8
CF + GI + CF2 + LOB	8984	25.8	1460.4	7497.8	89.3
CF + GI + CF2 + MF + LOB	9808	27.8	1460.4	8319.8	122.5

For total generator output levels other than those given in the table losses are approximated as follows for each generation scenario:

$$\text{Generator Transformer Losses (MW)} = (0.15 * \text{TLF} + 0.85 * \text{TLF}^2) * (\text{Max Generator Trans. Losses})$$

$$\text{TLF} = \frac{(\text{Current Total Generation})}{(\text{Maximum Total Generation})}$$

$$\text{Transmission System Losses (MW)} = (0.15 * \text{LF} + 0.85 * \text{LF}^2) * (\text{Losses at Maximum Load})$$

$$\text{LF} = \frac{(\text{Current Load at 230 kV Sending End})}{(\text{Maximum Load at 230 kV Sending End})}$$

$$\begin{aligned} \text{Current Load at 230 kV Sending End} &= \text{Current Total Generation} \\ &\quad - \text{Generation Transformer Losses} \\ &\quad - \text{230 kV Bus Load} \end{aligned}$$

$$\begin{aligned} \text{230 kV Bus Load} &= \text{Labrador West Load} \\ &\quad + \text{Labrador East Load} \\ &\quad + \text{Future Labrador Load} \\ &\quad + \text{HVDC Infeed Load} \end{aligned}$$

Note: Transmission Losses as provided by Newfoundland and Labrador Hydro. Revised numbers are presented in Table 6.1.