TECHNICAL REPORT TO THE
PPWB COMMITTEE ON HYDROLOGY

STREAMFLOW FORECASTING

CHURCHILL RIVER

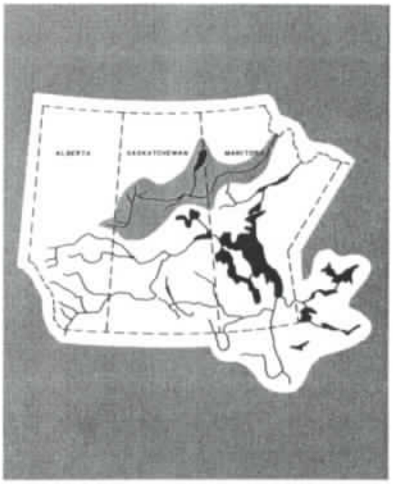
AT SASKATCHEWAN MANITOBA BOUNDARY

PPWB Report 44

PREPARED BY:

DEPARTMENT OF ENVIRONMENT
WATER SURVEY OF CANADA
ATMOSPHERIC ENVIRONMENT SERVICE

Nov 1975



SYNOPSIS

This study was carried out by Water Survey of Canada under an agreement with the Prairie Provinces Water Board. Advice and direction was received from the Prairie Provinces Water Board Committee on Hydrology.

The purpose of this study was to develop a method for forecasting flows in the Churchill River basin to the Saskatchewan-Manitoba border. After consultation with the Committee on Hydrology, locations were identified where forecasts were required and the type of forecast at each site was determined. Spring and summer, and winter water supply forecasts were developed for six localities, and one of these localities was Churchill River above Granville Falls, which is located in Manitoba downstream from the major area of study covered in this report. Short-range river flow forecasts were developed using the SSARR routing model. Extended forecasts based on watershed simulation were not developed as the users did not identify this as a requirement and, also, insufficient hydrometeorological data was available to develop this type of forecast.

Spring and summer water supply forecasts are adversely affected by the lack of areal snowpack water equivalent information and highly variable heavy summer precipitation. Winter water supply forecasts were good. The accuracy of short-range river flow forecasts varied from good to poor. When short-range river flow forecasts were poor, it was usually attributable to insufficient hydrometric data. Recommendations are made for the upgrading of both the hydrometric and meteorological networks, and data transmission facilities.

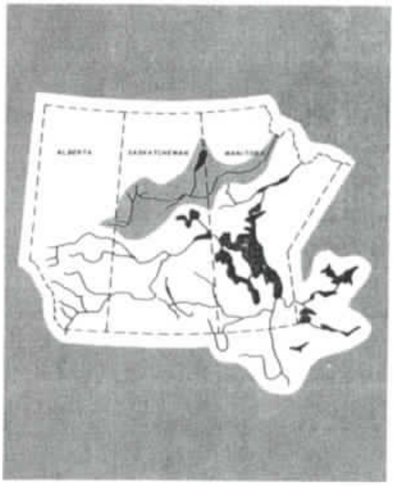
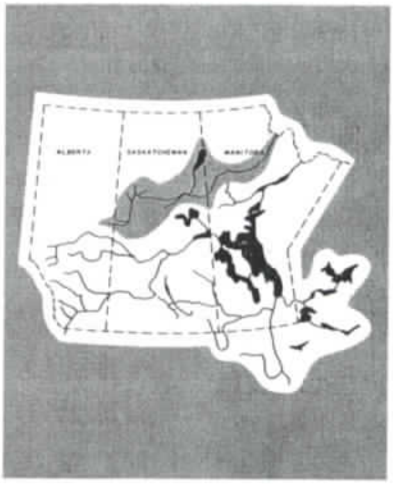


TABLE OF CONTENTS

Page

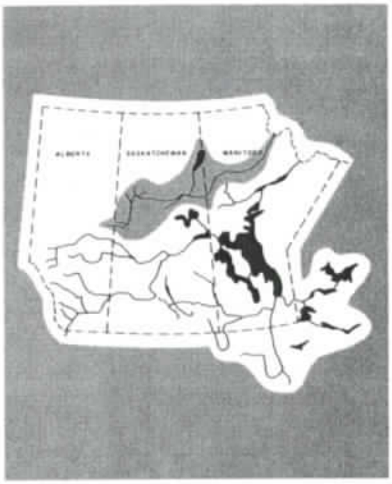
Page



F I G U R E S

Page

Page



TABLES

Page

INTRODUCTION

THE FORECASTING STUDY

The Draft Terms of Reference for this study, which refer specifically to the development of procedures to meet streamflow forecasting requirements on interprovincial streams, stipulate that:

1. The development of streamflow forecasts should include the following:
   a) Identification of forecasting requirements and locations.
   b) Integration of new and existing streamflow forecasting relationships into a single system for forecasting the runoff of interprovincial streams.
2. Existing data networks are to be identified and assessed with regard to their usefulness for runoff forecasting.
3. Recommendations shall be made for improvements that may be required in meteorological, hydrometric, or other data networks to increase the accuracy and efficiency of these networks for forecasting runoff.

Although the main area of this study is the Churchill River basin to the Saskatchewan—Manitoba border, water supply forecasts have been made for Churchill River above Granville Falls, which is located in Manitoba.

This report is one in a series of five to be published. Three reports dealt with the Saskatchewan River and its two tributaries. The Qu'Appelle River basin streamflow forecasting was described in the fourth report.

PHYSIOGRAPHIC CONSIDERATIONS

The Churchill River, throughout most of its length within Saskatchewan, is a series of inter-connected lakes rather than a distinct river channel. As a result, this river contains a large volume of water in channel storage.

A dominant physiographic feature of the entire basin is the relatively large area consisting of lakes and swamps. This factor, added to the large channel storage of the Churchill River, creates great lag times and attenuation at all points within the system.

The only areas of the basin developed for agriculture lie along the Beaver River and its southern tributaries above the confluence with the Waterhen River. The majority of the basin is covered with forest, the type of forest dependent on the topography, climate, forest fires and recent logging activities.

STRUCTURE OF THE REPORT

Forecasting considerations, as they relate to water supply and river flow forecasting, are discussed in the following chapter. User requirements are identified, and a forecasting system based on these requirements is outlined. Parameters which affect runoff are identified.

The chapter *Forecasting Procedures* describes some water supply forecasting procedures which were tested and presents the results. The SSARR routing model was used for short-term river flow forecasts, and the river system plan is outlined.

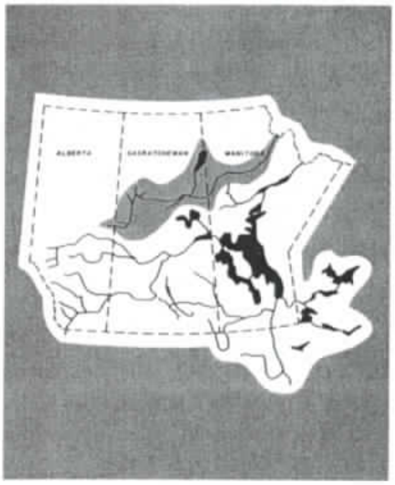
The recommendations are presented under that title and include recommendations for network expansion and upgrading.

An extension of this report was the preparation of user manuals to assist participating agencies to make streamflow forecasts for the Churchill River basin. These manuals were published both separately and as a combined, abbreviated version under the following headings:

User Manual — Water Supply,

User Manual — Routing,

Combined User Manual — Water Supply, Routing.



FORECASTING CONSIDERATIONS

USER REQUIREMENTS

Individual provincial river flow and water supply forecasting requirements were determined by consultation with water resource agencies concerned. Due to certain climatological and physiographic features within the Churchill River basin, shown in Figure 1, a river flow forecast may also serve as an accurate water supply forecast.

ALBERTA REQUIREMENTS

River Flow Forecasts

Heavy summer rainfall can result in destructive flood crests on the Beaver River. River flow forecasts are, therefore, required for the Beaver River at Cold Lake Reserve to monitor flood conditions.

SASKATCHEWAN REQUIREMENTS

Water Supply Forecasts

Spring and summer water supply forecasts are required for the Beaver River at Cold Lake Reserve and near Dorintosh. Current and potential future hydro-electric power developments along the Churchill River indicate the need for both winter and summer water supply forecasts. Forecasts are required for Churchill River above Otter Rapids and at the Island Falls Generating Station. Forecasts of Reindeer River flows are required at the outlet of Reindeer Lake.

River Flow Forecasts

Agricultural lands are subject to spring flooding along the Beaver River. River flow forecasts are required at Dorintosh below the confluence with Meadow River.

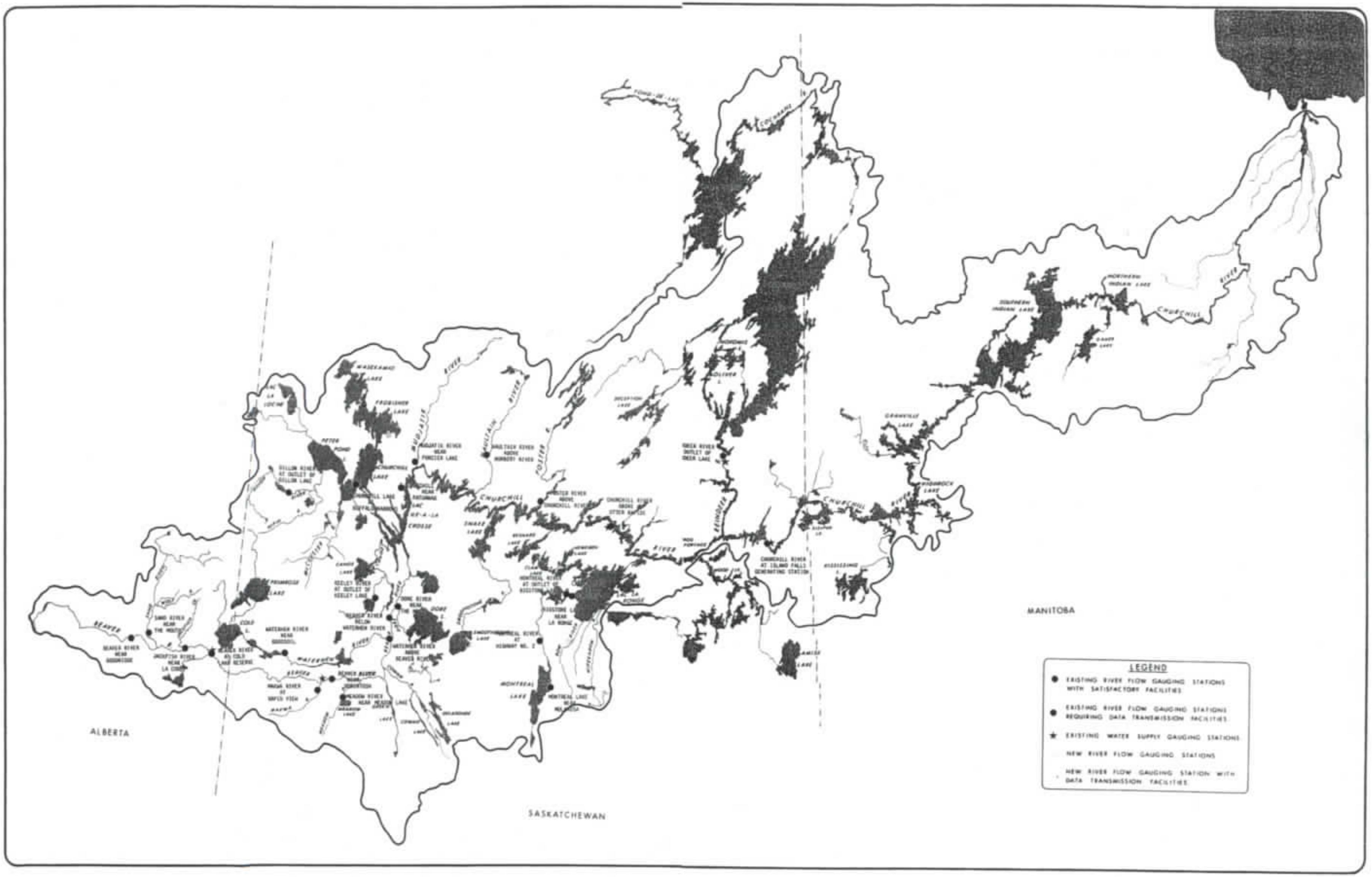


Figure 1: Churchill River Gauging Stations Required For Forecasting.

Figure 1

Forecasts of Lac la Ronge inflows, outflows and levels are required in connection with the operation of the Rapid River control structure at the outlet of the lake.

Churchill River forecasts are required at Patuanak, but expressed in terms of Churchill Lake levels rather than in terms of discharges. Downstream forecast locations include Otter Rapids and Island Falls Generating Station.

MANITOBA REQUIREMENTS

Water Supply Forecasts

Most of the Churchill River runoff which originates above Granville Lake will be diverted into the Nelson River system for power generation. Therefore, water supply forecasts are required for the Churchill River above Granville Falls.

River Flow Forecasts

Churchill River flows are diverted via Southern Indian Lake to provide a relatively firm flow into the Nelson River. One constraint on diversion rates is that an acceptable minimum flow must be maintained along the lower Churchill River below Southern Indian Lake. River flow forecasts are, therefore, required to determine the amount of diversion which can be made to the Nelson River system and still maintain a Churchill River riparian release.

THE FORECASTING SYSTEM

The forecasting system was developed on the basis of the aforementioned user requirements and is designed to meet the needs of apportionment and water resource management.

WATER SUPPLY FORECASTS

Spring and Summer

Forecast Period:

April to December.

Initial Forecast Date:

March 1.

Updating Frequency:

Monthly until October 1.

Forecast Locations:

Beaver River at Cold Lake Reserve.

Beaver River near Dorintosh.

Churchill River above Granville Falls.

Churchill River at Island Falls Generating Station.

Churchill River above Otter Rapids.

Reindeer River at Outlet Reindeer Lake.

Forecast Procedure:

Multiple linear regression analysis.

Winter

Forecast Period:

January to March.

Initial Forecast Date:

January 1.

Updating Frequency:

February 1 only.

Forecast Locations:

Churchill River above Granville Falls.

Churchill River at Island Falls Generating Station.

Churchill River above Otter Rapids.

Reindeer River at Outlet Reindeer Lake.

Forecast Procedure:

Simple correlation of December baseflow versus winter streamflow.

RIVER FLOW FORECASTS

River Routing

Forecast Period:

5 to 30 days subsequent to forecast date.

Initial Forecast Date:

Beaver River System: 3 to 5 days after spring runoff commences.

Churchill River System in Saskatchewan:

May 15.

Updating Frequency:

Beaver River System: As required.

Churchill River System in Saskatchewan: Weekly until October 31.

Forecast Locations:

Beaver River at Cold Lake Reserve.

Beaver River near Dorintosh.

Beaver River below Meadow River.

Beaver River below Waterhen River.

Bigstone River near La Ronge.

Churchill River at Buffalo Narrows.

Churchill River at Island Falls Generating station.

Churchill River above Otter Rapids.

Churchill River near Patuanak.

Lac Ile-a-la-Crosse.

Lac la Ronge at La Ronge.

Montreal River at Outlet Bigstone Lake.

Montreal River at Highway No. 2.

Rapid River at Outlet of Lac la Ronge.

Forecast Procedure:

Streamflow Synthesis and Reservoir Regulation (SSARR) routing model using recorded upstream discharges.

RELATED RUNOFF INFORMATION

General Data on Operation of Control Structures

Forecast Period:

7 to 28 days.

Initial Forecast Date:

May 1.

Updating Frequency:

Weekly until October 31.

Forecast Locations:

Island Falls Dam.

Rapid River Control Structure.

Whitesand Dam at Outlet Reindeer Lake.

Forecast Procedure:

Consultation with operating agencies.

Forecasting Parameters

Parameters:

Snow course, storage gauge and climatological station precipitation records, and winter baseflow data.

FACTORS FOR CONSIDERATION

CLIMATE

Temperature

The climate of the Churchill River basin is characterized by cold winters, hot summers, and a semi-arid precipitation pattern. Mean monthly summer temperatures range from 60° to 65° Fahrenheit, with maximum extremes occasionally approaching 100° Fahrenheit. Mean monthly winter temperatures are usually below zero with extreme lows reaching -60° Fahrenheit. In the Reindeer Lake portion of the basin, winter weather may arrive in October and remain until May. Spring snowmelt can commence during mid-March in the western portion of the Churchill River basin due to the influence of mild air from the Peace River Valley.

Moderate summer temperatures and relatively long winters contribute to much lower evaporation than in the southern prairie regions.

Precipitation

Average annual precipitation in the Churchill River basin is relatively uniform over the area. Precipitation at Buffalo Narrows averages about 17 inches, while at Island Falls it is nearly 20 inches. Summer rainfall accounts for nearly two-thirds of the total precipitation as shown in Figure 2. Extremes in monthly summer rain range from less than one inch to more than ten inches.

Excessive summer rainfall can contribute to high winter river flows at points along the main stem of the lower Churchill River because of the time lag. For example, December 1973 river discharge recorded above Otter Rapids as a result of heavy rainfall in August and September exceeded all other months except August, as shown in Figure 3.

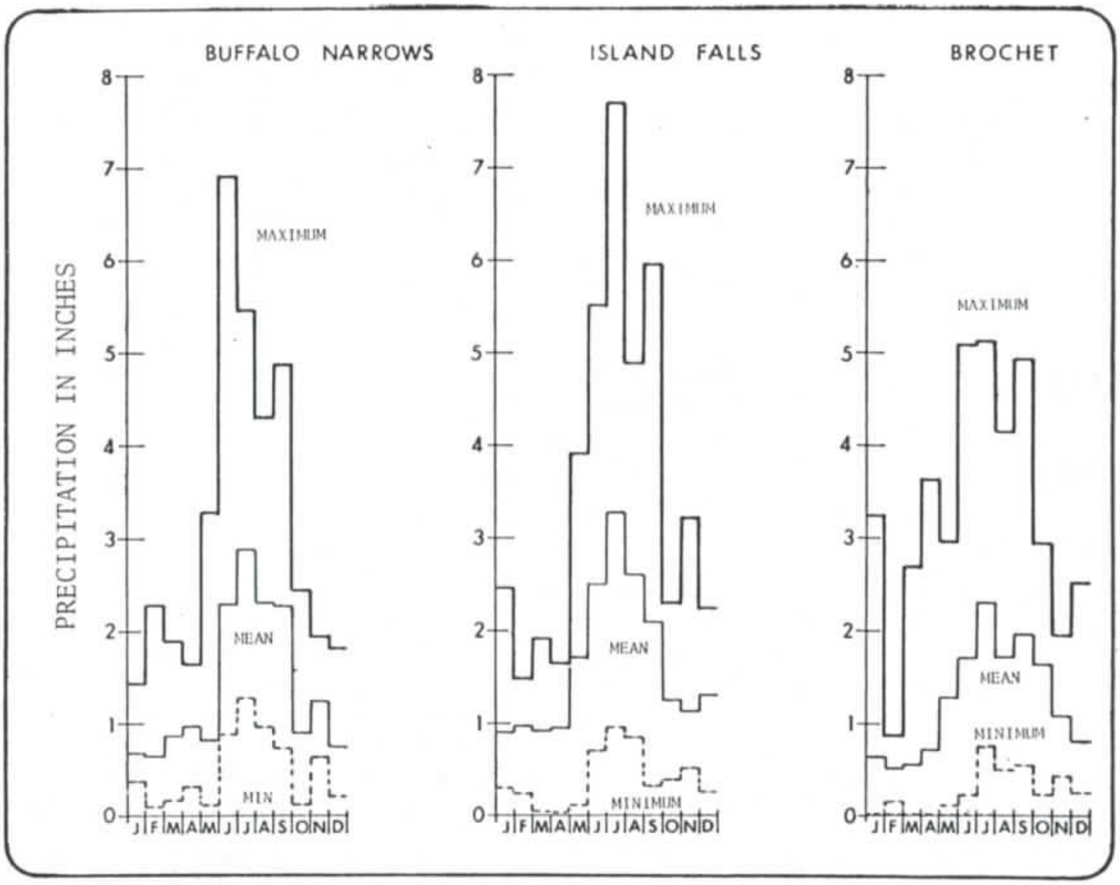


Figure 2: Mean Monthly Precipitation Graphs.

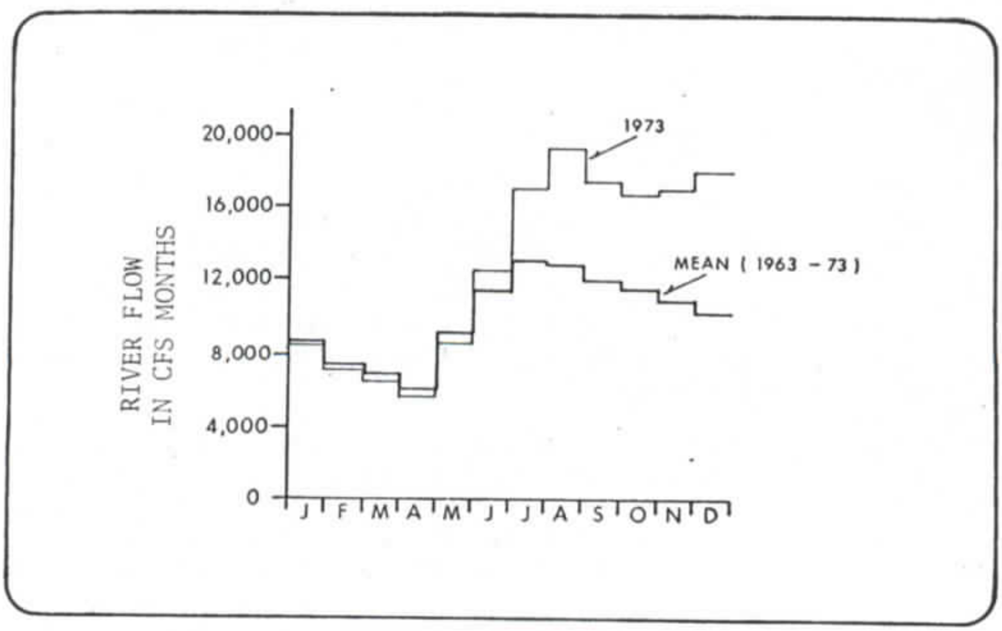


Figure 3: Monthly Discharges for Churchill River above Otter Rapids.

PHYSIOGRAPHY

Figure 4 illustrates the four major physiographic divisions of the Churchill River basin. The largest of these is the Rock Knob complex lying within the Canadian Shield. Due to severe glaciation, all former topographic highs have been planed down to form a rocky monoplain with elevations ranging from 1,000 to 1,500 feet. Regional lakes now occupy glacially-scoured depressions which are elongated in the direction of the ice sheet movement. Runoff coefficients are high in this region due to the large area of impervious rocky terrain and water surfaces.

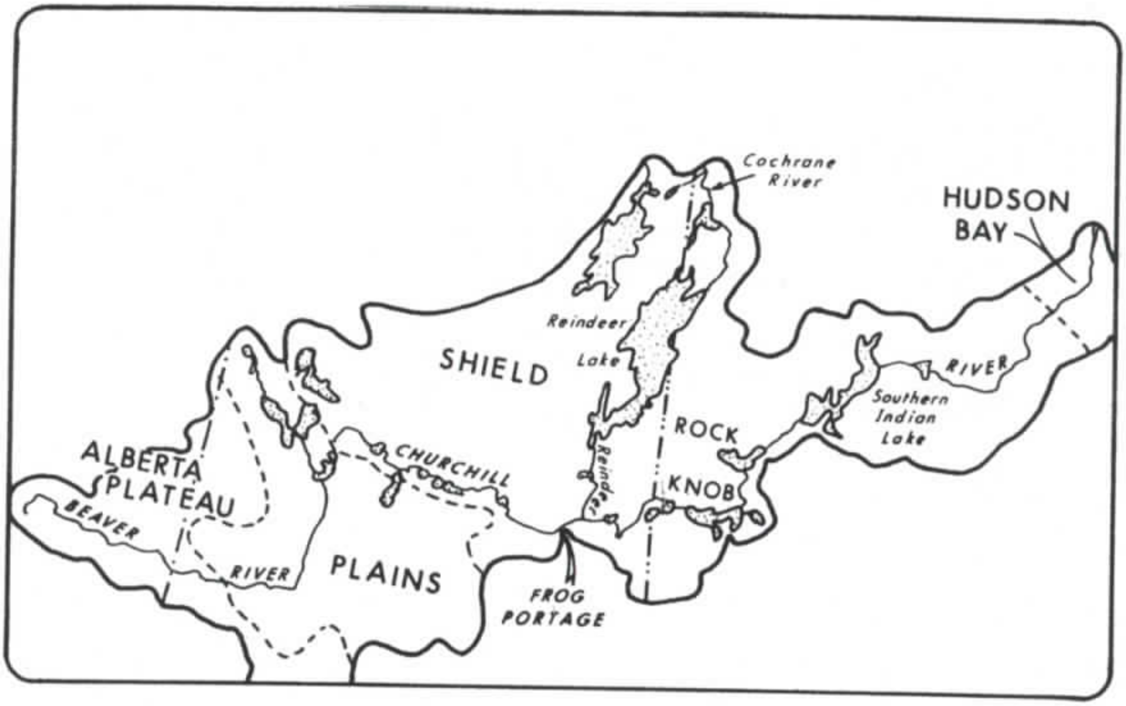


Figure 4: Main Physiographic Features of the Churchill River Basin.

The Saskatchewan Plains border the Churchill River to the southwest with elevations reaching 2,000 feet. The area is comprised of glacial deposits with extensive tracts of poorly drained land, or interior drainage. Attenuation and storage provided by these swamps contributes to high winter baseflow.

Agricultural production is limited to the Alberta Plateau which forms the Churchill River headwaters and the very southern portion of the Saskatchewan Plains. Spring and summer floods periodically create problems along the Beaver River. During high flood crests, water from Beaver River backs into Green Lake through the Green River Channel.

Flow reversal occurs in the Aubichon Arm which connects Churchill Lake and Lac Ile-a-la-Crosse; as well, Beaver River flood crests entering Lac Ile-a-la-Crosse raise the water *level above* that in Churchill Lake and cause a reversal of flow. Consequently, in routing Beaver River floods, both this flow reversal and the overflow into Green Lake must be considered.

The above-mentioned lakes, together with Dore, Peter Pond and Frobisher Lakes, create unusually large natural reservoirs in proportion to the total drainage area into them. From a knowledge of the water in storage, it is possible to make accurate short-range water supply forecasts at downstream points by using river routing procedures rather than conventional water supply forecasts based on linear regression techniques.

Major inter-basin diversion of water occurs at three points in the Churchill River basin:

1. Runoff from the large Wollaston Lake basin discharges not only into Churchill River (via Cochrane and Reindeer Rivers), but also into the Mackenzie River system via Fond du Lac and Slave Rivers.

2. From the Churchill River proper, natural overflow can occur into the Saskatchewan River basin at Frog Portage. Only a narrow, 100-foot, rocky shore separates the two river basins. Whenever Churchill River discharges exceed about 27,000 cfs, overflow commences. During flood crests, overflow rates may reach 2,000 cfs and must be accounted for in river flow forecasting procedures.

3. Much further downstream, control structures on Southern Indian Lake now permit diversions into the Nelson River system.

FORECASTING PROCEDURES

WATER SUPPLY FORECASTS

SPRING AND SUMMER

Existing Forecasting Relationships

A snowmelt runoff forecasting equation to predict the peak discharge for Beaver River near Dorintosh has been developed by the Saskatchewan Department of the Environment. The peak discharge is computed using the following equation:

$$Y = 2.44\ X_1 + 1423X_2 - 3{,}230$$

where,

Y = peak discharge in cfs,

X_1 = average September and October baseflow in cfs,

X_2 = average of precipitation in inches at Meadow Lake and Fort McMurray (November to March).

This equation has a correlation coefficient of 0.70.

Churchill River Power Company Limited has developed a complex computer program to predict the adequacy of Reindeer Lake storage for power generation requirements at Island Falls. Despite numerous studies, they have been unable to establish accurate long-range relationships between precipitation and runoff.

New Forecasting Relationships

Only fair accuracy was initially achieved for Churchill River main stem stations and the Reindeer River in developing water supply forecasting equations using a runoff period extending from April to October. The forecasts were generated by multiple linear regression analysis using winter precipitation, summer precipitation and baseflow as independent parameters. Two contributing factors to low accuracy were highly variable, heavy summer precipitation and late fall precipitation which did not appear as streamflow until outside the forecast period due to excessive lag times within the river system. The effects of heavy August and September rainfalls are not experienced until December as illustrated in Figure 3. When this characteristic of Churchill River basin runoff was recognized, the forecast period for Churchill River main stem stations and Reindeer River was extended to December. Water supply forecasting accuracy was greatly improved.

Simple correlation coefficients between November-to-March and April-to-September precipitation and runoff are presented in Tables 1 and 2, respectively. Winter correlation coefficients are generally poor. This is mainly attributable to total runoff being closely related to summer precipitation.

New water supply forecasting relationships were developed for the following six Churchill River basin stations using multiple linear regression.

- Beaver River near Cold Lake Reserve,
- Beaver River near Dorintosh,
- Churchill River above Granville Falls,
- Churchill River at Island Falls,
- Churchill River above Otter Rapids,
- Reindeer River at Outlet of Reindeer Lake.

The forecasting equations for these stations are presented in Table 3.

Forecasts Utilizing River Routing

The long travel times and significant attenuation inherent in the Churchill River system can be used to advantage in short-range water supply forecasting. Figure 5 provides a two-month water supply forecast for the Churchill River above Otter Rapids. A six-day, 52,000-cfs flood crest was artificially introduced into the Churchill River near Patuanak. Average discharges were used subsequent to the July 8 forecast date. The full effect of the Patuanak flood crest is not experienced at Otter Rapids until about four weeks later. By then, the 52,000-cfs flood crest is attenuated to 18,000 cfs.

Table 1

Correlation Between

November-to-March Precipitation and April-to-December Runoff*

Climatological Station	Churchill River at Island Falls	Churchill River above Granville Falls	Churchill River above Otter Rapids	Reindeer River at Outlet of Reindeer Lake
Big River	.072	.140	.198	-.216
Brochet	.077	-.096	-.483	.054
Buffalo Narrows	.233	.275	.076	.519
Choiceland	-.167	-.161	-.108	-.041
Churchill	-.058	-.245	-.305	-.006
Codette-Elkhorn	.329	.351	.335	.236
Cold Lake	.286	.389	.307	.159
Flin Flon	-.034	.027	-.062	.163
Foster Lake	.046	.068	.117	.041
Grand Rapids	.051	.035	.088	.135
Green Lake	.448	.511	.503	.091
Ile-a-la-Crosse	.374	.440	.356	.150
Island Falls	.169	.127	-.359	.456
Kinoosao	.381	.417	.348	.138
Lac La Biche	.051	-.012	-.011	.069
La Ronge	.088	.025	-.230	.369
Loon Lake	.290	.257	.398	-.242
Meadow Lake	-.223	-.036	-.073	-.182
Stanley	.382	.309	.223	.314
The Pas A	-.097	-.188	-.161	-.117
Uranium City	-.345	-.336	-.301	-.327
Waskesiu Lake	-.402	-.298	-.339	-.137
Whitesand	-.018	-.086	-.319	.222
Wollaston Lake	.011	.054	-.064	-.020

* 1961 to 1972 Test Period.

Table 2

Correlation Between

April-to-September Precipitation and April-to-December Runoff*

Climatological Station	Churchill River at Island Falls	Churchill River above Grenville Falls	Churchill River above Otter Rapids	Reindeer River at Outlet of Reindeer Lake
Big River	.195	.267	.314	.101
Brochet	.108	.212	-.190	.610
Buffalo Narrows	.281	.320	.478	-.101
Choiceland	-.213	-.083	.066	-.402
Codette-Elkhorn	-.265	-.160	-.123	-.422
Cold Lake	.301	.329	.345	.208
Flin Flon	.301	.504	.346	.377
Foster Lake	.328	.349	.438	.193
Grand Rapids	-.290	-.230	-.097	-.471
Green Lake	.175	.297	.276	.057
Ile-a-la-Crosse	.330	.382	.640	-.237
Island Falls	.256	.486	.194	.525
Kinoosao	.140	.114	.264	-.087
Lac La Biche	.263	.363	.489	-.061
La Ronge	.414	.550	.672	-.159
Loon Lake	.493	.541	.635	.015
Meadow Lake	.288	.444	.452	.056
Stanley	.356	.561	.525	.138
The Pas A	.180	.266	.195	.065
Waskesiu Lake	.232	.265	.267	.167
Whitesand	-.270	-.129	-.389	.303
Wollaston Lake	-.148	.023	-.147	.101

* — 1961 to 1972 Test Period.

Table 3

Churchill River Basin April-to-December Water Supply Forecasts

Forecast Location	Forecast Period	Regression Equation Y = Forecast Period Natural Flow (thousands of acre-feet)	Correlation Coefficient	Standard Error (SE) (1000's of acre-feet)	SE/Mean	Worst Error	
						Per Cent	Year
Beaver River at Cold Lake Reserve	April to October	$336X_1 + 68.2X_2 + 2.81X_3 - 1,672$	0.81	246	0.43	241	1968
Beaver River near Dorintosh	April to October	$417X_1 + 119X_2 + 4.94X_3 - 2,508$	0.82	380	0.47	218	1968
Churchill River above Granville Falls	April to December	$1,027X_1 + 807X_2 + 1.71X_3 - 4,152$	0.83	1,568	0.99	23.9	1956
Churchill River above Otter Rapids	April to December	$737X_1 + 411X_2 + 1.15X_3 - 3,640$	0.85	1,131	0.19	51.3	1968
Churchill River at Island Falls Generating Station	April to December	$808X_1 + 647X_2 + 0.50X_3 + 610$	0.84	1,158	0.08	13.8	1969
Reindeer River at Outlet of Reindeer Lake	April to December	$234X_1 + 136X_2 + 0.51X_3 - 2,750$	0.75	410	0.06	11.7	1970

X_1 is an index of November-to-March precipitation in inches.
X_2 is an index of April-to-September precipitation in inches.
X_3 is the antecedent October discharge in the Beaver River forecasts but January-to-March discharge in others.

WINTER WATER SUPPLY

Correlation studies indicated that there was a good relationship between December natural flow and the runoff for the following three months. The winter water supply forecasting equations subsequently developed are presented in Table 4.

Table 4

Churchill River Basin January-to-March Water Supply Forecasts

Forecast Location	Regression Equation Y = January-to-March Natural Flow (thousands of acre-feet)	Correlation Coefficient	Standard Error (SE) (1000's of acre-feet)	SE/Mean	Worst Error	
					Per Cent	Year
Churchill River above Granville Falls	$1,012 + 1.912X$	.88	360	0.14	14.0	1963
Churchill River at Island Falls Generating Station	$710 + 2.069X$	.96	162	0.04	9.0	1971
Churchill River above Otter Rapids	$209 + 2.014X$	.99	71	0.07	7.0	1965
Reindeer River at Outlet of Reindeer Lake	$19.5 + 2.322X$	.98	7	0.09	5.0	1948

X is the antecedent December Discharge.

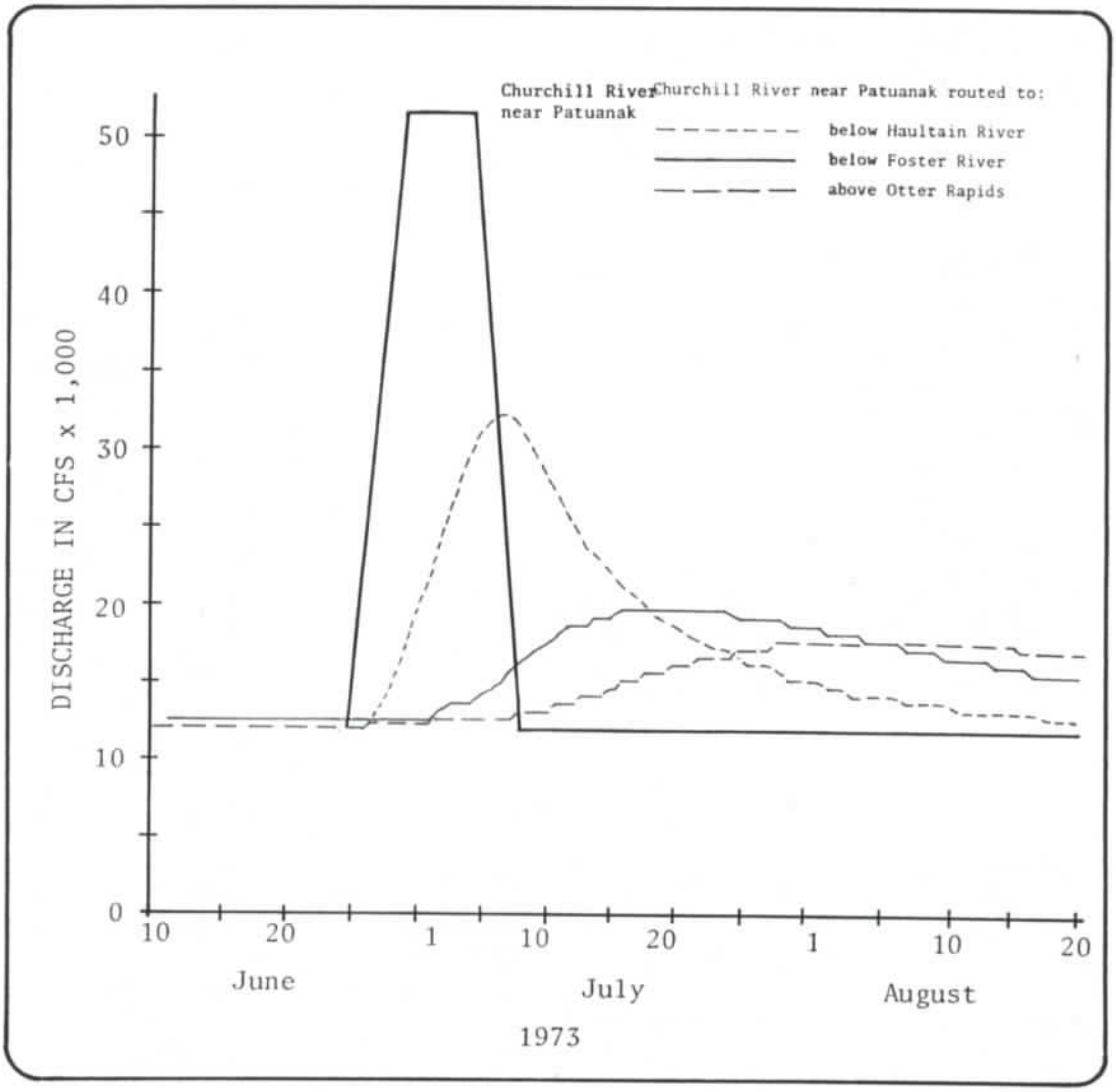


Figure 5: Attenuation of Churchill River Discharges between Patuanak and Otter Rapids

RIVER FLOW FORECASTS

River flow forecasts can be divided into the two categories of Short-Range River Flow Forecasts" and "Extended Forecasts Based on Watershed Runoff Simulation." For the Churchill River basin, procedures have been developed only for calculating short-range river flow forecasts as User Requirements did not identify the need for both and, also, insufficient information was available to develop forecasts based on watershed runoff simulation. The Streamflow Synthesis and Reservoir Regulation (SSARR) routing model which was developed by the United States Army Corps of Engineers was used. A Users' Manual for this basin provides a complete description of the routing theory and computer program.

SHORT-RANGE RIVER FLOW FORECASTS

The stream gauging stations used for short-range river flow forecasts are shown in Figure 1. A river system plan was developed on the basis of user requirements and preliminary studies. Gauging stations, which are either essential or required for verification of the forecasts, are listed in Table 5. The forecast locations are those

Table 5

Gauging Stations Required for Routing Churchill River

Gauging Station Location	WSC Number	SSARR Number	Remarks
Beaver River below Waterhen River	06AG001	63000	Essential station
Dore River near the Mouth	06AG002	61700	Essential station
Keeley River at Outlet of Keeley Lake	06BB004	63400	Essential station
Dillon River at Outlet of Dillon Lake	06BA002	63600	Essential station
Mudjatik River near Forcier Lake	06BC001	63700	Essential station
Churchill Lake at Buffalo Narrows	06BA001	63800	Verifies forecast
Churchill River near Patuanak	06BB003	64000	Verifies forecast
Beaver River near Goodridge	06AA001	60000	Essential station
Sand River near the Mouth	06AB001	60400	Essential station
Jackfish Creek near La Corey	06AC001	60600	Essential station
Beaver River at Cold Lake Reserve	06AD006	61000	Verifies forecast
Makwa River at Rapid View	06AD007	61500	Essential station
Beaver River near Dorintosh	06AD001	62000	Verifies forecast
Meadow River near Meadow Lake	DOE Sask.	61600	Essential station
Waterhen River near Goodsoil	06AF005	62300	Essential station
Waterhen River above Beaver River	06AF006	62700	Essential station
Haultain River above Norbert River	06BD001	64500	Essential station
Foster River above Churchill River	06CE001	64700	Essential station
Churchill River above Otter Rapids	06CD002	65000	Verifies forecast
Montreal Lake near Molanosa	06CA005	64200	Essential station
Montreal River at Highway No. 2	06CA003	64300	Verifies forecast
Bigstone Lake near La Ronge	06CA004	64560	Verifies forecast
Montreal River at Outlet of Bigstone Lake	06CA001	64600	Verifies forecast
Lac la Ronge at La Ronge	06CB001	65600	Verifies forecast
Reindeer River at Outlet of Reindeer Lake	06BD002	65800	Essential station
Churchill River at Island Falls Generating Station	06EA002	68000	Verifies forecast

stations indicated as being required to verify the forecast. The river system charts are shown in Figures 6, 7 and 8. The development and testing of short range river flow forecasts utilized only 1973 and 1974 streamflow data, as insufficient data was available prior to this period.

Short-range river flow forecasts can be provided for the Beaver River at Cold Lake Reserve, near Dorintosh and below Waterhen River. Recorded upstream discharges are routed and attenuated using the SSARR model river system chart shown in Figure 6. Ungauged local inflow is estimated as a function of gauged tributaries. Satisfactory routing results for the Beaver River below Waterhen River are shown in Figure 9.

Forecast locations on the main stem of the Churchill River commence at the gauging station near Patuanak and extend to the Island Falls generating plant. The region which includes Churchill Lake and Lac Ile-a-la-Crosse is the most complicated area to mathematically model. Reversal of flow occurs in the Aubichon Arm connecting the two lakes. Beaver River flood crests entering Lac Ile-a-la-Crosse cause the lake to rise and exceed the level of Churchill Lake. A better knowledge of the hydraulic parameters of this connecting arm and the runoff contribution of Frobisher Lake to the northwest may improve the forecasting accuracy for this area. River flow forecasts for the Churchill River near Patuanak are presented in Figure 10.

Three major tributaries north of the Churchill River between Patuanak and Otter Rapids are gauged. Ungauged local inflow can be estimated reasonably accurately from the gauged streams. Within this reach, the river flows through a series of large lakes which significantly attenuate flood crests originating from the local tributaries. Forecasts for the Churchill River above Otter Rapids are presented in Figure 11. There is up to 10 per cent discrepancy between recorded and forecast discharges for brief periods in 1974. This may be due to high ungauged inflow from some southern tributaries such as the Smoothstone River.

Between Otter Rapids and Island Falls, the Churchill River receives a considerable amount of inflow from Rapid River and Reindeer River. Reindeer River discharge is relatively uniform because of controlled releases from Reindeer Lake. Forecasts for Churchill River at Island Falls are presented in Figure 12. The discharge for mid-July, 1974 is appreciably under-computed. This is attributable to excessively high ungauged inflow beginning on July 9. The start of this period coincides with an extreme rainfall event centred about 50 miles southeast of Lac la Ronge. Rainfall at some locations exceeded eight inches within a 48-hour period. Due to the sparseness of the climatological network, it is not known what rainfall occurred west of the Reindeer River to Otter Rapids.

Lac la Ronge level forecasts are made by routing Montreal Lake outflow. A provisional outflow relationship has been developed for the upstream lake. Several large streams, which are not gauged, rise in the highlands south of Lac la Ronge. These streams contribute a significant amount of inflow to the lake. As a result, the forecast accuracy for Lac la Ronge is poor as shown in Figure 13.

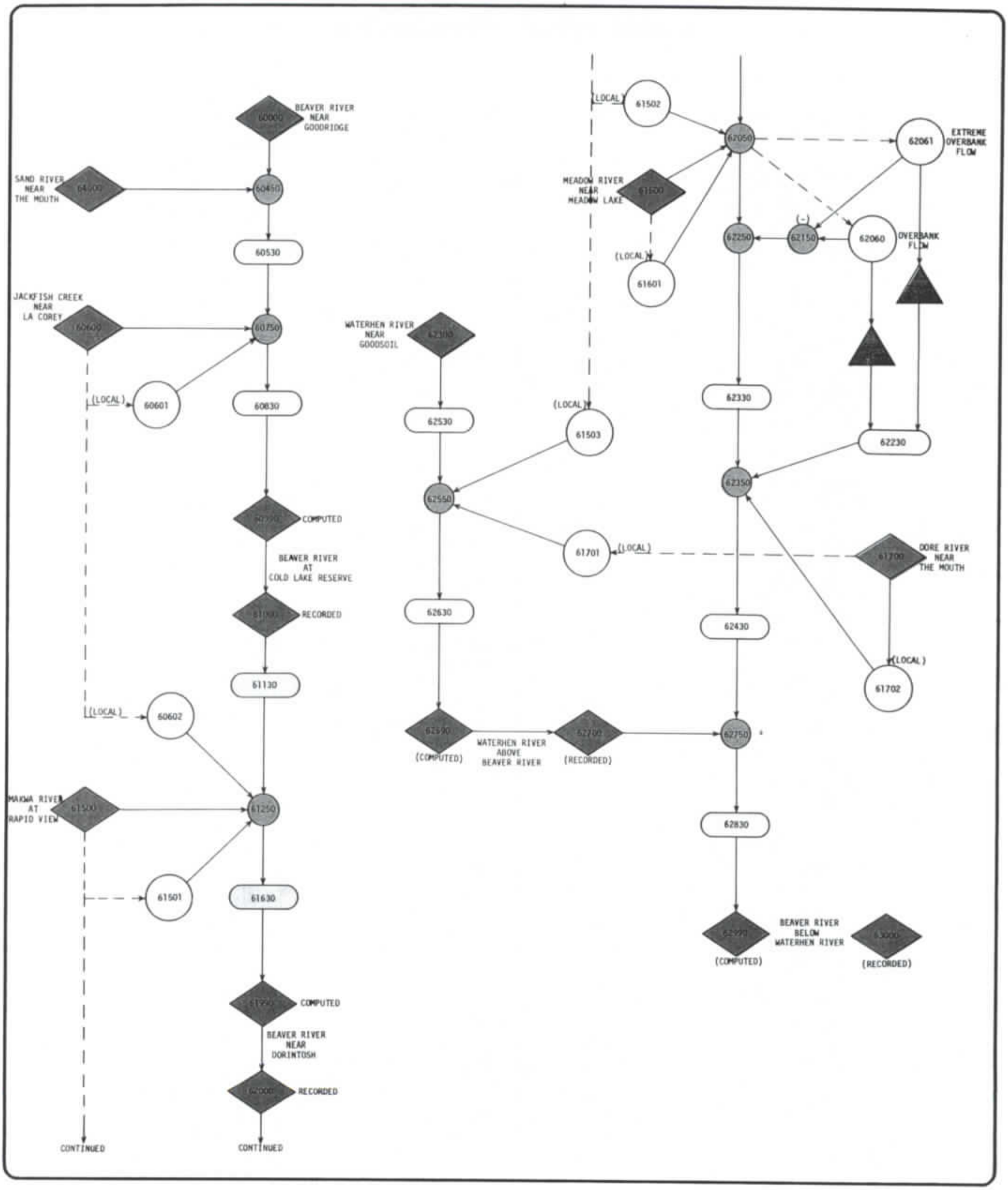


Figure 6: SSARR River System Chart for Beaver River to below Waterhen River.

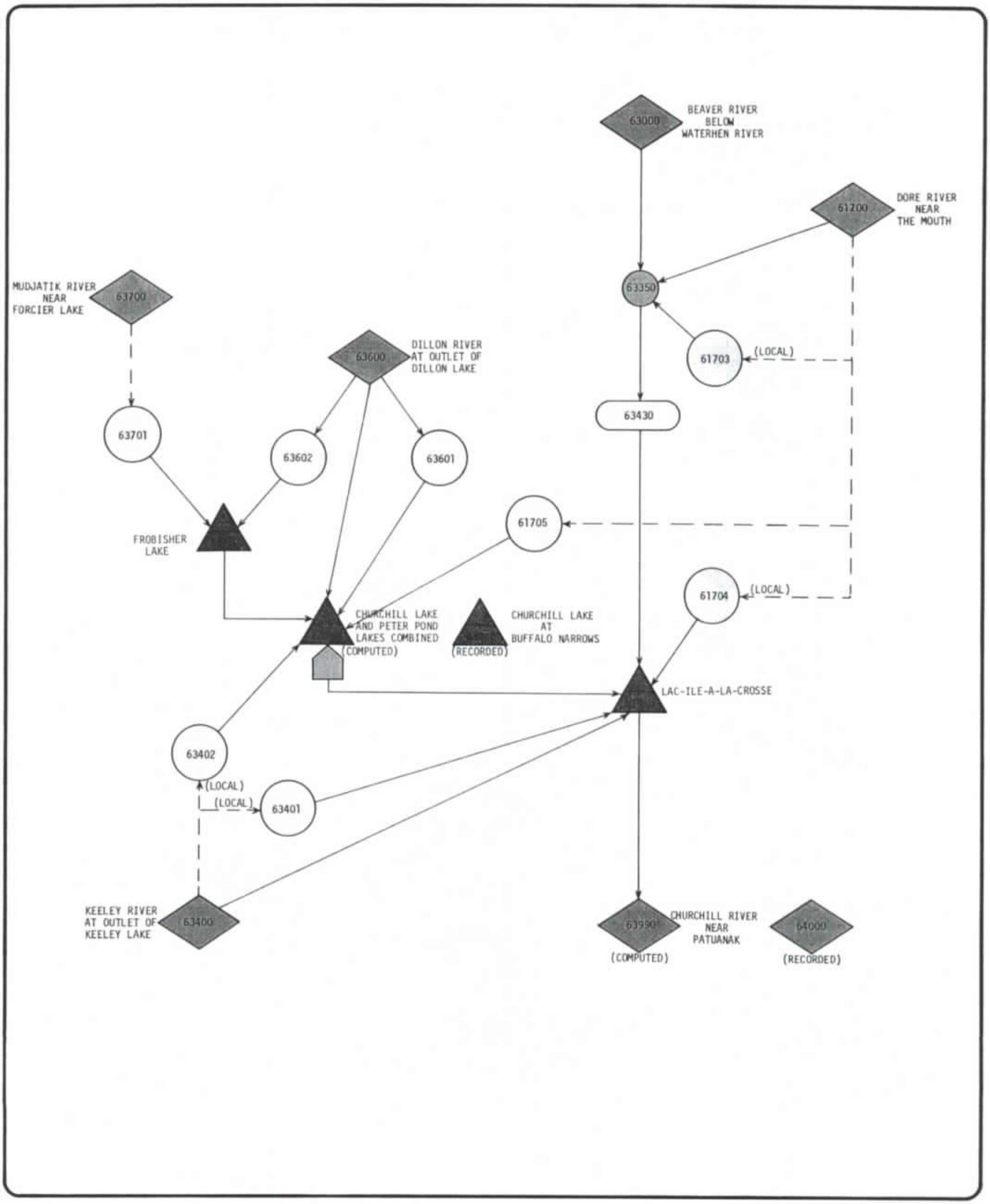


Figure 7: SSARR River System Chart for Churchill River to Patuanak.

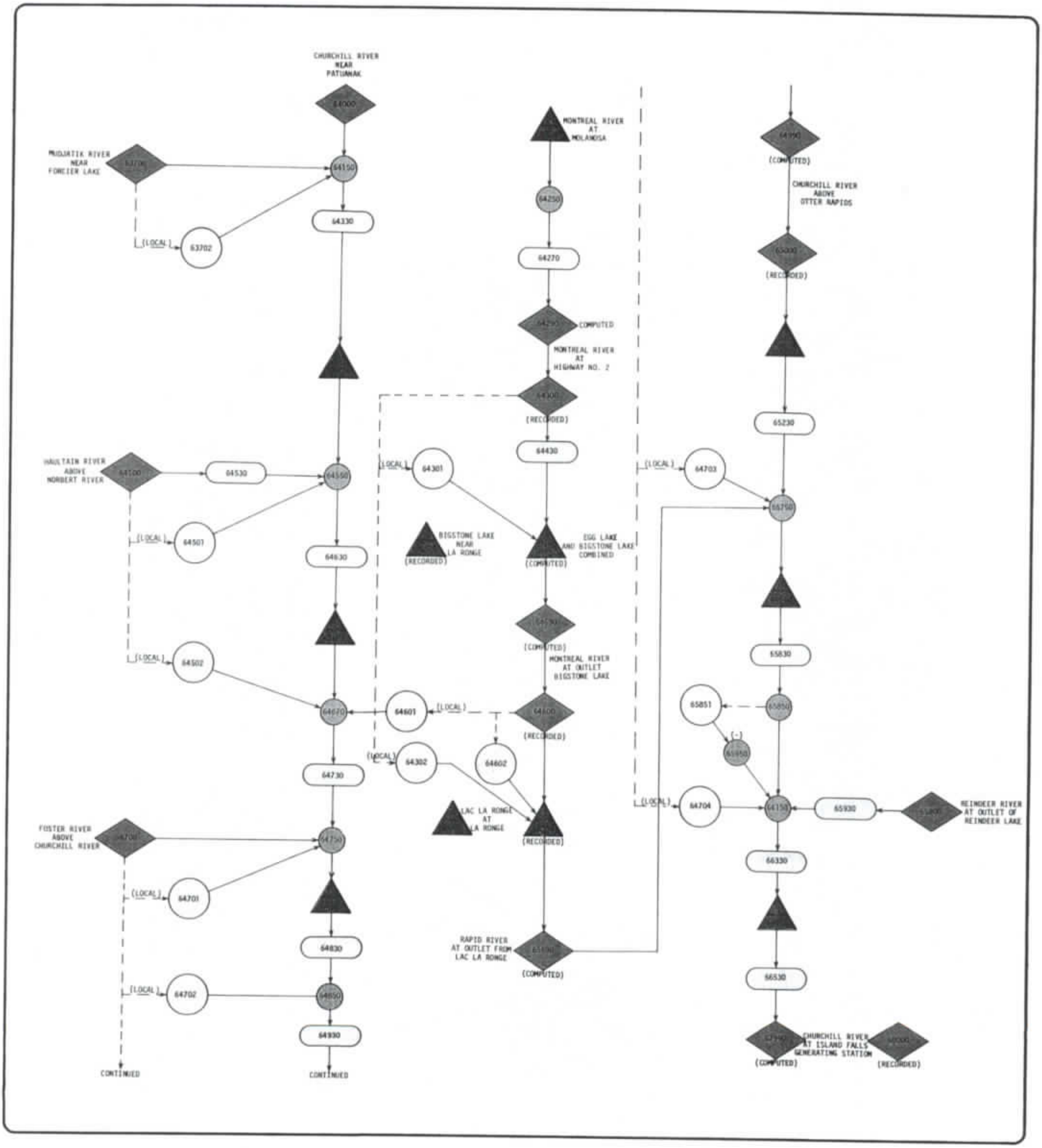


Figure 8: SSARR River System Chart for the Churchill River to Island Falls.

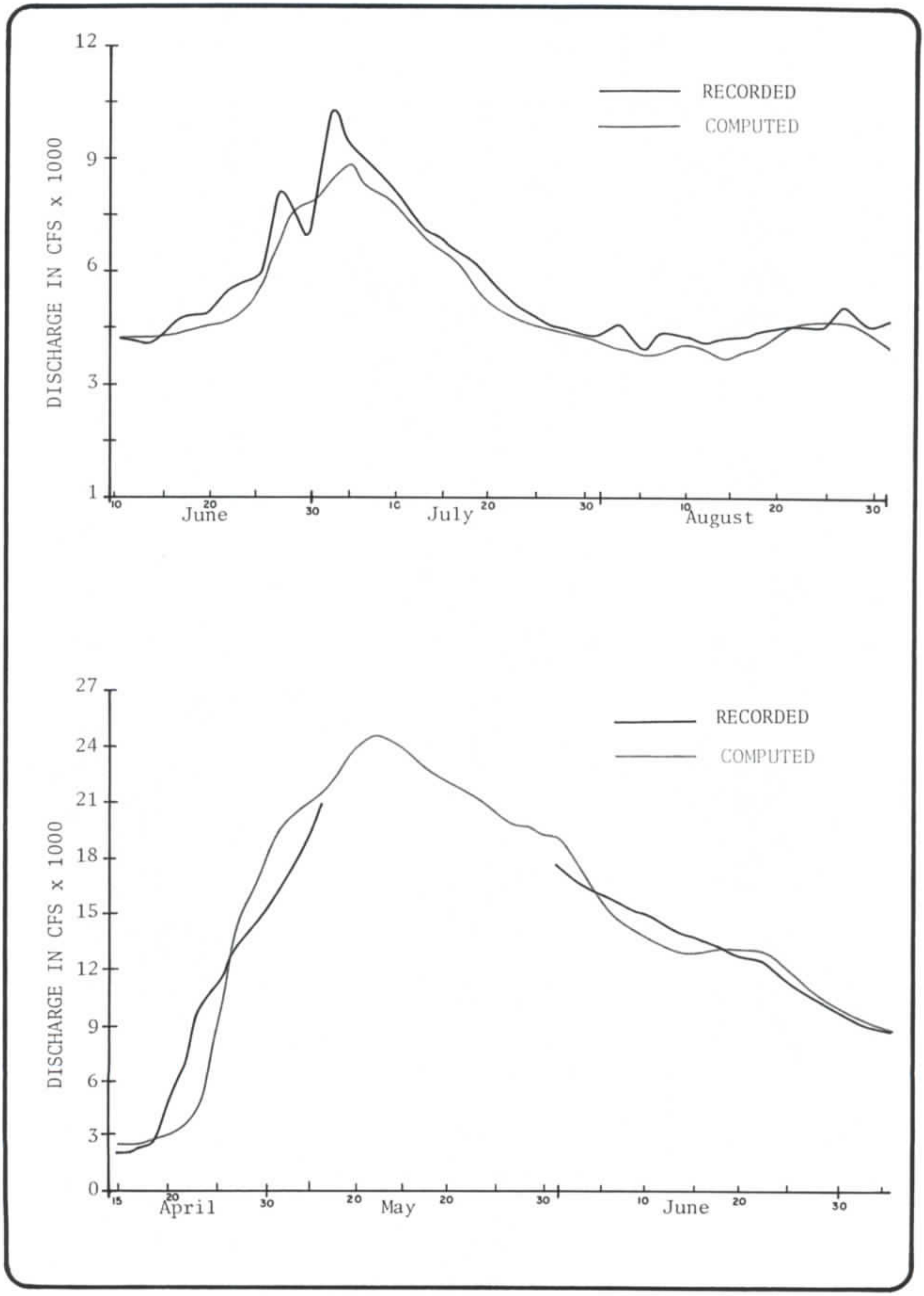


Figure 9: Recorded and Computed Discharges for Beaver River below Waterhen River.

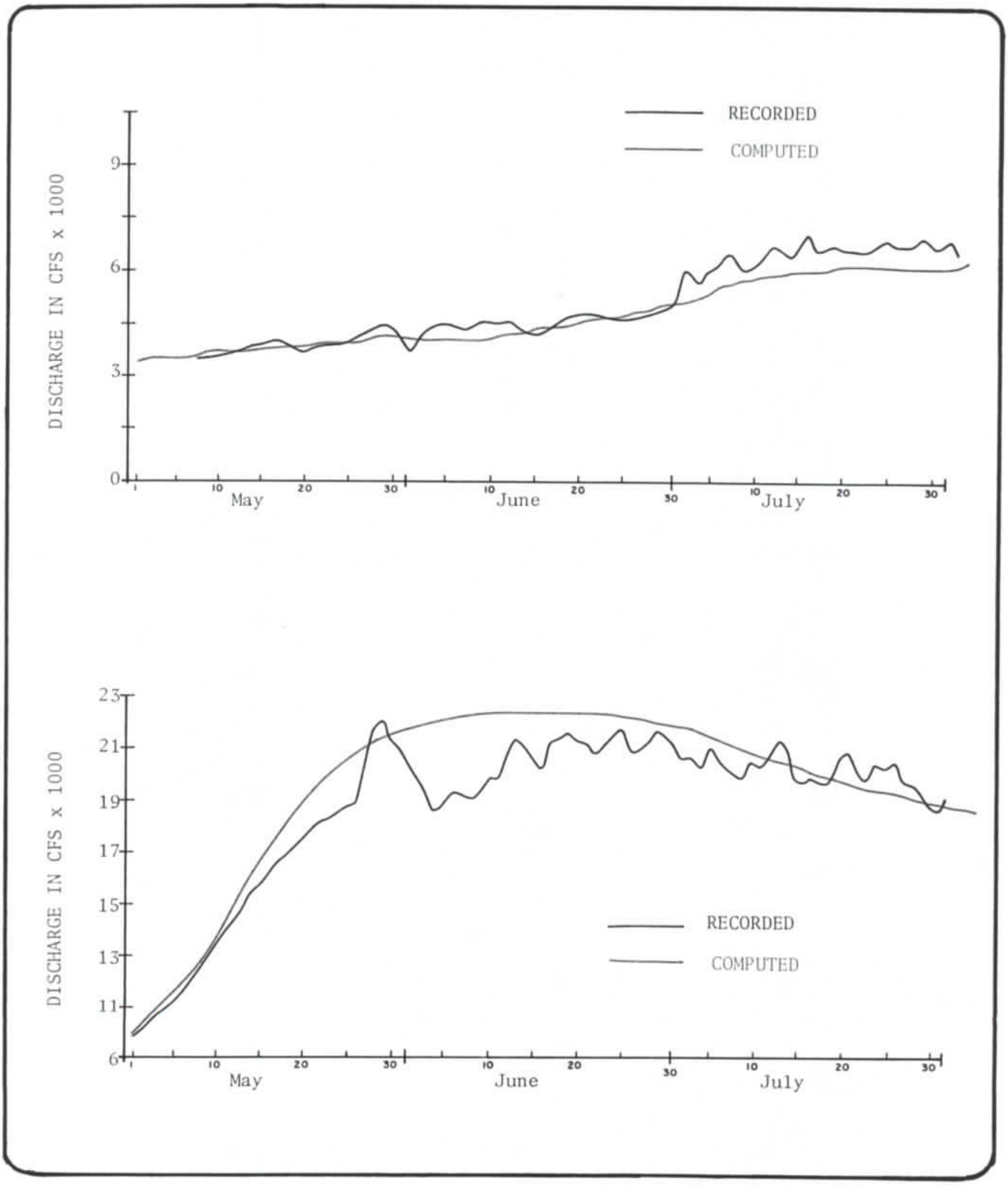


Figure 10: Recorded and Computed Discharges for Churchill River near Patuanak.

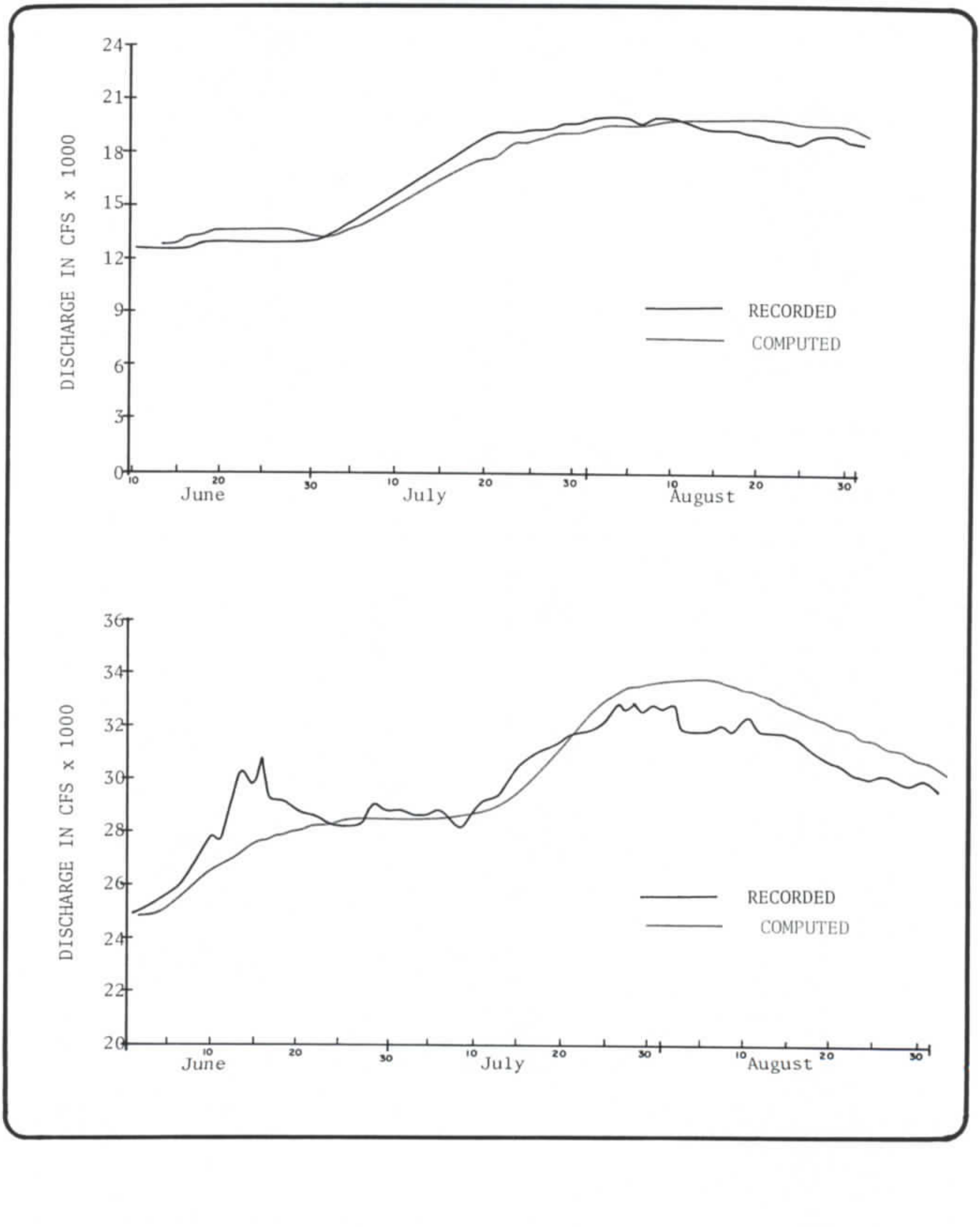


Figure 11: Recorded and Computed Discharges for Churchill River above Otter Rapids.

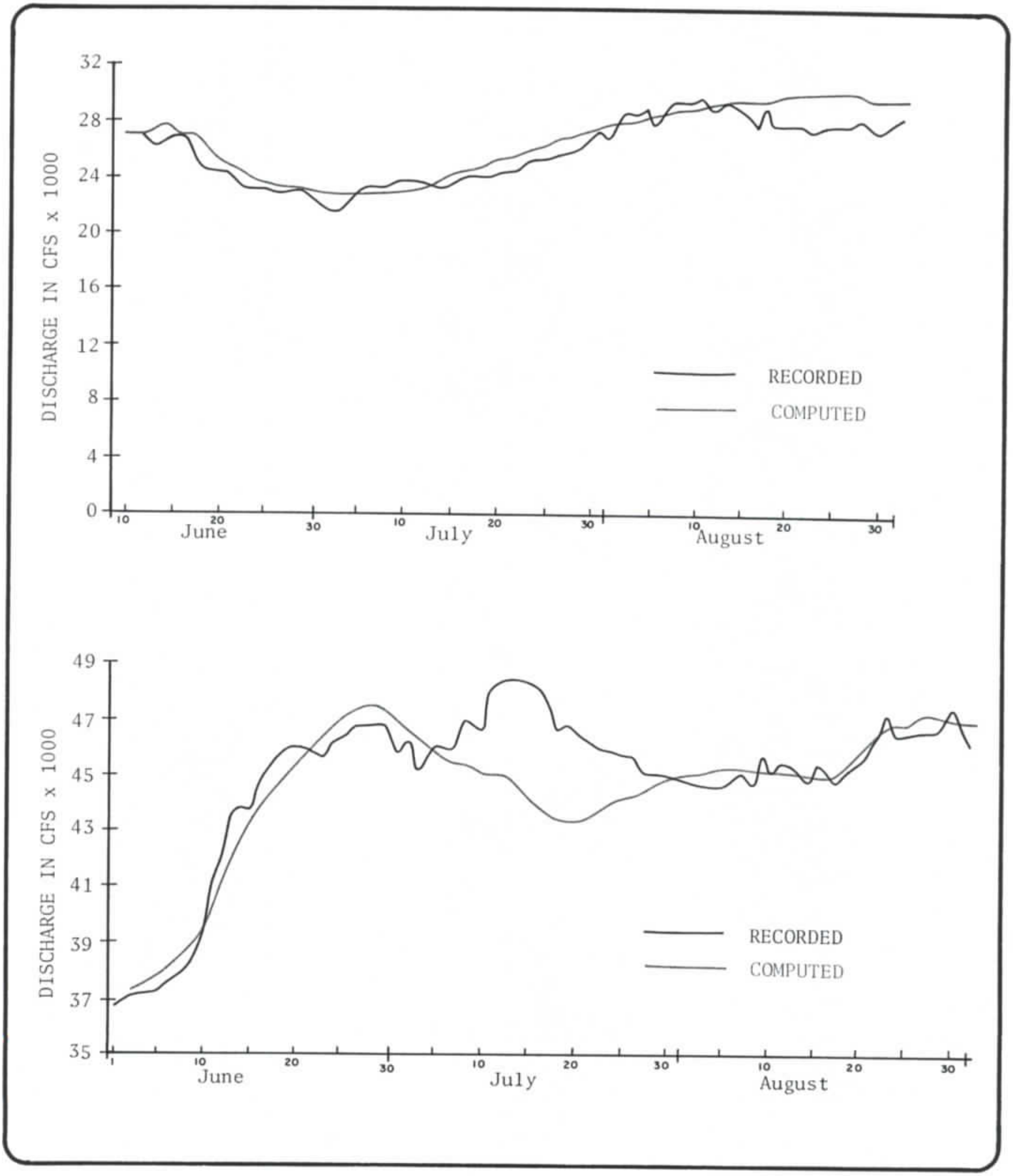


Figure 12: Recorded and Computed Discharges for Churchill River at Island Falls.

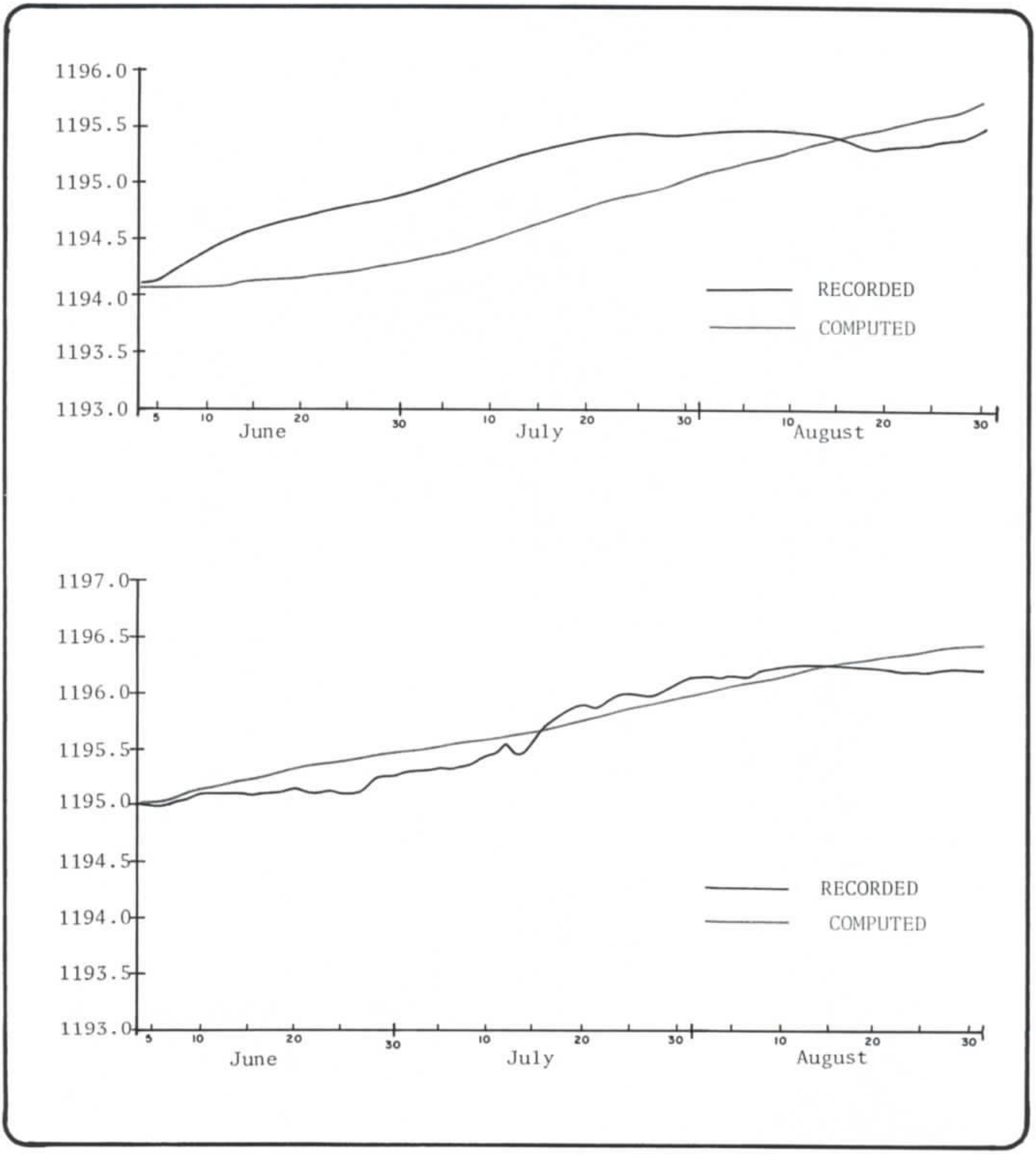
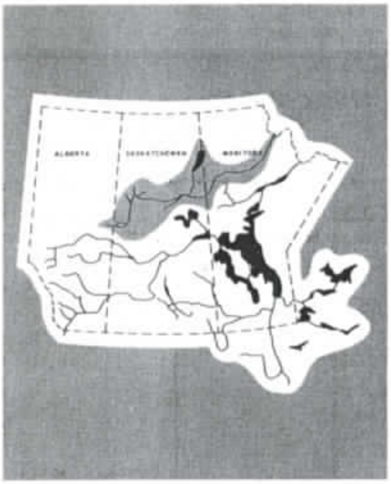


Figure 13: Recorded and Computed Level for Lac la Ronge at La Ronge.



RECOMMENDATIONS

All recommendations arising out of the Churchill River basin forecasting study are presented under the following headings:

A. Forecasting:

Water Supply —

Spring and Summer.

Winter.

River Flow —

During Periods of Normal Discharge.

B. Network Requirements:

Hydrometric Network.

Meteorological Network.

Localities at which forecasts should be made are summarized in Table 6. The recommended networks to facilitate these forecasts are identified in the report and in Appendix A, and are summarized in Table 7.

Table 6

Recommended Forecasts — Churchill River Basin

Forecast Category	Forecast Location	Initial Forecast Date	Updating Frequency
Water Supply:			
Spring and Summer	Beaver River at Cold Lake Reserve Beaver River near Dorintosh Churchill River above Granville Falls Churchill River above Otter Rapids Churchill River at Island Falls Generating Station Reindeer River at Outlet Reindeer Lake	March 1	Monthly until October 1
Winter	Churchill River above Granville Falls Churchill River above Otter Rapids Churchill River at Island Falls Generating Station Reindeer River at Outlet Reindeer Lake	January 1	February 1
River Flow:			
	Beaver River at Cold Lake Reserve Beaver River below Meadow River Beaver River below Waterhen River Beaver River near Dorintosh	3 to 5 days after spring runoff commences	As required
During Periods of Normal Discharge	Bigstone Lake near La Ronge Churchill Lake at Buffalo Narrows Churchill River above Otter Rapids Churchill River at Island Falls Generating Station Churchill River near Patuanak Lac Ile-a-la-Crosse Lac la Ronge at La Ronge Montreal River at Highway No. 2 Montreal River at Outlet of Bigstone Lake Rapid River at Outlet of Lac la Ronge	May 15	Weekly until October 31

Table 7

Network Requirements for Streamflow Forecasting

Churchill River Basin

Hydrometric Network	
Water Supply Forecasts	Existing: - 6 stations. Additional Requirements: - Forecasts of major reservoir operation.
River Flow Forecasts	Existing: - 4 stations with data transmission. - 13 stations visited by Water Survey of Canada. Additional Requirements: - 9 existing stations, data transmission required. - 1 new station with data transmission. - 2 new stations. - Forecasts of major reservoir operation.
Meteorological Network	
Water Supply Forecasts	Existing: - 14 climatological stations. - 18 snow courses. - 11 Nipher snow gauges. Additional Requirements: - 5 storage-precipitation gauges. - 4 snow courses.
Network Analysis and Development	- 7 snow courses.

A. FORECASTING

1. WATER SUPPLY

1.1. Spring and Summer

It is recommended that spring and summer water supply forecasts be made for Beaver River at Cold Lake Reserve, Beaver River near Dorintosh, Churchill River above Granville Falls, Churchill River above Otter Rapids, Churchill River at Island Falls Generating Station and Reindeer River at Outlet of Reindeer Lake.

The forecast equations are summarized in Table 3. Procedures and input parameters are described in detail in the manual *Churchill River Streamflow Forecasting — User Manual, Water Supply*. The first date of these forecasts should be March 1, with monthly updating until October 1.

1.2. Winter

It is recommended that winter water supply forecasts be made for Churchill River above Granville Falls, Churchill River above Otter Rapids, Churchill River at Island Falls Generating Station and Reindeer River at Outlet of Reindeer Lake.

The forecast equations are summarized in Table 4. Procedures and input parameters are described in detail in the manual *Churchill River Streamflow Forecasting — User Manual, Water Supply*. The forecasts should be prepared on January 1, with no subsequent updating.

2. RIVER FLOW

2.1. During Periods of Normal Discharge

It is recommended that these forecasts be made for the fourteen sites identified in Table 6 using the Streamflow Synthesis and Reservoir Regulation (SSARR) routing model.

Detailed procedures for making these forecasts are provided in the manual *Churchill River Streamflow Forecasting — User Manual, River Routing*. The first date of these forecasts for the Beaver River system should be immediately after spring runoff commences, with updating as required. For the main stem Churchill River, the first date of forecast should be May 15, with weekly updating until October 31.

B. NETWORK REQUIREMENTS

It is recommended that the hydrometric network as identified in Table 6 and summarized in Table 7, and the meteorological network identified in Appendix A and summarized in Table 7 be classified as key long-term forecasting stations.

The major cost for network upgrading will be the costs associated with remote data transmission. These costs will be discussed in the *Forecast Centre* report.

1. HYDROMETRIC NETWORK

1.1. Forecasts of Major Reservoir Operation for Water Supply and River Flow Forecasts

It is recommended that power companies and others regulating lake outflows be required to report their daily and planned reservoir operations to the appropriate agency.

This data is required for both water supply and river flow forecasts.

1.2. Existing Gauging Stations for Water Supply Forecasts

It is recommended that Beaver River at Cold Lake Reserve, Beaver River near Dorintosh, Churchill River above Granville Falls, Churchill River at Island Falls Generating Station, Churchill River above Otter Rapids and Reindeer River at Outlet of Reindeer Lake gauging stations be retained.

The locality of these six stations is shown in Figure 1.

1.3. Existing Gauging Stations for River Flow Forecasts

It is recommended that four existing stations with data transmission facilities, and thirteen existing stations visited monthly or bi-monthly by Water Survey of Canada, be retained.

The four stations with data transmission facilities are Beaver River at Cold Lake Reserve, Churchill River at Island Falls Generating Station. Lac la Ronge at La Ronge and Reindeer River at Outlet of Reindeer Lake. Data on a monthly or bi-monthly basis for the following thirteen stations will satisfy existing river flow forecasting requirements:

Bigstone Lake near La Ronge.

Churchill Lake at Buffalo Narrows.

Churchill River above Otter Rapids.

Churchill River near Patuanak.

Dillon River at Outlet of Dillon Lake.

Foster River above Churchill River.

Haultain River above Norbert River.

Keeley River at Outlet of Keeley Lake.

Makwa River at Rapid View.

Montreal River at Highway No. 2.

Montreal River at Outlet of Bigstone Lake.

Mudjatik River near Forcier Lake.

Waterhen River near Goodsoil.

Three of these stations, Churchill River above Otter Rapids, Churchill River at Island Falls Generating Station and Reindeer River at Outlet of Reindeer Lake, have been identified as water supply forecast locations. The locality of the aforementioned seventeen stations is shown in Figure 1.

1.4. Existing Gauging Stations Requiring Upgrading for River Flow Forecasts

It is recommended that the upgrading of data transmission facilities be undertaken at nine hydrometric stations.

The Beaver River basin is subject to flooding during periods of high flow, and the existing level of development in this basin necessitates river flow forecasts during these periods. Due to the relatively long travel times in the Beaver River system it would be satisfactory if data transmission upgrading were in the form of reporting observers, if they were available. The eight stations in the Beaver River basin where upgrading of data transmission facilities are required are:

Beaver River below Waterhen River.

Beaver River near Dorintosh.

Beaver River near Goodridge.

Dore River near the Mouth.

Jackfish Creek near La Corey.

Meadow River near Meadow Lake.

Sand River near the Mouth.

Waterhen River above Beaver River.

Also, data transmission upgrading is required for Montreal Lake near Molanosa to forecast levels of Lac la Ronge. The locality of the aforementioned nine stations is shown in Figure 1.

1.5. New Gauging Stations for River Flow Forecasts

It is recommended that a gauging station with data transmission facilities be installed on Bow River, and gauging stations be established on Frobisher Lake and Smoothstone River.

Inaccurate forecasts of Lac la Ronge levels are generated when heavy rainfall events occur in the highlands area to the south of the lake, as the level of Lac la Ronge is presently forecast by using the discharge of Montreal River which is not representative of the large streams rising in the highlands area and flowing into Lac la Ronge. Forecast accuracy of Lac la Ronge levels would improve if a gauging station with data transmission facilities were installed on Bow River.

Churchill Lake at Buffalo Narrows water level forecasts are based on the discharge of Dillon, Mudjatik and Keeley Rivers. However, these three rivers are not representative of local ungauged inflow to Churchill Lake, as much of this inflow originates from the north in the Turnor Lake and Frobisher Lake region. A gauging station on Frobisher Lake would index the contribution of this area.

The southern Churchill River tributaries which drain the plains region between Patuanak and Otter Rapids are not gauged. The contribution of this region is estimated by the discharge of Montreal River, a stream which does not drain directly into the Churchill River but into Lac la Ronge. If the Smoothstone River were gauged, a more accurate estimate of the inflow from the southern plains would be provided.

2. METEOROLOGICAL NETWORK

2.1. Existing Climatological Stations fow Water Supply Forecasts

It is recommended that thirteen climatological stations within the Churchill River basin and The Pas A, be retained for water supply forecasting.

The climatological stations which are used for water supply forecasting are:

Big River	Loon Lake
Brochet	Meadow Lake
Buffalo Narrows	Stanley
Cold Lake	The Pas A
Ile-a-la-Crosse	Waskesiu Lake
Island Falls	Whitesand
La Ronge	Wollaston Lake

Figure A1 shows the location of these stations. Although, as shown in Tables 1 and 2, the simple correlations between these stations and forecast locations are generally poor, there is nothing else on which to base water supply forecasts. Therefore, these stations must be retained for water supply forecasting until expansion of the meteorological network provides better information for water supply forecasts.

2.2. Existing Snow Courses for Water Supply Forecasts

It is recommended that the eighteen snow courses operated by the Atmospheric Environment Service, Manitoba Water Resources Branch and Water Survey of Canada within and adjacent to the Churchill River basin be retained.

These snow courses are shown in Figure A1, and they should be retained until sufficient data is available for evaluation.

2.3. Existing Nipher Snow Gauges for Water Supply Forecasts

It is recommended that eleven existing Nipher snow gauges within and adjacent to the Churchill River basin be maintained.

The locality of these Nipher gauges is shown in Figure A1. These gauges are required to augment the measurement of winter precipitation, and they should be retained until sufficient data is available for evaluation.

2.4. New Storage-Precipitation Gauges for Water Supply Forecasts

It is recommended that storage-precipitation gauges be co-located at five Water Survey of Canada stream gauging stations within and adjacent to the Churchill River.

The location of the sites for the proposed new storage-precipitation gauges is shown in Figure A1. Only one surface weather station exists within the basin north of the Churchill River and west of Reindeer Lake. The lack of precipitation data from this area is perhaps the most significant factor in limiting water supply forecast accuracy. Four storage-precipitation gauges, co-located with existing stream gauging stations are recommended for this area. South of the Churchill River, a storage gauge is recommended at the Dore River gauging station.

2.5. New Snow Courses for Water Supply Forecasts

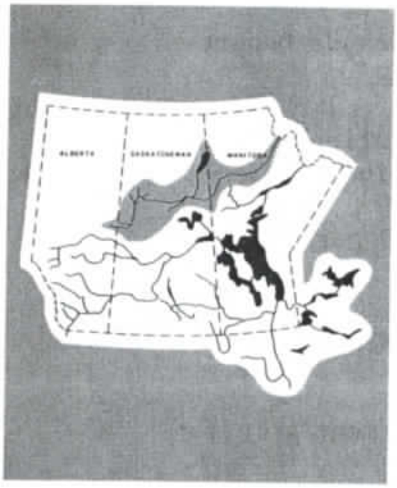
It is recommended that four snow courses be established.

The new courses should be located at the surface weather stations at Brocket, Buffalo Narrows, Collins Bay and Cree Lake. The locations are shown in Figure A1.

2.6. New Snow Courses for Network Analysis and Development

It is recommended that seven snow courses be established.

The new courses would be co-located at seven Water Survey of Canada stream gauging stations as shown in Figure A1. They would be located in various land forms and vegetative cover to provide data on the effect of these two variables on snow accumulation.



ACKNOWLEDGMENTS

This report was prepared by Mr. W, Nemanishen under the direction of Mr. G. H. Morton. Testing and development of the water supply forecasts was the responsibility of Mr. H. M. Wagner. Testing and development of the routing model was the responsibility of Mr. D. R. Graham. The majority of data extraction, preparation of charts and graphs, and reconstitution of basin parameters and river characteristics was carried out by Mr. C. Bearchief. Drafting was done by Mr. K. Cornelius. The typing and format of the report was the responsibility of Miss O. Kristjanson.

Mr. R. D. May of Water Survey of Canada, Calgary District, made his facilities and staff available as required and this was the major contribution toward the completion of this report and the associated user manuals. Another significant contribution was that of the University of Calgary providing computer facilities which resulted in a considerable saving in the cost of the study.

The United States Army Corps of Engineers provided the computer program and related reports for the Streamflow Synthesis and Reservoir Regulation (SSARR) routing model, and considerable assistance was received from their engineers. The advice of the Committee on Hydrology was provided in connection with the contents and organization of this report.

It would be difficult to adequately acknowledge the work done by each individual or agency involved. Therefore, the following is only a listing of agencies which made a major contribution.

<u>Agencies Represented on the Study</u>

Water Survey of Canada, Canada Department of the Environment.

Atmospheric Environment Service, Canada Department of the Environment.

Water Planning and Management Branch, Canada Department of the Environment.

Prairie Farm Rehabilitation Administration, Canada Department of Regional Economic Expansion.

Technical Services Division, Alberta Department of the Environment.

Water Resources Branch, Manitoba Department of Mines, Resources and Environmental Management.

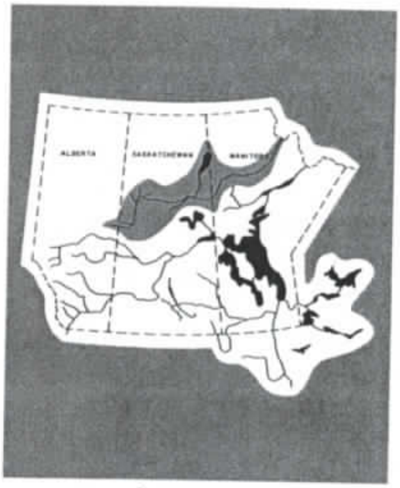
Hydrology Branch, Saskatchewan Department of the Environment.

The Secretariat, Prairie Provinces Water Board.

Other Co-Operating Agencies

United States Army Corps of Engineers.

University of Calgary.



BIBLIOGRAPHY

Beattie, C., and Steppuhn, H. *Snowcover Surveys for the Mackenzie Valley*. Progress Report, Division of Hydrology. University of Saskatchewan, 1973.

Bruce, J. P., and Clark, R. H. *Introduction to Hydrometeorology*. Pergamon Press, Toronto, 1966.

Buckler, S. J. *A Preliminary Study of Hydrometrical Deficiencies in Manitoba, Saskatchewan and Alberta*. Hydrometeorological Report No. 5, Prairie Hydrometeorological Office, Atmospheric Environment Service, Canada Department of the Environment, Regina, Saskatchewan, 1971.

Cheng, T. T., and Kerber, R. E. *Forecast Centre(s) Investigation*. Committee on Hydrology, Prairie Provinces Water Board, 1975.

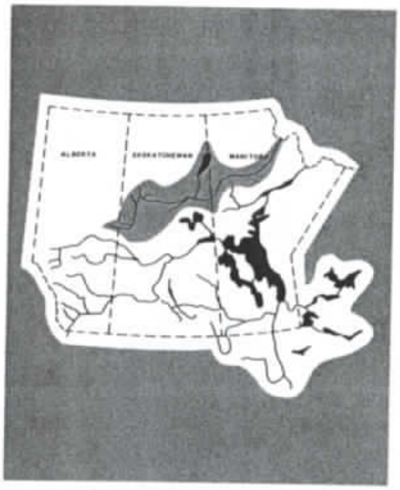
Kogan, R. M., Nazarov, I. M., and Fridman, Sh. D. *Determination of Water Equivalent of Snow Cover by the Method of Aerial Gamma-Survey*. Soviet Hydrology: Selected Papers, No. 2, 1965.

Loijens, H. S., and Grasty, R. L. *Airborne Measurements of Snow Water Equivalent Using Natural Gamma Radiation over Southern Ontario, 1972-73*. Water Resources Branch, Inland Waters Directorate, Canada Department of the Environment, Ottawa, Scientific Series No. 34, 1973.

Nemanishen, W. *Streamflow Forecasting, Qu'Appelle River*. Committee on Hydrology, Prairie Provinces Water Board, 1975.

Peck, E. L., Bissel, V. C., Jones, E. B., and Burge, D. L. *Evaluation of Snow Water Equivalent by Airborne Measurement of Passive Terrestrial Gamma Radiation.* Water Resources Research, Vol. 7, No. 5, pp. 1151-1159, 1971.

Uryvaev, V. A., and Vershinina, L. K. *Principal Rules in Selecting and Charting Courses for Airborne Measurement of Snow Water Equivalent in Determination of the Water Equivalent of Snow Cover.* Israeli Program for Scientific Translations, 1971.



APPENDIX A

SNOW MEASUREMENT NETWORK

The Churchill River system begins in Alberta and flows more than 1,000 miles to Hudson Bay, draining an area of some 115,000 square miles in the northern portion of the Prairie Provinces. Water from snowmelt contributes significantly to the flow of the Churchill River since one-third or more of the precipitation over the basin is in the form of snow. Reliable estimates of the snowpack water resource are essential to flow forecasting and water resource management, yet existing networks for measuring precipitation, particularly snowfall, are extremely limited. In this appendix, existing snow measurement networks are evaluated and recommendations are made for the improvement of snowpack evaluation in the Churchill River basin.

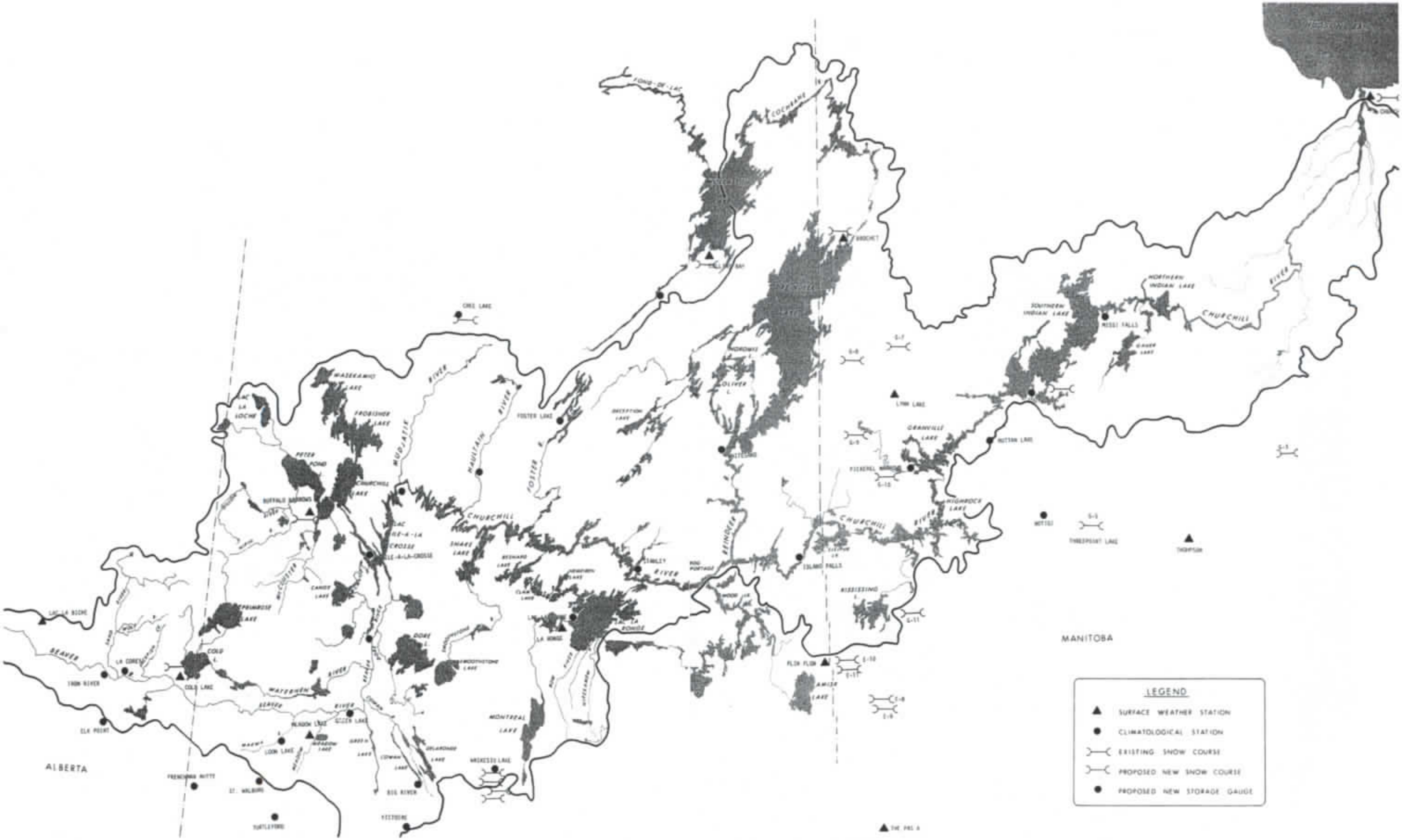
Some problems associated with snow measurement are discussed in Appendix C of the *Qu'Appelle River, Streamflow Forecasting* report. There would be additional problems associated with snow accumulation in forested areas and the rugged terrain of the Canadian Shield.

EXISTING NETWORKS

Currently there are three sparse networks in the Churchill River basin for the measurement of snowfall and snow water equivalent. These are:

1. Surface Weather Stations:

   In addition to other meteorological parameters, the depth of new snow and depth of snow on the ground are measured at least daily. Since the early 1960's most of these stations have also used a Nipher snow gauge to measure the water equivalent of snowfall. The locations of the eleven surface weather stations in and adjacent to the basin which are useful for forecasting are shown in Figure A1.


LEGEND
SURFACE WEATHER STATION
CLIMATOLOGICAL STATION
EXISTING SNOW COURSE
PROPOSED NEW SNOW COURSE
PROPOSED NEW STORAGE GAUGE
MANITOBA
ALBERTA
CHURCHILL
RIVER
SOUTHERN INDIAN LAKE
NORTHERN INDIAN LAKE
MONTREAL LAKE
PETER POND
CHURCHILL LAKE
FROBISHER LAKE
WASEKAMIO LAKE
COLD L.
COLD LAKE
BUFFALO NARROWS
LA RONGE
ISLAND FALLS
FLIN FLON
THOMPSON
GRANVILLE LAKE
LYNN LAKE
FOSTER LAKE
BEAVER
WATERHEN RIVER
LAC LA LOCHE
LAC ÎLE-A-LA CROSSE
ILE-A-LA-CROSSE
REINDEER
HAULTAIN RIVER
MUDJATIK
SNAKE LAKE
KISSISSING
PRIMROSE LAKE
DORE L.
SMOOTHSTONE LAKE
MONTREAL LAKE
BIG RIVER
ELK POINT
LAC LA BICHE
IRON RIVER
CREE LAKE
BROCHET
LA CORNE
LOON LAKE
MEADOW LAKE
HIGHROCK LAKE
OLIVER L.
STANLEY
NUTTAN LAKE
THREEPOINT LAKE

2. Climatological Stations:

Precipitation and, usually, temperature extremes are measured daily. Snowfall is measured as depth of new snow. Water equivalent is determined by assuming the snow density to be 0.1. Locations of the climatological stations in and adjacent to the basin are shown in Figure A1.

3. Snow Courses:

Snow tubes are used to sample the snowpack and to obtain depth, density and water equivalents. Figure A1 shows the location of the eighteen snow courses in and adjacent to the basin.

Tables A1, A2 and A3 give additional details as to location, observing program and length of record at each of the surface weather stations, climatological stations and snow courses shown in Figure A1.

It is apparent from Figure A1 that, except for the extreme southwest part of the basin, the sampling networks are very limited. Large areas in the west-central, northern and eastern parts of the basin are currently not being sampled.

Optimum densities for basin precipitation networks are difficult to determine since they depend upon the nature of the terrain, the variability of precipitation over the basin, the size of the basin and the use to which the data will be put. Bruce and Clark (1966) suggest a network of one station per 200-300 square miles to obtain gross seasonal precipitation values for comparison with seasonal runoff values. According to Buckler (1971) the Atmospheric Environment Service Strategic Operations Plan criteria for a national network is one station per 625 square miles in settled areas and implies a spacing of 50 miles, or one station per 2,500 square miles over sparsely settled areas. Over the major part of the Churchill River basin, station densities are less than one-half of this standard for sparsely settled areas.

The major reason for the sparse sampling networks is obviously logistical. Most of the basin is unsettled, there are few roads and, in general, access is difficult. The few observing sites that do exist are located at settlements such as lumbering, mining or hydroelectric sites.

ALTERNATIVE METHODS

At present, imagery from Earth Resources Satellites (ERTS) and Geostationary Operational Environmental Satellites (GOES) does not provide snowpack water equivalents and is of limited value. The advance and retreat of the snow line over the basin can be determined from the imagery and it is possible to identify areas of melting snow from some ERTS imagery. Eventually, as instrumentation and technology improve, it may be possible to estimate basin snow water equivalents

Table A1

Surface Weather Stations in and Adjacent to the Churchill River Basin

Station	Position	Year Current Observing Program Began	Observation Time
Alberta:			
Cold Lake A	54°25', 110°17'	1966	Hourly
Lac La Biche A	54°46', 112°02'	1958 (1944)	Hourly
Saskatchewan:			
Buffalo Narrows	55°51', 108°28'	1968 (1954)	Synoptic hours and intermediate hours plus some extra observations
Collins Bay	58°11', 103°41'	1974	Irregular observations each day
La Ronge A	55°06', 105°18'	1966 (1959)	Synoptic hours and intermediate hours plus some extra observations
Meadow Lake	54°07', 108°26'	1967 (1923)*	Synoptic and intermediate hours
Manitoba:			
Brochet	57°53', 101°40'	1948 (1945)	Irregular observations each day
Churchill A	58°45', 94°04'	1943 (1928)*	Hourly
Flin Flon A	54°41', 101°41'	1954	Irregular observations each day
Lynn Lake	56°52', 101°04'	1954 (1952)	Hourly
Thompson A	55°48', 97°52'	1967	Hourly

* = Break in record.

( ) = Year initial observations began — in many cases temperature extremes and daily precipitation only.

Table A2

Climatological Stations in and Adjacent to the Churchill River Basin

Climatological Station	Position	Year Current Observing Program Began	Elements Observed
Alberta:			
Elk Point	53°53', 110°54'	1911*	T, P.
Iron River	54°25', 111°00'	1925*	T, P.
La Corey	54°25', 110°46'	1967 (1962)*	T, P.
Saskatchewan:			
Big River	53°50', 107°02'	1956 (1951)*	P.
Foster Lake	56°48', 105°21'	1955*	P.
Frenchman Butte	53°33', 109°39'	1951*	T, P.
Green Lake	54°17', 107°48'	1956	P.
Ile-a-la-Crosse	55°27', 107°52'	1956	P.
Island Falls	55°32', 102°21'	1931	T, P, R (partial hourly program 1946-65)
Lac la Ronge	55°08', 105°23'	1956 (1921)*	P.
Loon Lake CDA-EPF	54°04', 109°03'	1962 (1930)*	T, P.
Parkside CDA	53°14', 106°35'	1962 (1929)*	T, P.
Rabbit Lake	53°09', 107°46'	1930*	T, P.
St. Walburg	53°36', 109°09'	1912*	T, P.
Stanley	55°25', 104°32'	1910*	P.
Stoney Rapids	59°16', 105°46'	1960	T, P.
Turtleford	53°24', 108°57'	1923 (1920)	T, P.
Victoire	53°29', 107°02'	1957	T, P.
Manitoba:			
Flin Flon CFB	54°41', 101°58'	1959	T, P, W.
Flin Flon	54°46', 101°51'	1927	T, P.
Notigi	55°54', 99°22'	1973	T, P.
Pickerel Narrows	56°13', 100°35'	1963	P.
South Bay	56°40', 99°00'	1973	T, P.

W = Wind mileage.
R = Rainfall rate.
T = Temperature extremes.
P = Daily Precipitation
* = Partial record.
( ) = Year initial observing program began, different from current program or at a different location.

Table A3

Snow Courses in and Adjacent to the Churchill River Basin

Snow Course	Position	Years of Record	Sampling Program
Alberta:			
Cold Lake A	54°25', 110°17'	10	5 points – four times a month throughout winter
Saskatchewan:			
Anglin Lake	53°42', 106°03'	14	7 points – mid-March
Namekus Lake	53°47', 106°04'	14	8 points – mid-March
Waskesiu Lake	53°51', 106°04'	14	8 points – mid March
Waskesiu Lake	53°55', 106°05'	3	5 points – four times a month throughout winter
Manitoba:			
Churchill A	58°45', 94°04'	11	1st & 15th day of each month throughout winter
Cranberry Portage	54°53', 101°22'	23	5 points – mid-February and mid-March
Cranberry Portage	54°36', 101°23'	23	5 points – mid-February and mid-March
Cold Lake	55°08', 101°07'	18	Mid-March
Dunphy Lake	56°40', 101°38'	18	Mid-March
Flin Flon	54°46', 101°51'	23	4 points – mid-February and mid-March
Flin Flon	54°46', 101°53'	23	6 points – mid-February and mid-March
Lynn Lake	56°52', 101°03'	18	Mid-March
Matheson Lake	56°25', 101°50'	18	Mid-March
Nelson House	55°45', 98°45'	18	Mid-March
South Indian Lake	56°48', 98°56'	18	Mid-March
Trophy Lake	56°15', 101°00'	18	Mid-March

from satellite imagery. At present, however, this is not an operational capability. Even when that capability is reached a suitable network of ground observation sites will be required for ground truth.

Airborne gamma radiation surveys have been used to measure basin snow water equivalent in Russia (Kogan et al 1965), the United States (Peck et al 1971) and southern Ontario (Loijens and Grasty 1973). The characteristics of the Churchill River basin, however, are such that it is extremely doubtful that airborne gamma surveys would provide useful measurements of the snow water resource in the basin. The large portion of the basin covered by lakes and bogs would make airborne gamma surveying difficult. Uryvaev and Vershinina (1971) point out that large errors may arise in the vicinity of marshes, flood plains and lakes, and suggest that such areas be avoided when laying out flight lines for the airborne gamma surveys. In addition, trees, especially conifers, attenuate the terrestrial gamma radiation, thus reducing what is normally an already weak signal. It is thus unlikely that airborne gamma surveys would be of more than limited value, except in the southwestern part of the basin along the Beaver River.

Neither satellite imagery nor airborne gamma surveys seem likely to provide additional snowpack water equivalent data in the Churchill River basin in the immediate future. It is not likely that the number of climatological or surface weather stations will increase appreciably in the near future. Thus, consideration should be given to methods of measuring accumulated snowfall amounts and/or snowfall water equivalents automatically.

Snowpillows have been used with success in wooded mountain areas which are not subject to wind erosion of the snowpack. It seems likely that snowpillows could be used in some of the forested areas in the Churchill River basin. Long-term precipitation gauges, such as the Sacramento and Fischer-Porter, can operate unattended for a month or more.

Automatic stations such as Atmospheric Environment Service's Hydrometeorological Recording and Telemetering System (HARTS) could be used to advantage in some of the more difficult to reach areas if costs are not prohibitive. The HARTS system has the ability to encode temperature data and accumulated precipitation from a Fischer-Porter gauge for transmittal by ERTS. Snowpillow data and wind run data have also been incorporated into this system.

CONCLUSIONS AND RECOMMENDATIONS

Existing snow measurement networks in the Churchill River basin are inadequate for even gross estimates of water equivalent for flow forecasting and water management purposes. There is a need to approximately double the existing precipitation measurement network and to supplement the data from this network with snow course data. There is little prospect of a significant increase in the number of climatological stations in the basin due to sparse settlement and difficult access. Recommendations for improving the measurement of snow water equivalent in the Churchill River basin must take into account the ruggedness of the terrain and above-average costs of installing and maintaining instruments in remote areas.

Recommendations are made for existing needs and for long-term network analysis and development.

Existing Requirements

1. Installation of storage gauges (Sacramento or other suitable accumulation type) at selected stream gauging sites to fill in some of the more obvious gaps in the network. Suggested locations are shown in Figure A1. These stream gauging sites are currently visited bi-monthly by Water Survey of Canada and the additional cost of reading and servicing a storage gauge at the same time would be minimal.

2. Establishment of snow courses at the following surface weather stations:

   Brochet,

   Buffalo Narrows,

   Collins Bay,

   Cree Lake.

   Personnel are available for the taking of weather observations at these sites and the additional expense for taking one or two snow surveys per year would be minimal.

3. Continued efforts to establish additional climatological stations, especially in areas which are not now sampled.

Long-Term Network Analysis

1. Establishment of additional snow courses near stream gauging sites to sample various landform and vegetation types. Snow surveys in the remote parts of the Churchill River basin entail considerable costs in transporting personnel to the site. If the survey can be combined with other travel, such as the regular bi-monthly visit to a stream gauging station, the additional cost of one or two snow surveys each winter would be kept to a minimum. Sites for the additional snow courses should be selected according to landscape and vegetative characteristics. In a study of snow cover in the Mackenzie Valley, Beattie and Steppuhn

(1973) found that regional snow cover amounts and variances often sorted into groups characterized by a common landscape of terrain and vegetation.

2. Investigate the possibility of using snowpillows in the basin.

3. Evaluate the benefits and costs of remote systems such as the HARTS system in extremely remote areas.

This appendix was prepared by D. J. Bauer, Meteorologist, Atmospheric Environment Service.