Environment Canada Environnement Canada

Application of the Water Use Analysis Model to the Richelieu River Basin

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SOCIAL SCIENCE SERIES NO. 22

INLAND WATERS DIRECTORATE
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Abstract

This study describes the application of the Water Use Analysis Model to the Richelieu River basin and outlines the various steps involved in this process.

It provides the main results. Water supply and demand, calculated on the basis of various growth scenarios, were compared. The study reveals that the Richelieu River basin has no water supply problems and that the supply is sufficient to meet forecasted demand requirements.

All components of the model could not be considered, however, because of insufficient data. Therefore, this study will serve as a starting point for the implementation of other studies and the establishment of data bases that are essential to the regional application of the model.

Résumé

Cette étude décrit la mise en application du modèle d'analyse d'utilisation de l'eau au bassin de la rivière Richelieu et relate les différentes étapes qui ont été suivies au cours de ce processus.

Elle fait état des principaux résultats qui ont été obtenus. Une comparaison de la disponibilité en eau par rapport à la demande évaluée selon plusieurs scénarios de croissance a été établie. L'étude fait ressortir que le bassin de la rivière Richelieu ne connaît pas de problème d'approvisionnement en eau et que l'offre est suffisamment élevée pour répondre aux besoins prévisibles.

L'ensemble des composantes du modèle n'a toutefois pu être considéré, faute de données suffisantes. Cette première phase servira donc de point de départ à la poursuite des études et au développement de bases de données qui sont essentielles à la mise en opération de ce modèle au niveau régional.

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L. Bernier

1. INTRODUCTION

1.1 PURPOSE OF THE STUDY

The purpose of this study is to identify the main steps in the application of the Water Use Analysis Model specifically to the Richelieu River basin and to present the results of the analysis.

1.2 BACKGROUND OF THE WATER USE ANALYSIS MODEL

The Water Use Analysis Model was developed in 1981 by Acres International Limited for the Water Planning and Management Branch of the Inland Waters Directorate, and sponsored by the Department of Energy, Mines and Resources. The study initially focused on energy projects in Canada with a view to identifying water requirements in critical regions over a forecast period of 20 years. Subsequent phases have made it possible to perfect the similation studies and to compare present and future supply with water demand and forecast requirements. For example, the Water Use Analysis Model can reveal conflicting types of water use, the optimal use of water with respect to available supply and, possibly, the impact of water pricing on water demand. Although the development of the model consisted of seven phases, this study is limited to the first five.[1] Figure 1.1 illustrates the operation of the model and all the variables that must be taken into consideration in the analysis. The following sections will discuss the various aspects of water supply and demand in more detail. We should mention that the groundwater and water quality components were being developed at the time of this study.

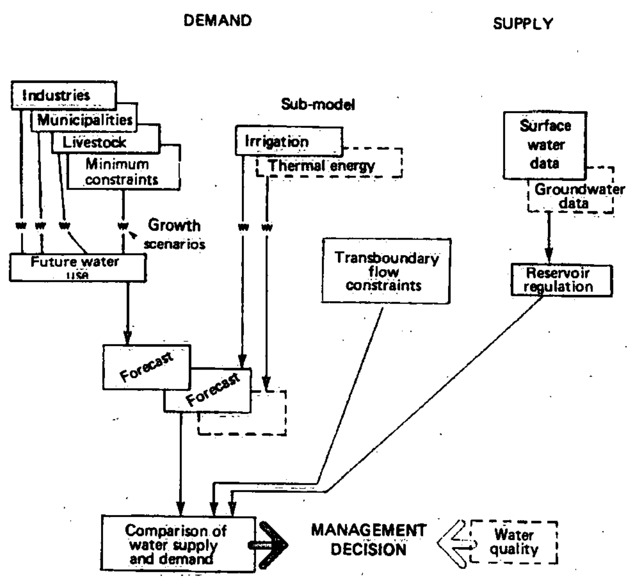


Figure 1.1 Water Use Analysis Model.

The selection of a drainage basin and the establishment of

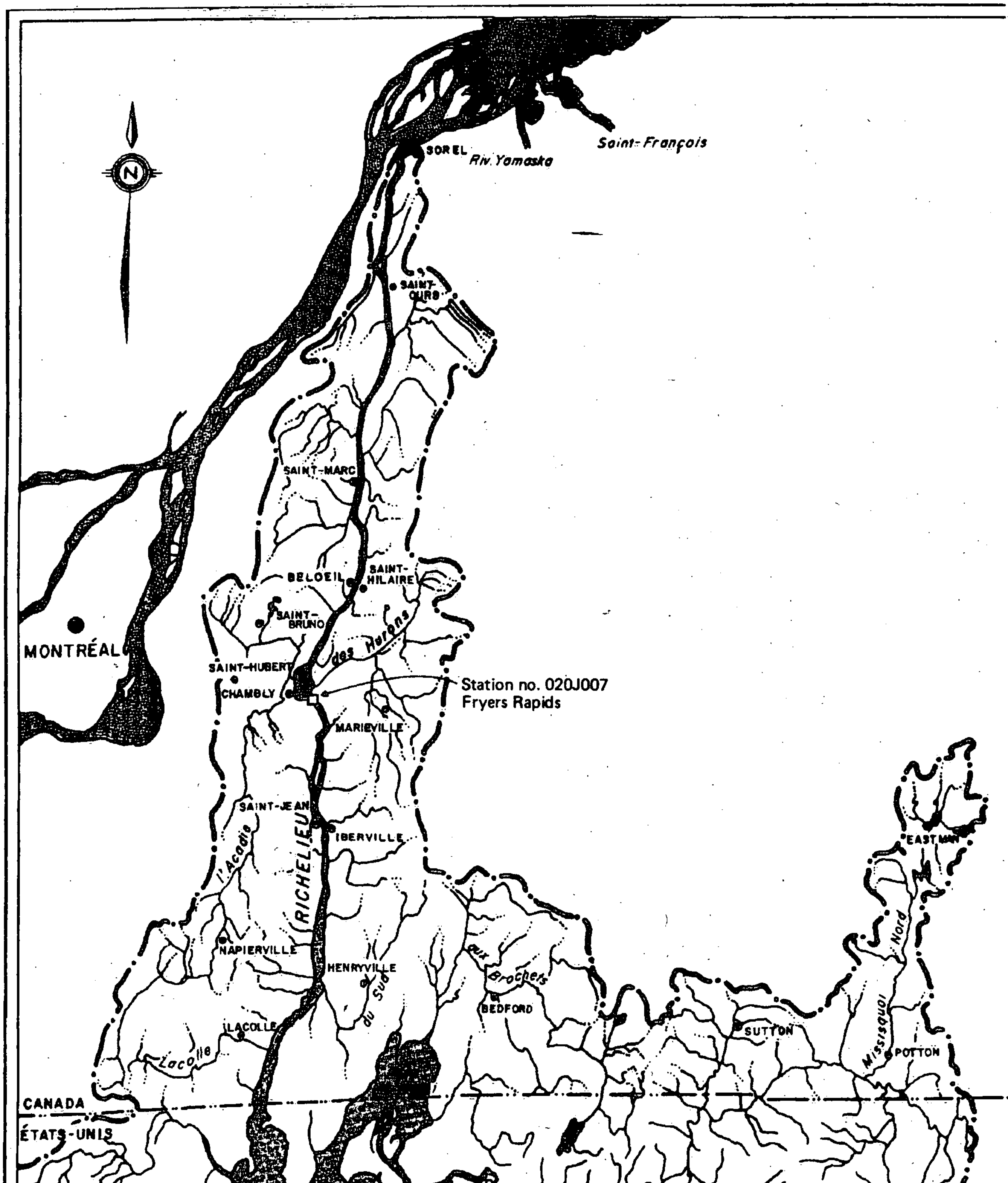


Figure 1.2 Drainage system of the Richelieu River basin

various data bases are essential to the development of the expertise required to apply the model, as was demonstrated by the study of the Saskatchewan-Nelson basin and Phase V of the ACRES project.

1.3 SELECTION OF THE RICHELIEU RIVER BASIN

The Richelieu River basin in Quebec was selected for the first application of the model because it is well documented and is not regulated.[2] In addition, the Richelieu River is a tributary of the St. Lawrence River and can serve as a starting point for the analysis of other tributaries located on the south shore of the St. Lawrence River. Figure 1.2 indicates the geographic location and boundaries of this river.

1.4 KEY FEATURES OF THE RICHELIEU RIVER BASIN

The Richelieu River is located south of the St. Lawrence River and covers 23 880 km^2. Only 3782 km^2 (16%) are in Canada. Owing to its location in relation to Montreal, intense development occurred in this drainage basin from 1961 to 1981. The following ten census divisions are entirely or partially located in this basin: Brome, Missisquoi, Iberville, Saint-Jean, Napierville, Chambly, Verchères, Rouville, Saint-Hyacinthe, and Richelieu. This study took only eight of these divisions into consideration. Brome and Missisquoi were eliminated. As a matter of fact, these two divisions had a relatively low growth rate from 1961 to 1981. According to 1981 population figures, the major urban centres located in this drainage basin are: Saint-Jean (35 640), Saint-Bruno-de-Montarville (22 880), Sorel (20 347), Beloeil (17 540), Tracy (12 843), Chambly (12 190), Mont-Saint-Hilaire (10 066), Iberville (8587), Marieville (4877), and Otterburn Park (4268).

1.5 CONFIGURATION OF THE RICHELIEU RIVER BASIN

One of the first steps involved in the application of the model is to define the configuration of the basin, or to specify the drainage system and the hierarchical relationship between each node or hydrologic station of the network.

Figure 1.3 illustrates the relationships between the hydrologic characteristics of the Richelieu River basin and the configuration developed to apply the model.

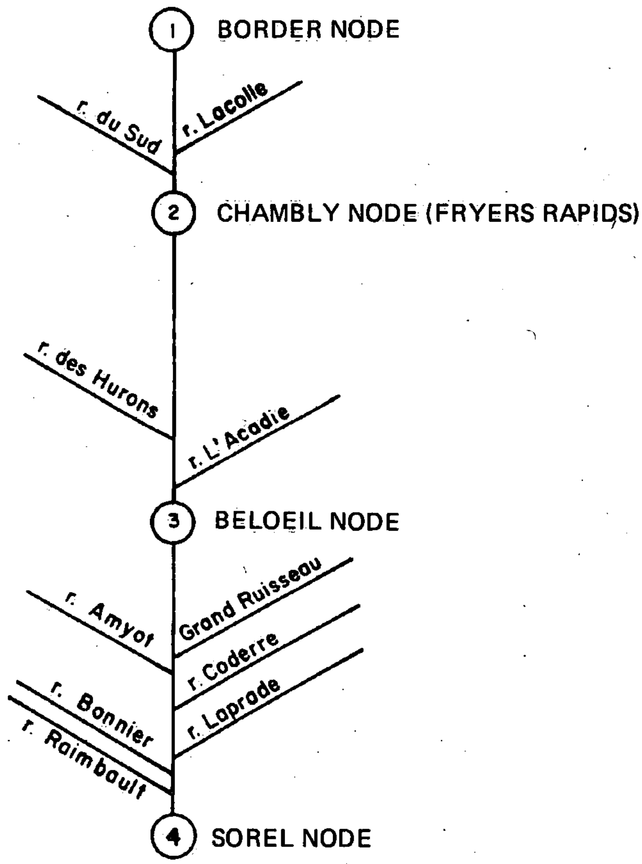


Figure 1.3 Configuration of the Richelieu River basin.

A number of tests were conducted before deciding on this configuration. The first configuration, which consisted of ten nodes, took the main tributaries (subbasins) into consideration by viewing them as nodes and applied socio-economic data to them. The advantage of this configuration was that it respected the drainage system of the Richelieu River precisely. However, this method resulted in an imbalance in the analysis of demand, that is, in the breakdown of the socio-economic data at each node, and did not correspond to the municipalities' main sources of water supply.

The configuration selected for the purposes of the analysis consists of four nodes located at the border, at Chambly, at Beloeil and at Sorel. This configuration excludes the Missisquoi, aux Brochets and de la Roche rivers from the analysis of water demand, but takes into account the cumulated flow of these three rivers at the "border" node. The other main tributaries are: Rivière des Hurons (drainage basin 300.5 km^2), Rivière l'Acadie (drainage basin 510.0 km^2), Rivière du Sud (drainage basin 143.5 km^2), Rivière Lacolle (drainage basin 121.5 km^2), Grand Ruisseau (drainage basin 112.5 km^2), Rivière Amyot (drainage basin 96.0 km^2), Ruisseau Coderre (drainage basin 85.5 km^2), Ruisseau Laprade (drainage basin 39.0 km^2), Ruisseau Bonnier (drainage basin 53.6 km^2), and Ruisseau Raimbault (drainage basin 15.5 km^2). The location of these nodes is essentially limited to the Richelieu River.

The "border" node is viewed as a starting node which comprises hydrologic data but no socio-economic data. Since most of this river basin is located in the United States, this approach is based on an assumption of stable growth both in the U.S. part of the basin and in the subbasins of the Missisquoi, aux Brochets, and de la Roche rivers in Canada. This assumption has not been tested and the historical flows used are limited exclusively to the Canadian part of the drainage basin.

2. WATER DEMAND

Water use is divided into three main categories: municipal, agricultural, and industrial. Each of these uses is examined in terms of water intake and consumption. The base year is 1981.

2.1 MUNICIPAL

Municipal water use refers to water used by the population for domestic purposes, that is, for non-industrial and non-agricultural purposes. The population is divided into urban and rural components and a corresponding rate of per capita intake is assigned to them.[3] In Quebec, the daily per capita intake in 1981 was estimated at 625 litres for the urban population and 160 litres for the rural population.[4]

The urban and rural populations were evaluated according to the municipalities and the enumeration areas of the various census divisions. All municipalities which obtained water supplies from the Richelieu River were retained, as well as large municipalities (1000 or more residents according to the MUNDAT data base).[5] Table 2.1 presents the population breakdown at each node. It should be noted that the population was divided on the basis of the subbasins where the municipalities

TABLE 2.1. Breakdown of the Population of the Richelieu River Basin by Node

NODE 2: CHAMBLY

Municipality	Urban	Rural
Saint-Luc	6514	2301
Saint-Jean	35640	
Iberville	8587	
Saint-Athanase		5138
Saint-Grégoire le Grand		1790
Chambly	12190	
Richelieu	1832	
Marieville	4877	
Notre-Dame-de Bon-Secours		1162
Subtotal	69640	10391
TOTAL NODE 2:	80031	

NODE 3: BELOEIL

Municipality	Urban	Rural
Saint-Bruno-de Montarville	22880	
Beloeil	17540	
McMasterville	3612	
Otterburn Park	4268	
Saint-Basile-le-Grand	6657	1001
Saint-Mathias		2929
Saint-Jean-Baptiste		2726
Napierville	2343	
Mont-Saint-Hilaire	8323	1743
Carignan	2753	1791
Sainte-Madeleine	1361	
Sainte-Marie-Madeleine		1516
Subtotal	69737	11706
TOTAL NODE 3:	81443	

NODE 4: SOREL

Municipality	Urban	Rural
Saint-Pierre-de Sorel	3175	1596
Sorel	20347	
Saint-Joseph de Sorel	2545	
Tracy	12843	
Saint-Bernard (partie sud)		517
Saint-Roch-sur Richelieu		1650
Saint-Amable	2424	1844
Saint-Denis (V)		861
Saint-Marc		1545
Saint-Mathieu de Beloeil		1535
Saint-Antoine-de-Padoue		585
Saint-Antoine-sur-Richelieu		903
Saint-Victoire-de-Sorel		2123
Sainte-Julie	14243	
Saint-Denis (P)		1135
Saint-Ours (P)		1094
Saint-Ours (V)		625
Saint-Charles (P)		1038
Saint-Charles (V)		401
Subtotal	55577	17452
TOTAL NODE 4:	73029	

obtain their water, not on the basis of physiographic variables. The population of the drainage basin was estimated at 234 503, 83.1% of which is urban.

2.1.1 Population forecasts

Nine population forecasts, based on data published by Statistics Canada and the Bureau de la Statistique du Québec, were used to calculate the annual growth rate from 1982 to 2001. Statistics Canada developed five national forecasts for each province and territory, and we chose three which applied to Quebec. The Bureau de la Statistique du Québec developed forecasts using three scenarios based on the intensity of future population growth for the whole of Quebec and for each administrative region.

Since most of the drainage basin is located in the region south of Montreal (Montérégie) and since the eight census divisions of the basin are located in this region, the three forecasts of this administrative region, which are much higher than the Quebec average, have been added and considered in the general forecast file. From 1971 to 1981, the population increase was concentrated in the larger cities of the basin, namely Chambly, Saint-Jean, Sorel, Beloeil, and Saint-Bruno-de-Montarville. The largest population increase occurred in the census division of Chambly, where the growth rate was 66.7% from 1966 to 1986.

The advantage of these forecasts is that they provide a very broad range, depending on the various scenarios (low, average and high). However, actual growth from 1981 to 1986 did not correspond to the regional population forecasts in the entire drainage basin. The average growth rate was only 3.1% during this period.[6] Table 2.2 provides the forecasts of Statistics Canada and the Bureau de la Statistique du Québec using the various scenarios for the entire province. Table 2.3 provides information on the regional population forecasts that were taken into consideration. It

TABLE 2.2. Population Forecasts for Quebec from 1982 to 2001

I - BASED ON STATISTICS CANADA DATA*

Year	Low Scenario Growth rate in Thousands	Average Scenario Growth rate in Thousands	High Scenario Growth rate in Thousands
1982	6.7	6.7	6.7
1983	5.4	5.4	5.4
1984	5.5	5.3	5.5
1985	5.5	5.3	5.7
1986	5.4	5.4	5.9
1987	5.0	5.1	6,0
1988	4.5	4.9	6.1
1989	3.6	4.9	6.3
1990	3.0	4.6	6.3
1991	2.4	4.2	6.3
1992	1.8	3.7	6.0
1993	1,2	3.2	5,8
1994	0.8	2.7	5.6
1995	0.3	2.2	5,3
1996	-0.1	1,8	5,0
1997	-0.5	1.4	4.7
1998	-0.8	1.0	4.3
1999	-1.2	0.7	3,9
2000	-1.5	0,4	3.6
2001	-1.8	1,1	3,3

II - BASED ON DATA FROM THE BUREAU DE LA STATISTIQUE DU QUEBEC †

Year	Low Scenario	Average Scenario	High Scenario
1982	6.7	6.7	6.7
1983	5.4	5.4	5.4
1984	4.1	4.2	4.4
1985	3.4	4.7	5.1
1986	3,1	5.4	5.8
1987	3,1	6.0	6.4
1988	3,1	6.2	6.9
1989	3.0	6.0	7.3
1990	2,9	5.7	7.6
1991	2.6	5.5	7.9
1992	2,3	5.3	7,7
1993	2.0	5,0	7.3
1994	1,6	4.6	6.9
1995	1.2	4.1	6.7
1996	0.9	3.8	6.3
1997	0.6	3,4	5.9
1998	0.3	3.1	5.5
1999	0.0	2.8	5.2
2000	-1.7	2.5	4.9
2001	-0,4	2.3	4.6

*Source. *Population projections for Canada, provinces, and territories, 1984-2006,* Catalogue 91-520.

†Source. Bureau de la Statistique du Québec, *Perspectives démographiques,* 1981-2006.

TABLE 2.3. Population Forecasts for South Montreal from 1982 to 2001

Year	Low Scenario Growth rate in Thousands	Average Scenario Growth rate in Thousands	High Scenario Growth rate in Thousands
1982	11.5	11.5	11.5
1983	11,5	11.5	11.5
1984	9,9	10,0	10,1
1985	8,9	15.9	16.3
1986	8.3	16.1	16.5
1987	8.1	16.1	16,6
1988	7.8	15.7	16.5
1989	7.4	15.0	16,4
1990	7.0	14.3	16.3
1991	6.6	13,7	16.1
1992	6.0	13.0	15.4
1993	5.4	12,3	14.6
1994	4.8	11.4	13,7
1995	4.2	10.6	13.1
1996	3.6	9.8	12.3
1997	3.1	9.1	11.5
1998	2.6	8.5	10.9
1999	2.2	7,8	10.2
2000	1.8	7,3	9.7
2001	1.4	6.8	9.1

*Source: Bureau de la Statistique du Québec, *Perspectives démographiques régionales,* 1981-2006 Québec, 1984.

should be noted that the growth rate decreases beginning in 1987 and that some forecasts even show a negative growth rate beginning in 1996.

2.2 AGRICULTURAL

2.2.1 Livestock

Livestock water requirements are assessed on the basis of intake per head per day and a corresponding rate of consumption for each livestock type surveyed. Livestock was broken down into various types (beef cattle, dairy cattle, pigs, sheep, horses, poultry) for each node of the network.

This breakdown was based on census divisions, which did not correspond exactly to the study area. These divisions were regarded as a whole and were assigned to the node in which most of their area was located. For data processing purposes, these figures were rounded off the nearest thousand, which substantially reduced the degree of accuracy for a drainage basin the size of that of the Richelieu River. Table 2.4 shows the breakdown of livestock at each node.

In 1981, the Montérégie region south of Montreal, although it extends beyond the bounds of the drainage basin, accounted for a large share of Quebec's livestock: 20.8% of beef cattle, 23.6% of dairy cattle, 35.8% of pigs, 16.4% of sheep and 30.9% of poultry.[7]

TABLE 2.4 Breakdown of the Livestock Population of the Richelieu River Basin by Node

Livestock	Node 2 Chambly	Node 3 Beloeil	Node 4 Sorel
Beef cattle	18503	15253	20252
Dairy cattle	20363	17564	24269
Horses	492	900	929
Pigs	68288	201403	122496
Sheep	992	2137	3644
Poultry	209201	1305294	1367289

Node 2: Chambly comprises the census divisions of Iberville and Saint-Jean.

Node 3: Beloeil comprises the census divisions of Rouville, Chambly, and Napierville.

Node 3: Sorel comprises the census divisions of Richelieu, Saint-Hyacinthe, and Verchères.

Source: Statistics Canada.

This analysis does not take into consideration the share of livestock that obtains its water supplies from groundwater. Since some studies show that approximately 80% of the water used for livestock is groundwater, it can be concluded that the use of water from the Richelieu River for livestock purposes is negligible compared to municipal and industrial uses.[8] These variables will have to be taken into account in later studies, since a more precise evaluation of livestock per node would not necessarily produce conclusive results without precise information on the source of water supply.

Other components of agricultural water use, such as irrigation, were not taken into consideration because of insufficient data. Previous studies have shown that irrigation is not widespread in this drainage basin, but that it might be used more extensively in the future.[9]

2.2.2 Forecasts of livestock growth rates

2.2.2.1 Analysis of past trends

Forecasts of livestock growth rates were based on an analysis of past trends in all census divisions of the drainage basin from 1971 to 1981. This analysis revealed that variations in livestock growth rates in the basin corresponded to those in Quebec as a whole during the same period for beef and dairy cattle, but differed for pigs, sheep, lambs and poultry. During this period, the growth rate of pigs almost quadrupled in the basin but increased by only 2.5% in Quebec; the growth rate of sheep almost doubled in the basin but grew by only 26.8% in Quebec.

2.2.2.2 Development of livestock growth rate scenarios

Changes in livestock growth rates after 1981 reveal that caution is necessary in developing growth rate scenarios and that the focus should not be exclusively on the 1971 to 1981 period. Trends for the 1971 to 1981 period have for the most part remained constant for beef and dairy cattle but differ completely for sheep and pigs. Table 2.5 provides an overview of the annual variation for three of these livestock types for the entire province.

TABLE 2.5. Annual Variation in Livestock Population from 1975 to 1987 in Quebec

Year*	Beef Cattle	Dairy Cattle	Sheep and Lambs
1975-76	-5.2 %	-4.2 %	-10 %
1976-77	-3.9 %	-0.9 %	-6.9 %
1977-78	-5.2 %	-3.6 %	4.4 %
1978-79	0.3 %	-0.7 %	26.3 %
1979-80	3.3 %	1.5 %	21.7 %
1980-81	2.8 %	2.3 %	12.3 %
1981-82	-0.9 %	-1.8 %	10.8 %
1982-83	-2.1 %	-2.7 %	6.7 %
1983-84	-2.7 %	-0.4 %	-2.3 %
1984-85	0.3 %	-2.2 %	-2.4 %
1985-86	-0.5 %	-2.2 %	-2.5 %
1986-87	-0.9 %	-2.8 %	-1.3 %

*Data compiled beginning on July 1 of each year.
Source: Quebec Department of Agriculture, Fisheries and Food, *Bovins et ovins dans les fermes.*

In order to produce forecasts for beef and dairy cattle, the average annual increase was established for the entire province for the period 1975 to 1985. Major deviations during the 1980 to 1986 period were used for the high and low scenarios. The same method was used for the growth scenarios of the other livestock types, and adjusted to the Quebec average. The growth rate of pigs and sheep was less than the Quebec average in the Richelieu River basin during the 1982 to 1985 period, but exceeded the average during the 1971 to 1981 period. Owing to the fluctuations in the growth rates of these livestock types, we selected scenarios with broad ranges between the high and low scenarios.

Since statistics on horses and poultry were less accurate, we simply took changes in these types in Quebec from 1971 to 1981 into consideration for the average scenario, and used an increase or decrease factor for the other two scenarios.

Table 2.6 provides the scenarios used in the Richelieu River basin model. These Quebec scenarios differ somewhat from the scenarios of the other provinces because the deviations are higher. However, adaptation to the regional level and the substantial variation during the past five years explain the scenarios used.

Table 2.6. Livestock Population Growth Rate Scenarios

	(Growth Rate %)		
	Low	Average	High
Beef cattle	-2.7	-1.2	2.8
Dairy cattle	-2.8	-1.9	2.3
Pigs	-2.8	3.7	7.7
Sheep	-2.5	0	6.7
Horses	-1.1	-0.9	0.4
Poultry	1.2	2.4	4.8

2.3 INDUSTRIAL

For purposes of analysis, industrial water use is divided into 30 industrial sectors, including the manufacturing, mining and thermal power production sectors. For each of these sectors, the model determines the water intake and consumption of the province or region, the basin, and the subbasin or node.

Two main sources of data were used for the analysis: the industrial water use survey[10] and a theoretical assessment based on the number of employees per plant.[11]

2.3.1 Industrial water use survey

In order to determine the exact breakdown of industries, we examined all questionnaires of the 1981 industrial water use survey conducted by Environment Canada and Statistics Canada. Although this survey covers only 11 of the 17 manufacturing sectors, these sectors account for most of the total water intake and consumption. For example, the national survey revealed that four sectors -- paper and allied products, primary metals, chemicals and chemical products, and petroleum and coal products -- account for 91% of both total intake and total discharge and 87% of total consumption.[12]

The first step consisted of reporting the number of plants per industrial sector at each node in the municipalities located in the drainage basin. Although the Chambly node contains more than a third of the basin's work force, it represents only 10.7% of the total intake.

The 1981 survey revealed that water intake for industrial purposes in the Richelieu River basin is relatively low, 20.9 million m^3, and represents 0.09% of the total intake of Quebec, estimated at 2.3 billion m^3.

This can be explained by the type of plant located in the drainage basin. There are few plants from the four sectors previously mentioned that use large amounts of water. Furthermore, the water intake figures of plants located in Tracy had to be adjusted downward because it was observed that some of them obtained virtually all of their water from the St. Lawrence River and not the Richelieu River. In these cases, only the amount of water taken from the Richelieu River was retained. For example, the total water intake of a plant in Tracy was 59.6 million m^3. Only 2650 m^3 came from the Richelieu River. One case like this completely changes the results of the analysis for a basin the size of that of the Richelieu River, as will be shown in the application of the model.

The drainage basin has only one plant in the paper and allied products sector with 25 employees, and none in the petroleum and the coal products sector. After adjustment of the data for Tracy, the water intake of the primary metals industry in the basin was no more than 6.3 million m^3, although the five plants in this sector had a total of 4278 employees. The intake of six plants in the chemicals and chemical products sector (790 employees) was 11.5 million m^3. This analysis indicates that these three sectors account for 85% of total water intake in the basin.

2.3.2 Theoretical analysis

The theoretical analysis is based on the number of employees per industrial sector and the corresponding water intake coefficients. Data on the number of employees is taken from Scott's industrial directory for Quebec for the year 1982 to 1983. The water intake coefficients per employee are based on the Quebec average. This analysis does not distinguish between office workers and plant workers.

At the Chambly node, the urban centres of Saint-Jean and Iberville represent 40% of the basin's industrial work force. However, the major employers are concentrated in the textiles and clothing sector and the electrical products and manufacturing sectors, which are not large water users. The chemicals and chemical products sector has 490 employees, and the primary metals sector has 1169 employees, which represents a water intake of approximately 32 million m^3, based on the average water use coefficients.

Marieville and Chambly are two other major industrial centres with 2136 and 1848 employees respectively. The principal employers, however, are not located in sectors that require high water intakes, except in Chambly, where there is a plant with more than 100 employees in the chemicals and chemical products sector, and in Marieville, where there is a plant with more than 500 employees in the primary metals industry.

At the Beloeil node, a single plant in the chemicals and chemical products sector accounts for 32% of the work force and 89% of the industrial water intake attributed to this node. Most of the other plants are in the food and beverages sector.

At the Sorel node, Sorel-Tracy is a major industrial centre with 7684 workers, half of whom are employed in the primary metals sectors. Since the main part of this industry is located in Tracy and draws its water supply from the St. Lawrence River, the theoretical water intake is less significant. The other major employers are in the transportation equipment, machinery and textile sectors.

Taking these factors into account, and the fact that the reference year does not exactly correspond to that of the industrial surveys, the theoretical analysis was limited to the sectors which were not evaluated in the industrial survey (tobacco, furniture, leather, machinery, electrical products, miscellaneous industries for plants with 100 or more employees) and to the four subgroups that were the largest water users. Differences were observed between the theoretical results and the survey results for these four subgroups, particularly in the Chambly node.

2.3.3 Overall assessment of industrial water intake

Table 2.7 gives the results of the industrial survey, indicating the water intake and number of employees of each sector. For the Chambly node, it includes the industries listed in Scott's industrial directory. This second assumption allows an examination of the long-term effects of the higher industrial water intake at this node. *Le documentaire sur le bassin de la rivière Richelieu* indicated that Chambly county had the highest average annual growth rate of all counties in the basin from 1961 to 1971. The addition of theoretical data to this node will have a significant impact on the water demand forecasts, as we will see in the section on the application of the model.

2.3.4 Industrial growth scenarios

The industrial growth scenarios were not modified. These scenarios, which have already been

TABLE 2.7. Water Intake for Industrial Purposes with Addition of Theoretical Data at the Chambly Node

Sector	Industrial Water Use Survey: Number of employees	Industrial Water Use Survey: Intake (m³)	Addition of Theoretical Data: Number of employees	Addition of Theoretical Data: Intake (m³)
NODE 2: CHAMBLY				
Food and beverages	451	408274		
Rubber and plastics	370	1010327		
*Leather	-	-	478	172619
Textiles	625	449418		
*Furniture	-	-	353	187250
*Paper and allied products	25	4262	249	7538948
*Primary metals	-	-	1169	11612674
Metal fabricating	636	343904		
*Electrical products	-	-	1317	1386237
Transportation equipment	23	5852		
Non-metallic mineral products	89	18782		
*Chemicals and chemical products	28	591	490	20487330
*Miscellaneous industries	-	-	472	197575
Total	2247	2241410	4528	41582633*
NODE 3: BELOEIL				
Food and beverages	485			
Transportation equipment	65			
Chemicals and chemical products	416			
**Total	966	11789869**		
NODE 4: SOREL (with adjustments at Tracy)* **				
Food and beverages	108	130872		
Primary metals - iron	1278	6301585		
Primary metals - other	2000	2650		
Transportation equipment	2500	385279		
Non-metallic mineral products	240	6234		
Chemicals and chemical products	346	95473		
Total	6472	6922093		

* Theoretical evaluation with intake indicator based on the number of employees. The evaluation of sectors not listed in the survey are based on water use coefficients taken from U.S. sources using Canadian data on employment. Data for the paper, primary metals and chemical products sectors are based on Quebec averages.

** For reasons of confidentiality, the breakdown of water intake per industrial sector was not indicated at this node.

*** The number of employees corresponds to all plants in Tracy, whereas the intake column shows only water taken from the Richelieu River. The thermal plant at Tracy was not included because it draws more than 99.9% of its water from the St. Lawrence River.

integrated into the model, were developed by the Economic Council of Canada (high scenario) and the University of Toronto (low scenario). (See Table 2.8.)

3. WATER SUPPLY

The evaluation of the water supply is based on two main sources of data: surface water and groundwater. In this study, only surface water data, or historical average monthly flows, were analyzed.

3.1 ENTRY OF HYDROLOGIC DATA

Hydrologic data for the four nodes were generated using a single station, Fryers Rapids, which was documented for more than forty years (1938-1981). This exercise was not the subject of a regional analysis, but of theo-

TABLE 2.8. Industrial Growth Scenarios in Quebec

Industry	ANNUAL PERCENTAGE OF GROWTH	
	HIGH SCENARIO	LOW SCENARIO
	Economic Council of Canada* 1981-1990	University of Toronto* 1981-1995
1 Agriculture	-0,68	0.67
2 Forestry	4.52	1.29
3 Metal mines	4.17	0.05
4 Mineral fuels	3.20	2.52
5 Non-metal mines	4.90	0.05
6 Food and beverages	1.38	0.78
7 Tobacco	0.35	0.78
8 Rubber and plastics	2.75	0.67
9 Leather	2.31	0.82
10 Textiles	2.46	0,82
11 Wood	3.29	1.20
12 Furniture	2.74	1.20
13 Paper and allied products	4.15	1.63
14 Printing	3.44	1.63
15 Primary metals-iron	3.50	0.82
16 Primary metals-other	2.19	0.82
17 Metal fabricating	4.10	0.82
18 Machinery	3.48	1.11
19 Transportation equipment	2.46	1.11
20 Electrical products	4.05	-0.39
21 Non-metal minerals	3.65	1.57
22 Petroleum and coal products	1.66	0.67
23 Chemicals and chemical products	2.54	0.67
24 Miscellaneous manufacturing industries	3.34	-0.83
25 Construction	2.76	2.50
26 Transportation	2.76	2.50
27 Electric power	4.63	3.87
28 Other utilities	2.76	2.50
29 Trade	2.80	2.57
30 Other	2.76	2.50

*Excluding regional effects

retical calculations using a module observed by proportional breakdown of the flow at the area of the various subbassins. The drainage network with the limits of the subbasins presented in *Documentaire sur le bassin de la rivière Richelieu* was used for these calculations.

The average annual flow recorded at the Fryers Rapids station is 336 m^3/s for a recording period of 44 years (1938-1981), whereas the area of the drainage basin, cumulated at this same station on the Richelieu River, is 22 032.4 km^2. The corresponding average annual flows were established for each of the nodes or stations on the basis of the area of the drainage basins cumulated on the Richelieu River at various points, in accordance with the configuration of the basin which had been defined.

For the purposes of the application of the model, the flows entered into the hydrologic file are average monthly flows. These flows were generated, for each station or node of the network, on the basis of flows registered at Fryers Rapids (station no. 020J007) for the 1938 to 1981 observation period.

Appendix A provides information on the key physiographic variables of the subbasins of the Richelieu River. Appendix B indicates the average monthly flows for the period 1938 to 1981 at each node. The model requires that the period of data be similar at each node.

3.2 MINIMUM FLOW CONSTRAINT

Provision has been made in the model to consider a minimum flow in the analysis and to ensure that this flow is maintained for all types of water use analyzed. The criteria for determining minimum flow could be the subject of many analyses which should evaluate all indirect uses of water relating to recreational activities (fishing, swimming, boating, etc.) and to the protection of the aquatic environment. Although it was impossible for us to conduct these analyses and although the selection of a minimum flow was arbitrary at this point, we felt it was important to retain this variable in order to obtain more diversified results and to have a more global approach to the operation of the model.

Le documentaire sur le bassin de la rivière Richelieu states, on the basis of frequency analysis of daily flows at the Fryers Rapids station for the period 1938 to 1972, that the guaranteed minimum flow, with a recurrence interval of 100 years, was 41 m^3/s and that this flow amply met the forecast for domestic and industrial needs, estimated at 1.93 m^3/s in 1986. For a recurrence interval of 2 years, the minimum flow was 84 m^3/s.

During the period 1938 to 1981, the minimum flow was 66.8 m^3/s in October 1941. The low water mark of the Richelieu River is generally recorded in September and October, whereas the annual freshet occurs in April and May. For the purposes of this study, the minimum flow constraint was established at 80 m^3/s.

3.3 VARIABLES NOT CONSIDERED

A number of water supply variables were not considered, either because they were not applicable or because sufficient data were not available. For example, groundwater supplies and transfers of water among basins were not evaluated. In addition, we proceeded on the assumption of a fixed "border" starting node, the flows of which were generated in the same way as the others.

4. APPLICATION OF THE MODEL TO THE RICHELIEU RIVER BASIN

4.1 OPERATION OF THE WATER USE ANALYSIS MODEL

In Phase V of its development, the Water Use Analysis Model was composed of 10 modules and 19 data files, 15 of which had to be created by the user. The model requires the processing of a substantial amount of data, but gives the user considerable flexibility in arranging the various files. Each module is run as a separate program that the user must put into operation; each module is

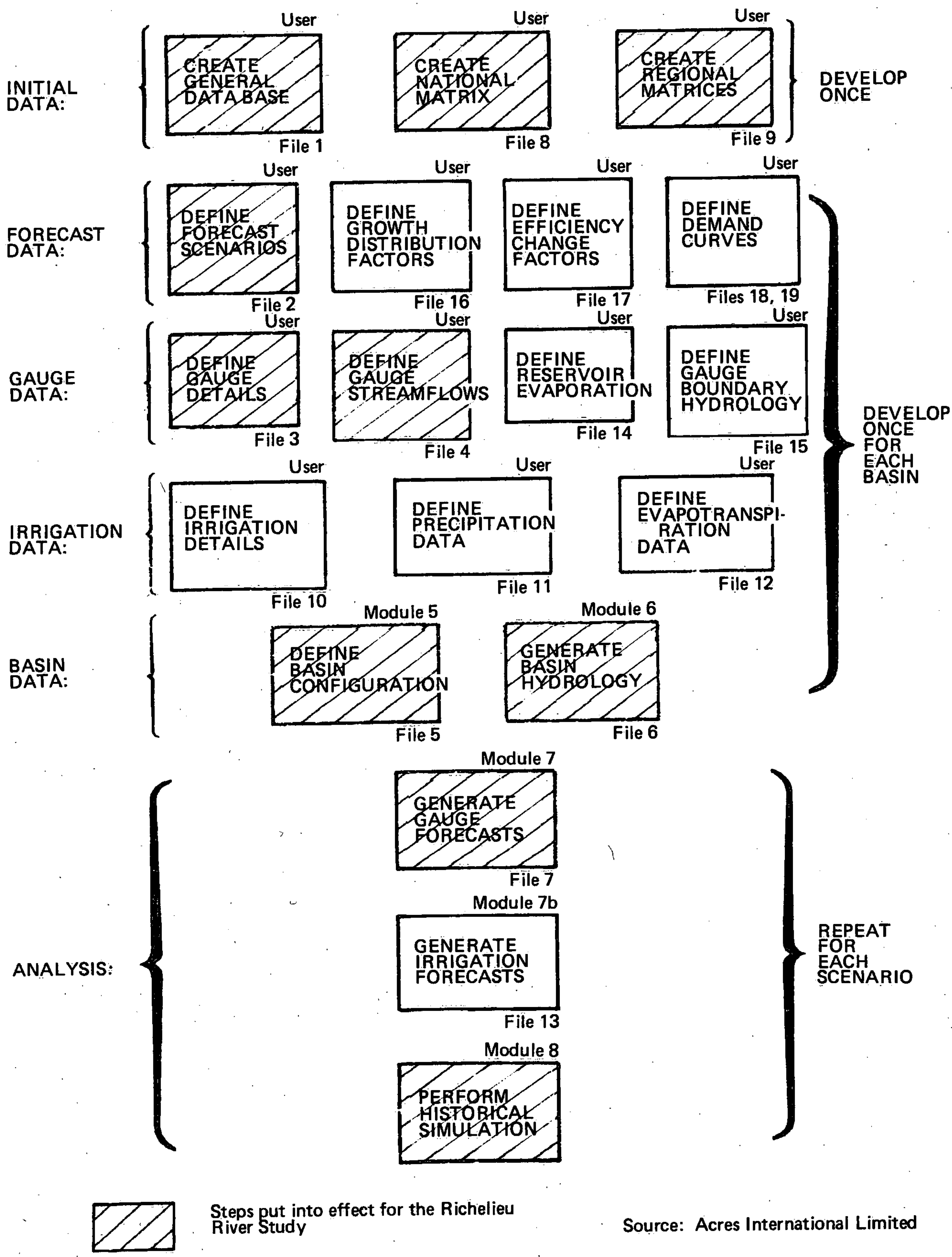


Figure 4.1 Operation of the model

thus associated with the corresponding data file. Figure 4.1 illustrates the various modules and data files and describes the operating procedure. Several of these aspects have already been addressed in the sections dealing with water supply and demand. This chapter will concentrate on historical simulations and on the results obtained using the model.

Although we were unable to test all components of the model (such as irrigation and reservoirs, etc.), the first application of the model to the Richelieu River basin allowed us to conduct simulation studies, which indicated no major water supply problem in the relatively long term (the forecast period extending as far as 2001).

Figure 4.2 indicates the various variables that were taken into consideration in the regional application of the model. As this diagram shows, the results are produced by Module 8: historical

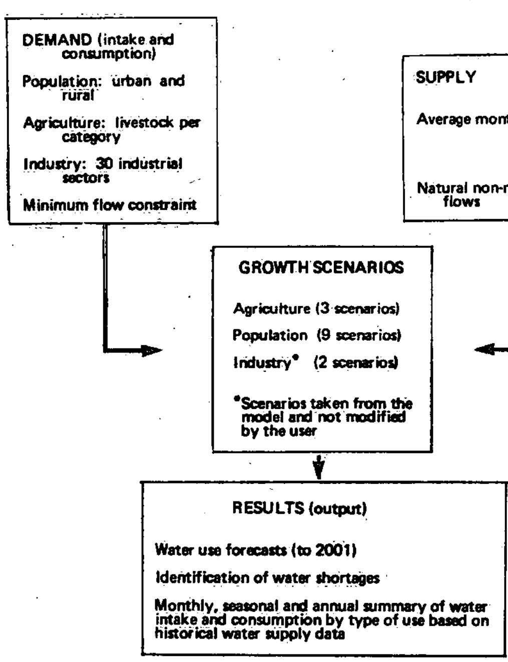
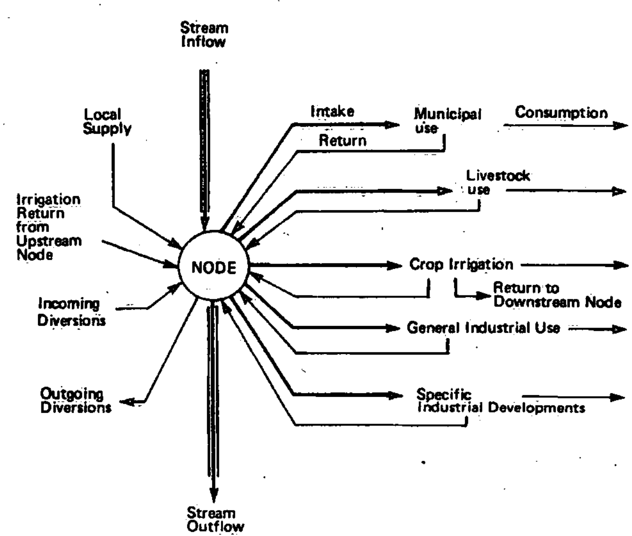


Figure 4.2 Regional application of the Water Use Analysis Model to the Richelieu River basin

simulation. Using the historical simulation, it is possible to make a synthesis of supply and demand components on the basis of various growth scenarios. Therefore, the model can be used to analyze the impact of various development scenarios on the available water supply of the drainage basin.

4.2 CALCULATION DETAIL AT EACH NODE

When the socio-economic (demand) and hydrologic (supply) data are adapted to the configuration of the basin, the model calculates the difference between water available and water consumed on the basis of the various scenarios. This difference is then forwarded to the next node for further calculation. The process is illustrated in Figure 4.3.



Source: Acres International Limited, Water Supply Constraints to Energy Development - Phase V, July 1986.

Figure 4.3 Calculation detail at each node

It should be noted that for each type of use described in section 2, the model computes both intake (the total amount of water withdrawn from the source of supply) and consumption (that part of intake which is not returned to the network). Consumption is a percentage of the intake and is determined by the model by type of use at different times of the year.

4.3 HISTORICAL SIMULATION: MODULE 8

Before the historical simulation (Module 8) can be performed, the choice of a forecast year and of population, livestock and industry growth scenarios must be integrated into Module 7. The growth scenarios will be applied to the various nodes of the network on the basis of forecast year.

The historical simulation (Module 8) constitutes the final step in the application of the model. It makes it possible to compare supply and demand. The historical data (monthly flows) are taken into consideration in the analysis of supply (water availability), whereas demand is evaluated on the basis of the various growth scenarios for each of the forecast years (1982 to 2001).

The various historical simulation output (Module 8) when comparing supply and demand are as follows:

Module 8.DTL: Detailed analysis of supply and demand (intake and consumption) for each subbasin (node).

Module 8.SUM: Summary tables for each node of the network:

(1) comparison of total intake and total supply by indicating the percentage of occurrences of intake for the various levels of supply.

(2) comparison of total consumption and total supply.

(3) comparison of stream outflow and minimum flow constraint.

Module 8.ANL: Annual summary: comparison of supply, demand and consumption at each node.

Module 8.SNL: Summary of results by type of use and season.

Module 8.DMD: Forecast demand (intake and consumption) by use for different forecast years at each node.

4.4 INTERPRETATION OF RESULTS

In light of the many application difficulties previously mentioned, the results must be interpreted with reservation.

Various analyses have been conducted with different scenarios and different forecast years by considering the periods of variable historical flow from 1938 to 1981.

These analyses reveal that municipal and industrial uses predominate in the entire basin, and that water intake for livestock watering is relatively low compared to other uses.

4.4.1 Detailed analysis of water use based on the various scenarios

The purpose of this section is to examine the effects of the various growth scenarios on the intake and consumption of water at each node on the basis of the various forecast years. We selected high and low scenarios for population, livestock, and industry, and a minimum flow constraint of 80 m^3/s for the forecast years 1991 and 2001. The entire historical flow period (1938-1981) was taken into consideration.

The low and high population scenarios (scenarios 7 and 9) were based on regional forecasts, since they were higher than the others and were more applicable to the basin. The industry (1 and 2) and livestock (1 and 3) growth scenarios were described in the section on demand.

The baseline data remained the same, with the exception of the industrial sector where the data from the 1981 survey were first considered and then modified upward at the Chambly node based on theoretical data.

By using the historical simulation DMD, which develops forecasts of water intake and consumption, it was possible to observe the impact of the various growth scenarios and the changes that can result from the addition of theoretical data from the Chambly node.

The long-term effects of the two scenarios (high and low) on the equilibrium between supply and demand were not significant because the uses analyzed (municipal, industrial, and livestock) were relatively minor, given the available supply.

However, the theoretical evaluation of industrial use at the Chambly node reveals a significant increase in intake, the repercussions of which are felt throughout the basin.

The analyses continued but were limited to high growth scenarios, and in some cases, a theoretical evaluation of industrial intake to identify potential problems in the basin.

The data from the industrial water use survey indicate the Beloeil node accounts for 42% of the total intake from the basin for both 1991 and 2001. When the theoretical data are included, the Chambly node accounts for approximately 55% of the total intake for the years 1991 and 2001.

However, the high growth scenarios indicate that from 1991 to 2001, the total intake from the basin increases by 21% with the industrial water use survey data and by 27% with the theoretical industrial data. Fig. 4.4 represents the breakdown of the various types of use for the year 2001, based on the high growth scenario. The maximum intake reaches 104.4 million m^3 at the Chambly node with the addition of the theoretical data for industrial use.

If we consider consumption alone, that is water actually used and not returned to the source of supply, and exclude theoretical industrial data, annual municipal water consumption for 1991 accounts for 80% of total consumption at the Chambly node, 42% at the Beloeil node and 57% at the Sorel node. Using the same scenarios, municipal consumption for the forecast year 2001 accounts for 75% of total consumption at the Chambly node, only 36% at the Beloeil node and 49% at the Sorel node.

With the addition of the theoretical data at the Chambly node, industrial consumption reaches 72% of the total consumption attributed to this node for the year 1991 and 75% for the year 2001. It therefore exceeds municipal consumption in the entire basin.

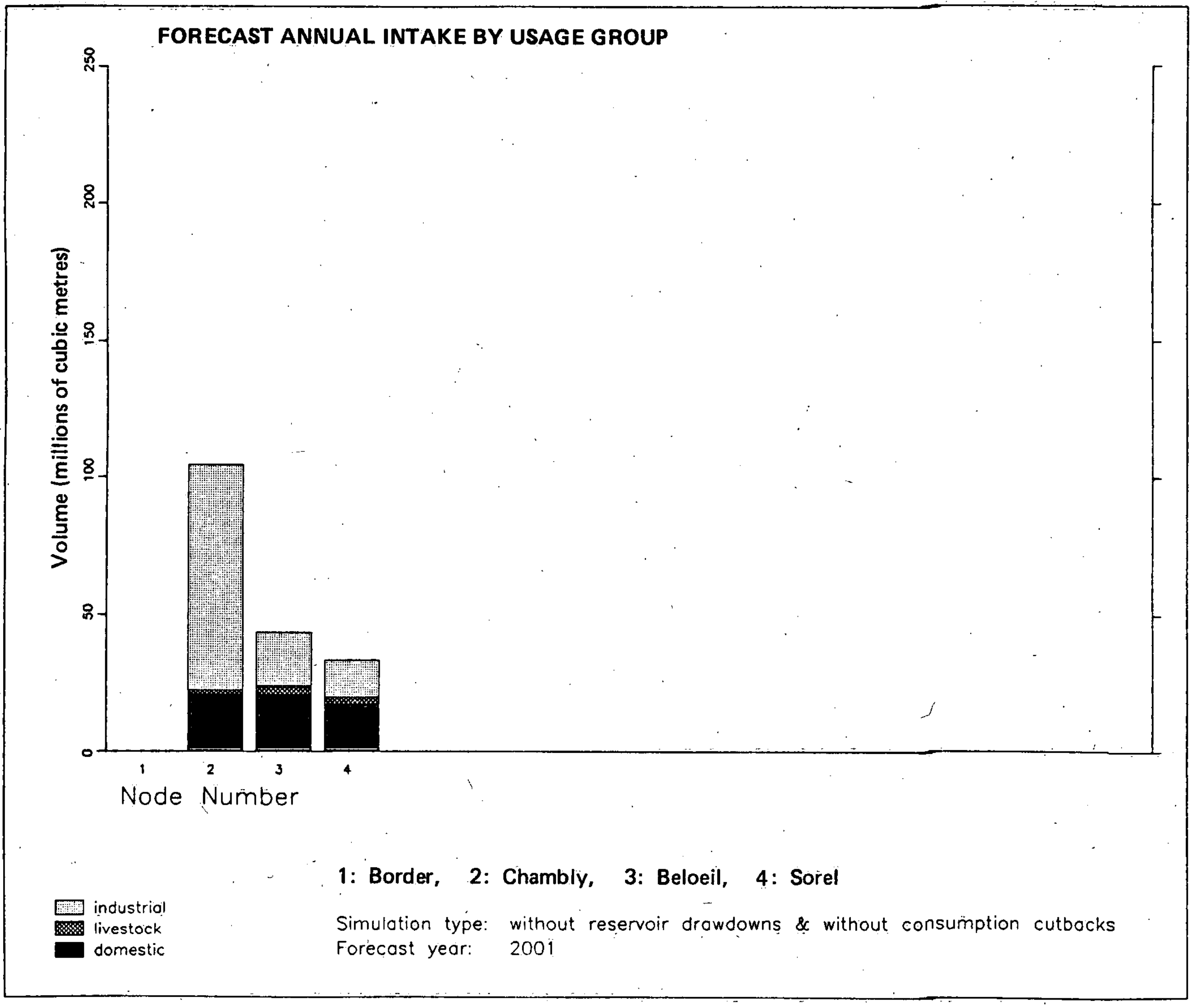


Figure 4.4 Annual intake by usage group

These analyses reveal the impact of the various scenarios on the equilibrium between the various water uses and the priorities that can be assigned to them. When the model identifies water shortages, the available water may be allocated on the basis of priorities established by the user. In the case of the Richelieu River, the supply was always sufficient to satisfy the various requirements.

4.4.2 Overall analysis of water supply and water use

The historical simulation (module 8.SUM) compares total supply and total use. It is a calculation of the proportion of water used, either as intake or consumption, from the available supply for the different months of the year at each node of the network. The results obtained by the summary comparison of the demand for water with available supply are comparable to those established in *Documentaire sur le bassin de la rivière Richelieu*. The forecasts of municipal and industrial water requirements were evaluated at 1.93 m^3/s for 1986, which would correspond to 0.6% of the average annual flow.

By maintaining the minimum flow constraint at 80 m^3/s, the historical simulation analysis reveals that the intake of water was relatively minor compared to supply, taking the flows for the entire period under study (1939 - 1981) into consideration.

With high growth scenarios and the addition of the theoretical industrial data at the Chambly node, the average annual intake did not exceed 1% of total average annual supply at the Chambly, Beloeil, and Sorel nodes for the forecast years 1991 and 2001. This percentage may vary during critical times of the year and is obviously the highest in August, September, and October.

4.4.3 Analysis of the minimum flow constraint

The only problems that may arise in the analysis of the water supply in the Richelieu River basin are associated with the minimum flow constraint.

On the basis of a detailed analysis of the water supply and demand of each month of the year, module 8.DTL highlights, with an asterisk, major problems that may occur at the various nodes:

a) total intake exceeds total supply;
b) total consumption exceeds total supply;
c) stream outflow is less than the minimum flow requirement.

The first two problems were never encountered because the total supply is sufficient to meet the forecast requirements. The third problem may occur if all historical flows from the period under study (1938-1981) are included.

Through historical simulation, the model ensures that a minimum flow of 80 m^3/s, which has priority over all other uses, is maintained. Since all of the other uses account for less than 1% of the average annual available supply, this constraint can be met in most cases (Appendix C).

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 PROBLEMS ENCOUNTERED IN THE APPLICATION OF THE MODEL

The problems encountered in the application of the model were related primarily to the lack of data required to meet the operating requirements.

The hydrologic data (historical flows) were limited to the Fryers Rapids station, since none of the other stations of the Richelieu River met the requirements of the model in terms of the minimum data period necessary. The reliability of the hydrologic data is essential to the continuation of the studies. More detailed regional analyses should be conducted to compensate for the lack of data for most of the river basins in Quebec.

Furthermore, the size of the Richelieu River basin, compared to the Saskatchewan-Nelson basin or even the Saint John River basin in New Brunswick, created a number of problems. For example, the breakdown of livestock on the basis of census divisions was not representative at some nodes. Moreover, the industrial use attributed to each node was not as significant as was suggested by the level of industrial development of the river basin, when compared to the rest of Quebec.

The breakdown of the population based on the municipalities that are within the basin can also create problems for bordering areas. With respect to the Richelieu River, we were able to reproduce, relatively accurately, the municipalities which draw their water supplies from this river. We also took the major tributaries into consideration without excluding the municipalities that could obtain water from groundwater supplies. It should be noted, however, that according to the MUNDAT data base, the use of groundwater supplies by municipalities is minimal in the Richelieu River basin.

As previously stated, we were unable to apply several variables because we did not have sufficient data. However, the initial objectives of becoming familiarized with the Water Use Analysis Model and applying it at the regional level were met. We were able to perform historical simulations, and the various tests revealed that water intake and consumption can vary consistently with the assumptions set forth.

5.2 FUTURE TRENDS

This study contributed to the creation of a socio-economic data base (population projections, 1981 census, breakdown of industries etc.) that can be used for subsequent studies. This data base can be further developed by entering 1986 census data and by a possible breakdown at the subbasin level.

The study of the Richelieu River basin was designed to be a starting point in becoming familiarized with the Water Use Analysis Model. Substantial experience was acquired and regional needs, with respect to this analysis tool, are now known. Although the results must be interpreted with reservation, water supply problems do not appear to predominate in the Richelieu River basin.

The analyses reveal that the minimum flow can be set at 80 m^3/s to satisfy other requirements with the exception of several extreme historical flow cases. However, the simulations indicate that if the minimum flow constraint had to be more than 80 m^3/s, problems could arise at certain critical times of the year.

One of the problems encountered in interpreting these results is not being able to assess to what degree the minimum flow of 80 m^3/s satisfies the other water uses that were not defined at the outset and maintains certain water quality standards.

In fact, no conclusion on the long-term water supply can be established without examining the question of water quality. The Water Use Analysis Model will satisfy regional needs more adequately when these aspects can be analyzed concurrently with water availability.

6. FOOTNOTES

(1) Acres Consulting Services Limited, *Water Supply Constraints to Energy Development*, August 1982.

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(2) Environment Canada. *Documentaire sur le bassin de la rivière Richelieu*, Québec, 1976.

(3) Statistics Canada defines urban region as a region with a population concentration of 1000 residents or more and a population density of 400 habitants or more per square kilometre.

(4) These evaluations are based on those produced in the 1976 Canada *Water Year Book*, taking an annual growth rate into consideration.

(5) Environment Canada. MUNDAT: Municipal Water Use Data Base, 1986.

(6) The 1986 populations are taken from *Répertoire des municipalités du Québec*, 1986.

(7) Bureau de la Statistique du Québec, *Portrait statistique régional, Région de la Montérégie et Municipalités régionales de comté*, 1987.

(8) Land, Vol. 7, No. 3, December 1986.

(9) Environment Canada. *Documentaire sur le bassin de la rivière Richelieu*, Québec, 1976.

(10) Environment Canada. National data base on the survey of water use in industry, unpublished, 1981.

(11) Scott's *Répertoire industriel du Québec*, 11th edition, 1982-1983, Penstock Publications Limited.

(12) Tate, Donald M. and David N. Scharf, Environment Canada, *Water use in Canadian Industry, 1981*, Social Science No. 19, Ottawa, 1985, p. 5.

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Appendix A

Physiographic Variables: Subbasins of the Richelieu River

Appendix A

Physiographic Variables: Subbasins of the Richelieu River*

SUBBASINS AREA	RICHELIEU RIVER AT	AREA (km^2)	CUMULATED AREA (km^2)
Area at the border			20098
Rivières Missisquoi and aux Brochets	* *	* *	* *
Rivière Lacolle	Notre-Dame du Mont-Carmel	121.5	* *
Rivière du Sud	Henryville	143.5	* *
Richelieu River above Fryers Rapids at Notre-Dame-du-Bon-Secours			22032.4
Rivière des Hurons	Saint-Mathias	300.5	* *
Rivière L'Acadie	Chambly (cité)	510.0	* *
Le premier Grand Ruisseau	Saint-Marc (P)	112.5	* *
Rivière Amyot	Saint-Charles (P)	96.0	* *
Ruisseau Coderre	Saint-Marc	85.5	* *
Ruisseau Laprade	Saint-Roch-de-Richelieu	39.0	* *
Ruisseau Raimbault	Saint-Ours (P)	15.5	* *
La rivière Richelieu			23880

* Only subbasins on the Canadian side were considered. However, the area of the Richelieu River was calculated at its source.
** Figures unavailable.
*** Total area of the Richelieu is divided as follows:
20 098 km^2 (84%) in the United States
3 782 km^2 (16%) in Canada

Sources: Quebec, Department of Natural Resources, *Superficie des bassins versants du Québec,* Part 1, 1979.
Environment Canada, *Documentaire sur le bassin de la rivière Richelieu*, February 1976.

Appendix B

Evaluation of Average Annual Flows at Each Node Based on Historical Flows Recorded at the Fryers Rapids Station[1]

[1] The flows were converted into ft^3/s because model 6 of the model is expressed in imperial units.

NODE 1 (Border)

YEAR	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1938	4706	8764	12446	22710	17425	10264	6308	5456	7809	12378	9514	12583
1939	9582	7127	9889	26291	34441	19198	10435	6308	4058	4092	4092	3819
1940	3260	2687	2728	20153	32327	22847	12344	7434	4467	3785	5558	6104
1941	11287	8252	6888	15652	12890	8013	5456	3990	2875	2278	3372	3233
1942	4331	4194	9889	22301	21210	14151	9821	5217	3785	5013	5933	5217
1943	5285	5183	11526	18823	28507	21074	13810	9991	8150	5763	10639	9343
1944	6718	5933	7570	21858	26564	13879	8695	5081	3683	3751	4501	3921
1945	4910	5149	14799	27484	29189	21278	13367	8934	6888	18312	18448	12276
1946	9412	8218	18584	20153	16129	13810	7843	5149	4024	5865	9582	9582
1947	9957	13299	14492	28303	32702	37510	24995	13708	7843	5081	4501	3717
1948	2708	2568	9343	23563	18960	14629	9036	6649	4535	3376	5456	7434
1949	14629	11014	11935	21517	17220	9514	5149	3444	3785	3342	4365	4740
1950	8730	9446	8593	23836	21040	11321	6513	4126	4467	4126	4944	12481
1951	9684	10059	13504	32258	25234	13197	9446	6684	5354	4126	8423	9207
1952	10810	11628	10844	28132	23188	20324	11185	5388	4433	3990	3332	5626
1953	7025	10980	13435	26189	28610	15856	7775	4672	3853	2817	2916	3956
1954	3301	5524	16982	26700	31235	22676	13231	7604	7877	12822	11594	12140
1955	12412	8968	15788	29394	26291	14561	7093	5558	5388	5047	8354	5967
1956	4944	5081	5285	18857	28371	21040	10332	5456	4297	4501	3921	4092
1957	4092	5899	9377	13333	12890	10128	7638	5013	4126	3546	4638	7468
1958	11117	9821	9991	27212	30519	19335	10230	7195	5797	7127	11253	6649
1959	5592	6820	8934	29530	22131	12617	7331	3546	3185	4467	9684	16163
1960	12992	10707	10673	30690	26905	15106	7945	5149	4160	4876	7229	5490
1961	3615	2755	14151	17050	22813	15856	10707	7025	5933	5081	4808	5285
1962	3546	2786	5217	23972	23699	12140	6308	6649	5695	7877	10537	9650
1963	5354	4467	5149	30860	26359	14015	6206	4774	4842	4126	4944	5183
1964	4501	5797	11764	17971	17425	10878	5183	3410	3233	2769	2772	3055
1965	4126	4433	6308	8218	9923	5933	3580	2939	4160	7127	9309	11969
1966	10400	8218	16266	20835	18823	13504	6343	3649	3683	4194	4774	6138
1967	5661	5456	5251	17664	19062	14151	8286	5251	4569	5933	8013	10298
1968	8968	7707	12242	24552	19062	12446	8457	4740	3717	3410	4740	10571
1969	7672	8661	8764	28166	33588	21722	10503	6718	5456	4774	9002	11185
1970	8184	7741	10503	26325	30383	15652	7775	3785	3297	5047	6513	6206
1971	3819	4433	11355	25200	35805	20937	8832	5763	7331	6581	5388	7297
1972	8184	7331	9787	22608	36146	23563	16300	12617	6990	5456	9548	14799
1973	16607	18243	25200	31508	25575	23802	19062	10537	7331	8730	7979	13538
1974	21551	17425	19164	27621	31372	21074	12617	8695	7025	6718	7877	12446
1975	11594	9957	13435	20392	22915	13128	6274	3615	4501	9616	15174	16504
1976	10094	12719	25097	34100	27962	19983	13128	14186	13128	15038	16334	15311
1977	13401	9071	18584	30178	22745	11764	6377	4842	6411	18107	20562	17527
1978	15072	13265	12856	30758	30690	19232	11253	6240	4194	4399	4501	3649
1979	8559	10332	23086	30690	23733	15379	6820	4501	6547	7638	9684	11764
1980	10537	6649	6206	16982	15379	8968	4876	4297	5115	6172	7366	9343
1981	7331	12992	22267	20494	16607	11935	6649	6649	8184	14663	20358	15004

Flow in ft^3/s

NODE 2 (Chambly)

YEAR	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1938	4873	9076	12890	23520	18046	10630	6533	5650	8087	12819	9853	13031
1939	9923	7381	10241	27228	35668	19882	10806	6533	4202	4238	4238	3955
1940	3376	2783	2825	20871	33478	23661	12784	7699	4626	3920	5756	6321
1941	11689	8546	7134	16209	13349	8299	5650	4132	2977	2359	3493	3348
1942	4485	4344	10241	23096	21966	14656	10171	5403	3920	5191	6145	5403
1943	5474	5368	11936	19494	29523	21824	14302	10347	8440	5968	11018	9676
1944	6957	6145	7840	22637	27510	14373	9005	5262	3814	3885	4662	4061
1945	5085	5333	15327	28464	30229	22036	13843	9252	7134	18964	19105	12713
1946	9747	8511	19246	20871	16704	14302	8122	5333	4167	6074	9923	9923
1947	10312	13773	15009	29311	33867	38846	25886	14196	8122	5262	4662	3849
1948	2804	2659	9676	24402	19635	15150	9358	6886	4697	3496	5650	7699
1949	15150	11407	12360	22284	17834	9853	5333	3567	3920	3461	4520	4909
1950	9041	9782	8899	24685	21789	11724	6745	4273	4626	4273	5121	12925
1951	10029	10418	13985	33408	26133	13667	9782	6922	5544	4273	8723	9535
1952	11195	12042	11230	29135	24014	21048	11583	5580	4591	4132	3450	5827
1953	7275	11371	13914	27122	29629	16421	8052	4838	3991	2917	3019	4097
1954	3418	5721	17587	27651	32348	23484	13702	7875	8158	13278	12007	12572
1955	12855	9288	16351	30441	27228	15079	7345	5756	5580	5227	8652	6180
1956	5121	5262	5474	19529	29382	21789	10700	5650	4450	4662	4061	4238
1957	4238	6109	9712	13808	13349	10488	7910	5191	4273	3673	4803	7734
1958	11513	10171	10347	28181	31607	20023	10594	7451	6003	7381	11654	6886
1959	5792	7063	9252	30583	22919	13066	7593	3673	3298	4626	10029	16739
1960	13455	11089	11053	31783	27863	15644	8228	5333	4308	5050	7487	5686
1961	3743	2853	14656	17657	23626	16421	11089	7275	6145	5262	4979	5474
1962	3673	2885	5403	24826	24544	12572	6533	6886	5898	8158	10912	9994
1963	5544	4626	5333	31960	27298	14514	6427	4944	5015	4273	5121	5368
1964	4662	6003	12184	18611	18046	11265	5368	3531	3348	2868	2871	3164
1965	4273	4591	6533	8511	10277	6145	3708	3044	4308	7381	9641	12395
1966	10771	8511	16845	21577	19494	13985	6569	3779	3814	4344	4944	6357
1967	5862	5650	5438	18293	19741	14656	8581	5438	4732	6145	8299	10665
1968	9288	7981	12678	25427	19741	12890	8758	4909	3849	3531	4909	10948
1969	7946	8970	9076	29170	34785	22495	10877	6957	5650	4944	9323	11583
1970	8476	8016	10877	27263	31465	16209	8052	3920	3415	5227	6745	6427
1971	3955	4591	11760	26098	37080	21683	9146	5968	7593	6816	5580	7557
1972	8476	7593	10135	23414	37434	24402	16880	13066	7240	5650	9888	15327
1973	17198	18893	26098	32631	26486	24650	19741	10912	7593	9041	8264	14020
1974	22319	18046	19847	28605	32489	21824	13066	9005	7275	6957	8158	12890
1975	12007	10312	13914	21118	23731	13596	6498	3743	4662	9959	15715	17092
1976	10453	13172	25992	35315	28958	20694	13596	14691	13596	15574	16916	15856
1977	13879	9394	19246	31253	23555	12184	6604	5015	6639	18752	21295	18152
1978	15609	13737	13314	31854	31783	19917	11654	6463	4344	4556	4662	3779
1979	8864	10700	23908	31783	24579	15927	7063	4662	6780	7910	10029	12184
1980	10912	6886	6427	17587	15927	9288	5050	4450	5297	6392	7628	9676
1981	7593	13455	23060	21224	17198	12360	6886	6886	8476	15185	21083	15538

Flow in ft^3/s

NODE 3 (Beloeil)

YEAR	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1938	5105	9508	13503	24639	18905	11136	6844	5919	8472	13429	10322	13651
1939	10396	7732	10729	28524	37366	20829	11321	6844	4402	4439	4439	4144
1940	3537	2915	2960	21864	35072	24787	13392	8065	4846	4107	6030	6622
1941	12246	8953	7473	16981	13984	8694	5919	4328	3119	2471	3659	3507
1942	4698	4550	10729	24195	23011	15353	10655	5660	4107	5438	6437	5660
1943	5734	5623	12505	20422	30928	22863	14983	10840	8842	6252	11543	10137
1944	7288	6437	8213	23714	28820	15057	9434	5512	3996	4070	4883	4254
1945	5327	5586	16056	29818	31668	23085	14502	9693	7473	19867	20015	13318
1946	10211	8916	20163	21864	17499	14983	8509	5586	4365	6363	10396	10396
1947	10803	14428	15723	30706	35479	40695	27118	14872	8509	5512	4883	4033
1948	2937	2786	10137	25564	20570	15871	9804	7214	4920	3663	5919	8065
1949	15871	11950	12948	23344	18683	10322	5586	3737	4107	3626	4735	5142
1950	9471	10248	9323	25860	22826	12283	7066	4476	4846	4476	5364	13540
1951	10507	10914	14650	34998	27377	14317	10248	7251	5808	4476	9138	9989
1952	11728	12616	11765	30521	25157	22049	12135	5845	4809	4328	3614	6104
1953	7621	11913	14576	28413	31039	17203	8435	5068	4181	3056	3163	4291
1954	3581	5993	18424	28968	33888	24602	14354	8250	8546	13910	12579	13170
1955	13466	9730	17129	31890	28524	15797	7695	6030	5845	5475	9064	6474
1956	5364	5512	5734	20459	30780	22826	11210	5919	4661	4883	4254	4439
1957	4439	6400	10174	14465	13984	10988	8287	5438	4476	3848	5031	8102
1958	12061	10655	10840	29523	33111	20977	11099	7806	6289	7732	12209	7214
1959	6067	7399	9693	32038	24010	13688	7954	3848	3455	4846	10507	17536
1960	14095	11617	11580	33296	29190	16389	8620	5586	4513	5290	7843	5956
1961	3922	2989	15353	18498	24750	17203	11617	7621	6437	5512	5216	5734
1962	3848	3023	5660	26008	25712	13170	6844	7214	6178	8546	11432	10470
1963	5808	4846	5586	33481	28598	15205	6733	5179	5253	4476	5364	5623
1964	4883	6289	12763	19497	18905	11802	5623	3700	3507	3004	3008	3315
1965	4476	4809	6844	8916	10766	6437	3885	3189	4513	7732	10100	12985
1966	11284	8916	17647	22604	20422	14650	6881	3959	3996	4550	5179	6659
1967	6141	5919	5697	19164	20681	15353	8990	5697	4957	6437	8694	11173
1968	9730	8361	13281	26637	20681	13503	9175	5142	4033	3700	5142	11469
1969	8324	9397	9508	30558	36441	23566	11395	7288	5919	5179	9767	12135
1970	8879	8398	11395	28561	32963	16981	8435	4107	3577	5475	7066	6733
1971	4144	4809	12320	27340	38845	22715	9582	6252	7954	7140	5845	7917
1972	8879	7954	10618	24528	39215	25564	17684	13688	7584	5919	10359	16056
1973	18017	19793	27340	34184	27747	25823	20681	11432	7954	9471	8657	14687
1974	23381	18905	20792	29966	34036	22863	13688	9434	7621	7288	8546	13503
1975	12579	10803	14576	22123	24861	14243	6807	3922	4883	10433	16463	17906
1976	10951	13799	27229	36996	30336	21679	14243	15390	14243	16315	17721	16611
1977	14539	9841	20163	32741	24676	12763	6918	5253	6955	19645	22308	19016
1978	16352	14391	13947	33370	33296	20866	12209	6770	4550	4772	4883	3959
1979	9286	11210	25046	33296	25749	16685	7399	4883	7103	8287	10507	12763
1980	11432	7214	6733	18424	16685	9730	5290	4661	5549	6696	7991	10137
1981	7954	14095	24158	22234	18017	12948	7214	7214	8879	15908	22086	16278

Flow in ft^3/s

NODE 4 (Sorel)

YEAR	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1938	5279	9832	13964	25479	19549	11515	7077	6121	8761	13887	10674	14117
1939	10750	7996	11094	29496	38639	21538	11706	7077	4553	4591	4591	4285
1940	3657	3015	3061	22610	36267	25632	13849	8340	5012	4246	6236	6848
1941	12663	9258	7728	17560	14461	8990	6121	4476	3225	2556	3784	3627
1942	4859	4706	11094	25020	23795	15876	11018	5853	4246	5624	6657	5853
1943	5930	5815	12931	21118	31982	23642	15494	11209	9143	6465	11936	10482
1944	7537	6657	8493	24522	29802	15570	9755	5700	4132	4208	5050	4399
1945	5509	5777	16603	30835	32747	23872	14997	10023	7728	20544	20697	13772
1946	10559	9220	20850	22610	18095	15494	8799	5777	4514	6580	10750	10750
1947	11171	14920	16259	31753	36688	42082	28042	15379	8799	5700	5050	4170
1948	3038	2881	10482	26435	21271	16412	10138	7460	5088	3787	6121	8340
1949	16412	12357	13390	24140	19319	10674	5777	3864	4246	3749	4897	5318
1950	9794	10597	9641	26741	23604	12701	7307	4629	5012	4629	5547	14002
1951	10865	11286	15150	36191	28310	14805	10597	7498	6006	4629	9449	10329
1952	12127	13045	12166	31562	26014	22801	12548	6045	4973	4476	3738	6312
1953	7881	12319	15073	29381	32097	17789	8722	5241	4323	3160	3271	4438
1954	3703	6198	19052	29955	35043	25440	14843	8531	8837	14384	13007	13619
1955	13925	10061	17713	32977	29496	16335	7957	6236	6045	5662	9373	6695
1956	5547	5700	5930	21156	31829	23604	11592	6121	4820	5050	4399	4591
1957	4591	6618	10521	14958	14461	11362	8569	5624	4629	3979	5203	8378
1958	12472	11018	11209	30529	34239	21691	11477	8072	6504	7996	12625	7460
1959	6274	7651	10023	33130	24828	14155	8225	3979	3573	5012	10865	18134
1960	14576	12013	11974	34431	30184	16948	8914	5777	4667	5471	8110	6159
1961	4055	3091	15876	19128	25594	17789	12013	7881	6657	5700	5394	5930
1962	3979	3126	5853	26894	26588	13619	7077	7460	6389	8837	11821	10827
1963	6006	5012	5777	34622	29572	15723	6963	5356	5432	4629	5547	5815
1964	5050	6504	13198	20161	19549	12204	5815	3826	3627	3106	3110	3428
1965	4629	4973	7077	9220	11133	6657	4017	3298	4667	7996	10444	13428
1966	11668	9220	18248	23375	21118	15150	7116	4093	4132	4706	5356	6886
1967	6351	6121	5891	19817	21385	15876	9296	5891	5126	6657	8990	11553
1968	10061	8646	13734	27545	21385	13964	9488	5318	4170	3826	5318	11859
1969	8608	9717	9832	31600	37683	24369	11783	7537	6121	5356	10100	12548
1970	9182	8684	11783	29534	34086	17560	8722	4246	3699	5662	7307	6963
1971	4285	4973	12739	28271	40169	23489	9908	6465	8225	7383	6045	8187
1972	9182	8225	10980	25364	40552	26435	18287	14155	7843	6121	10712	16603
1973	18631	20467	28271	35349	28692	26703	21385	11821	8225	9794	8952	15188
1974	24178	19549	21500	30988	35196	23642	14155	9755	7881	7537	8837	13964
1975	13007	11171	15073	22877	25708	14729	7039	4055	5050	10788	17024	18516
1976	11324	14270	28157	38256	31370	22418	14729	15915	14729	16871	18325	17177
1977	15035	10176	20850	33857	25517	13198	7154	5432	7192	20314	23069	19664
1978	16909	14882	14423	34507	34431	21577	12625	7001	4706	4935	5050	4093
1979	9602	11592	25900	34431	26626	17254	7651	5050	7345	8569	10865	13198
1980	11821	7460	6963	19052	17254	10061	5471	4820	5738	6924	8263	10482
1981	8225	14576	24981	22992	18631	13390	7460	7460	9182	16450	22839	16833

Flow in ft^3/s

Appendix C

Historical DTL Simulation (Problem Cases) for the Year 2001 with a Minimum Flow Constraint of 80 m^3/s

Historical Simulation: without reservoir drawdowns & without consumption cutbacks

Forecast Year: 2001
Season Months: May to Sept. (inclusive)

Year	Month	Node	Supply (MCM) Local	Upstream	Diversn	Irrigtn	Reservr	Total	Intake (MCM) Municipl	Livestk	Industl	Irrigtn	Total	%	Consumption (MCM) Municipl	Livestk	Industl	Irrigtn	Total	%	Outflow MCM	Minimum MCM	Flag	Shortage (MCM) Consume	Boundry
1940	Feb.	1	184.4	.0	.0	.0	.0	184.4	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	0	184.4	193.5	..!	0	0
1940	Feb.	2	6.2	184.4	.0	.0	.0	190.6	1.1	.1	6.8	.0	8.1	4	.2	.1	1.4	.0	1.7	1	188.9	193.5	..!	0	0
1940	March	1	207.3	.0	.0	.0	.0	207.3	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	0	207.3	214.3	..!	0	0
1940	March	2	7.0	207.3	.0	.0	.0	214.3	1.2	.1	6.8	.0	8.2	4	.3	.1	1.4	.0	1.8	1	212.5	214.3	..!	0	0
1941	Oct.	1	173.1	.0	.0	.0	.0	173.1	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	0	173.1	214.3	..!	0	0
1941	Oct.	2	5.8	173.1	.0	.0	.0	178.9	1.8	.1	6.8	.0	8.7	5	.4	.1	1.4	.0	1.9	1	177.0	214.3	..!	0	0
1941	Oct.	3	8.5	177.0	.0	.0	.0	185.5	1.8	.3	1.6	.0	3.7	2	.4	.2	.5	.0	1.1	1	184.4	214.3	..!	0	0
1941	Oct.	4	6.4	184.4	.0	.0	.0	190.9	1.5	.2	1.1	.0	2.8	1	.3	.2	.2	.0	.7	0	190.2	214.3	..!	.0	0
1948	Jan.	1	205.7	.0	.0	.0	.0	205.7	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	0	205.7	214.3	..!	0	0
1948	Jan.	2	7.0	205.7	.0	.0	.0	212.7	1.2	.1	6.8	.0	8.2	4	.3	.1	1.4	.0	1.8	1	210.9	214.3	..!	.0	0
1948	Feb.	1	176.2	.0	.0	.0	.0	176.2	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	0	176.2	193.5	..!	0	0
1948	Feb.	2	6.0	176.2	.0	.0	.0	182.2	1.1	.1	6.8	.0	8.1	4	.2	.1	1.4	.0	1.7	1	180.4	193.5	..!	0	0
1948	Feb.	3	8.7	180.4	.0	.0	.0	189.1	1.1	.2	1.6	.0	3.0	2	.2	.2	.5	.0	.9	0	188.2	193.5	..!	0	0
1953	Oct.	1	214.0	.0	.0	.0	.0	214.0	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	0	214.0	214.3	..!	.0	0
1961	Feb.	1	189.1	.0	.0	.0	.0	189.1	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	0	189.1	193.5	..!	.0	0
1962	Feb.	1	191.2	.0	.0	.0	.0	191.2	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	0	191.2	193.5	..!	.0	0
1964	Oct.	1	210.4	0	.0	.0	.0	210.4	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	0	210.4	214.3	..!	0	0
1964	Nov.	1	203.8	.0	.0	.0	.0	203.8	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	0	203.8	207.4	..!	.0	.0