LAND AND WATER APPRAISAL FOR IRRIGATION IN RICHELIEU AND ST-HYACINTHE COUNTIES, QUEBEC.

by

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IRRIGATION PLANNING FOR RICHELIEU ANDST-HYACINTHE COUNTIES

ABSTRACT

Suitable areas for subirrigation and sprinkler irrigation were identified in Richelieu and St-Hyacinthe counties, using a set of criteria established by experimental work.

Land suitable for subirrigation includes uniform sandy textured profiles deeper than 1 m, with hydraulic conductivities greater than 0.5 m/d and lying on a clay layer at approximately 2 m from the surface, and with slopes less than 0.5 % and little or no microrelief.

Soils that failed to satisfy the subirrigation criteria and that would most benefit from sprinkler irrigation were identified. These soils had available water holding capacities of less than 7.5 cm per 100 cm of soil. Most of the soils suitable for sprinkler irrigation were shallow sand (50 cm) over clay. The land was relatively flat.

A total of 15 000 ha complied with subirrigation criteria. Of this area, 10 000 ha were cleared. Subirrigation block SI-09 was the most promising for a regional subirrigation project. The total area that would benefit the most from sprinkler irrigation covers 14 477 ha of cleared, flat land.

The irrigation requirements and water available in the St-Lawrence, Richelieu and Yamaska Rivers were calculated. Both the Richelieu and St-Lawrence Rivers could meet the flow demand for the total irrigated area. However, 57 % of the subirrigable land is located at more than 20 km from the Richelieu and St-Lawrence and could be more economically supplied by the Yamaska River. The Yamaska River could supply all the subirrigated land in its vicinity (4 900 ha) and part of the land suited for sprinkler irrigation (1 000 ha) 4 out of 5 years.

RESUME

Les zones propices à l'irrigation souterraine et l'irrigation par aspersion des comtés de Richelieu et St-Hyacinthe furent identifiées, suivant des critères établis à partir de travaux expérimentaux.

Les terres propices à l'irrigation souterraine sont constituées de sols sableux de plus de 1 m, ayants une conductivité hydraulique égale ou supérieure à 0.5 m/j, et reposants sur une argile imperméable. La topographie est plane et sans microrelief. Les terres relativement planes et dont les sols sont des sables minces (50 cm) ayants une réserve en eau utile inférieure à 7.5 cm/100 cm de sol, furent sélectionnés pour l'irrigation par aspersion.

Au total, 15 000 ha, dont 10 000 ha défrichés, satisfaisaient les critères d'irrigation souterraine. Le périmètre d'irrigation souterraine SI-09 démontre le plus de potentiel de développement régional. Quant à l'irrigation par aspersion, elle pourrait être bénifique à 14 477 ha de terres défrichées dans les deux comtés.

Les besoins en irrigation, et les débits disponibles dans le St-Laurent at les rivières Richelieu et Yamaska ont été calculés. Il appert que le St-Laurent et le Richelieu pourraient, sans problèmes, satisfaire la demande en eau de toutes les terres irrigables. Cependant, 57 % de cette superficie seraient desservis par la rivière Yamaska. Il semble qu' en moyenne, 4 années sur 5, la Yamaska peut suffir aux besoins de tous les périmètres identifiés pour l'irrigation souterraine adjacents à la rivière (4 900 ha), et une partie seulement des zones disponibles pour l'irrigation par aspersion (1 000 ha).

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NOMENCLATURE

The following abbreviations and symbols are found in the text.

AWC	Available Water Capacity
AI	St-Aimé soil series
AS	Aston Soil Series
BL	Bellevue Soil Series
C.E.C.	Cation Exchange Capacity
CHU	Corn Heat Unit
cm	Centimeter
E.T.	Evapotranspiration
ha	Hectare
JS	Joseph Soil Series
km^2	Kilometer squared
m	Meter
m^2	Meter squared
m^3	Meter cubed
m^3/s	Meter Cubed per second
meq/l	Milliequivalent per liter
mg/l	Milligrams per liter
mm	Millimeter
mmhos/cm	Millimhos per centimeter
RAW	Readily Available Water
SDM	Standard Deviation of the Mean
SI	Subirrigation suitability class
SI-07	Subirrigation Block 07
SP1	Sprinkler irrigation suitability class (AWC $<$ 50 mm)

SP2	Sprinkler irrigation suitability class (50 mm<AWC<75 mm)
SPR	Soil Potential Rating Index
tonne	metric ton = 1 000 kg

CHAPTER I

INTRODUCTION

1.1 Background.

In the last few years, Canadians have come to realize that their land is a finite and limited resource. With a growing population, production of crops to feed humans and domestic animals must increase. This must not be done at the expense of soil degradation. Most of the uncultivated land that could be put into production (class IV, V, VI, VII land) is currently forested, wet or rocky or has climatic limitations. These soils are often too fragile to be cultivated without rapidly deteriorating . An increase in crop production would optimally stem from improved management of the land already cultivated.

In Québec, the major concentration of arable land is found in the St-Lawrence lowlands. The counties of Richelieu and St-Hyacinthe are in the center of the agricultural zone with the most favourable climate, the greatest heat units and the longest growing season in the province. A majority of farmers in both counties have shifted from dairy to cash crop farming. Currently, grain maize is grown on more hectares than any other crop. Many farmers are now showing an interest in increasing the area devoted to soya beans. A soya bean micronization plant was built in 1987 at St-Robert in Richelieu county. Unfortunately, the lowest summer rainfall in Québec occurs in this region making the production of soya difficult. It has been determined that there are several thousands of hectares of flat, stone free, sandy soil underlain by clay in these two counties. This land absorbs rainfall and snowmelt readily. In its natural state it is usually saturated to the surface in April, May and early June. The installation of subsurface drains between 1965 and 1980 has improved conditions for planting and harvesting. However, crops suffer from a lack of water in July and August in most years.

Massin (1971) calculated that on the light soils in the St-Hyacinthe and Sorel region having a water holding capacity of 50 mm , dry conditions would recur 2 out of 3 years. Lake (1968) evaluated the irrigation requirements of the same region. He found an average need for 2 mm/d of supplemental irrigation water from June 15 to September 10.

Irrigation, coupled with better cultural practices, would be a good solution. Unfortunately, the counties are faced with a problem of water availability for irrigation. Most of the sandy soils are located in the vicinity of the Yamaska River which has low flows in summer, when the water is the most needed. Well water is extremely saline and could have detrimental effects on soils and plants. Sprinkler irrigation could easily be used on these flat lands. However, sprinkler irrigation requires an initial investment that few farmers can afford. Also, sprinkler irrigation is usually done in daytime and requires higher flows during a 12 hour period. This is difficult to accomplish in a region where water is scarce.

Subirrigation appears as a low cost, beneficial solution for the soils to which it is suited. After seeding, the valves on the main drain pipes are closed to conserve the water in the soils. Adding water to the system raises the water table. Water then moves upwards toward the plant roots by capillarity. Subirrigation has been tested since 1983 in Richelieu county and is performing efficiently, increasing yields of grain corn from 17 % to 45 %. This is not the only factor that makes subirrigation attractive. This form of irrigation requires less inputs than other types of irrigation. It has been demonstrated that the drainage systems currently in place in the light soils of Richelieu county can be used to distribute water to the fields. Not all subsurface drained land is suitable for subirrigation. Specific conditions of soil types and topography are required.

At the present time, farmers are not advised on whether their land is suited for controlled drainage, sprinkler or subirrigation. Thus, they are spending moneys on irrigation systems for which the land might not be suited. It is important now to differentiate between land that will profit from subirrigation and land that can only benefit from controlled drainage or will require sprinkler irrigation. This is an important step toward maximizing the resources available to make the best use of the land and water available.

1.2 Objectives

The objectives of this thesis are to:

1. Define criteria for the selection of land for irrigation and to differentiate between the land suitable for subirrigation and that to be irrigated with sprinklers.

2. Identify the land suitable for subirrigation, according to a set of criteria and plot the subirrigable zones on topographical maps.

3. Identify the land suitable for sprinkler irrigation and plot the defined units on the same topographical maps as used for identifying these lands suitable for subirrigation.

4. Assess the needs for, and availability of water in the Richelieu, St-Lawrence and Yamaska rivers.

1.3 Scope

The field work, soil and water appraisal and mapping work were carried out for this thesis in order to determine the approximate extent and location of land suitable for subirrigation and land which would most likely benefit from sprinkler irrigation in Richelieu and St-Hyacinthe counties. This thesis provides a general overall land and water appraisal for irrigation. No economic analysis is involved. The maps should be used as a guide to indicate the areas which could benefit from irrigation. Technical and economic feasibility studies should be made in the detailled planning stage of irrigation for particular lands, to find the most suitable places for pumping stations, water control structures, and water table control chambers.

CHAPTER 2

LITERATURE REVIEW

2.1 General Information on the Area Examined

2.1.1 Location

In Québec, land suitable for subirrigation and other forms of irrigation is spread in a dozen counties. However, the largest concentration is in the Yamaska and Richelieu river basins, which are the most productive regions of the province. Both Richelieu and St-Hyacinthe counties are located in these river basins and therefore were selected to analyse their potential for irrigation.

The location and boundaries of Richelieu and St-Hyacinthe counties are shown in figure 2.1. However, for this study, because only partial soil information was available, the south boundary was set at Route 20.

2.1.2 Climate

The climate in St-Hyacinthe and Richelieu counties is among the best in Québec. It permits the growth of a wide variety of crops. This climate is classified as "continental temperate" (Brouillette et al., 1971) because of the contrasting seasons and the widely varying temperatures.

The frost free period normally lasts 125 to 140 days. In 50 % of the years it will extend from the 11th of May to the 2nd of October.

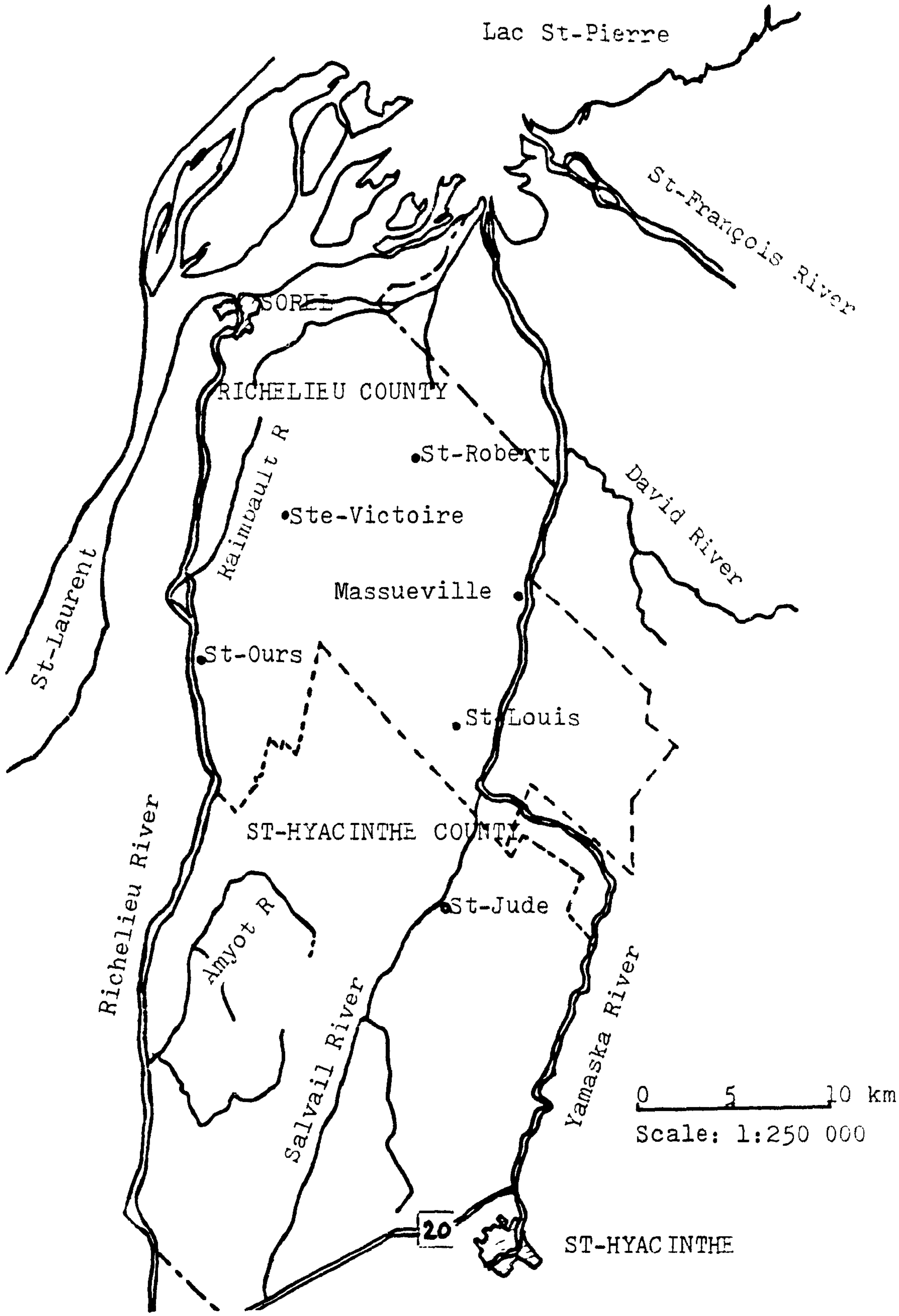
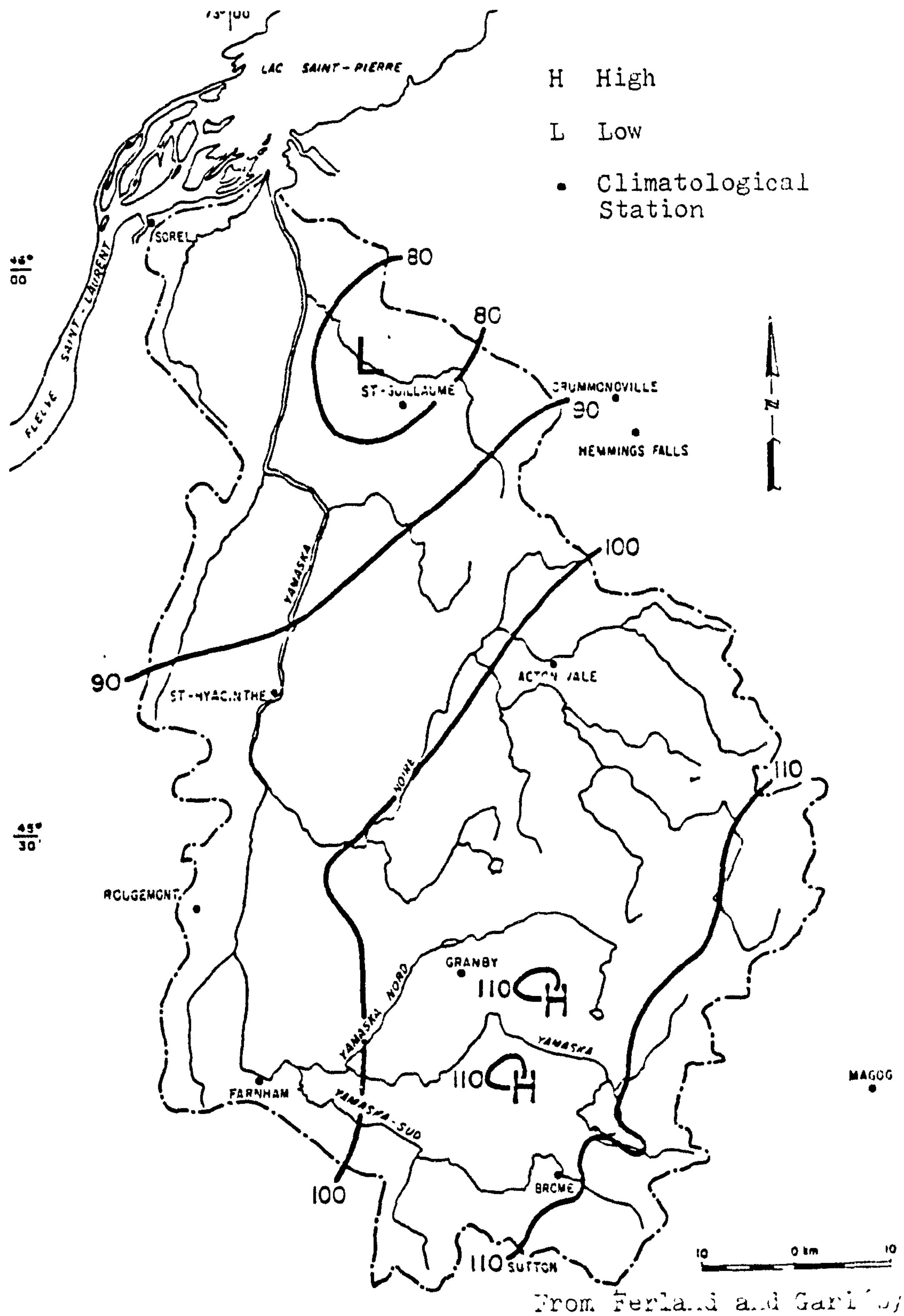


Figure 2.1 Map of Richelieu and St-Hyacinthe Counties.

(Environment Canada, 1982). The length of the growing season with temperatures above 5°C ranges from 200 to 208 days. The growing season usually starts around the 10th of April and ends between the 31st of October and 4th of November. The Richelieu and St-Hyacinthe counties have the greatest corn heat units available in Québec with 2700 CHU (Dubé et al., 1982).

In the region from St-Hyacinthe to Sorel, mean monthly precipitation in June, July and August varies from 90 mm at St-Hyacinthe to 80 mm at Sorel. Figure 2.2 shows the spatial distribution of precipitation in the Yamaska basin for the month of July. Mean monthly rainfalls reach 110 mm in July in the hilly lands southeast of Granby. The potential evapotranspiration is approximately 120 mm/month, in June, July and August. The region experiences drought conditions in the summer months at a frequency of 2 out of 3 years for soils with low readily available water (Massin, 1971). Massin calculated the deficits for soils with readily available water of 100 mm. In Richelieu and St-Hyacinthe counties, many of the soils have readily available water storage capacity of less than 100 mm. The probability of recurrence of drought periods found in tables 2.1 and 2.2 for the St-Hyacinthe and the Sorel meteorological stations is likely to increase for these soils with available water less than 100 mm. Lake (1968) had evaluated that the water deficits at the St-Hyacinthe station would recur 4 out of 5 years. The drought conditions experienced in the region are due to a deficit between evapotranspiration and the water readily available to the plants. The very low water holding capacities of the light sandy soils of the region, combined with excessive drainage have accentuated the dryness. Corn monoculture has also reduced the organic matter content of



From Ferland and Gariépy (1979)

Figure 2.2 Spatial Distribution of Rainfall in the Yamaska Basin for the Month of July.

Table 2.1 Frequency of Deficits at the Sorel Meteorological Station

Readily Available Water Month	100 mm	138 mm	177 mm
June	43 %	27 %	13 %
July	73 %	57 %	43 %
August	67 %	60 %	50 %
June to August	61 %	48 %	36 %

Note: The percentage in the body of the table is the recurrence interval of the water deficits for a given soil. For example, in the month of June, a soil with a readily available water of 100 mm is likely to experience a deficit 43 % of the years, ie. 2 out of 5 years.

(From Massin, 1971)

Table 2.2 Frequency of Deficits at the St-Hyacinthe Meteorological Station

Readily Available Water Month	100 mm	138 mm	177 mm
June	43 %	23 %	7 %
July	63 %	57 %	47 %
August	67 %	67 %	53 %
June to August	58 %	49 %	35 %

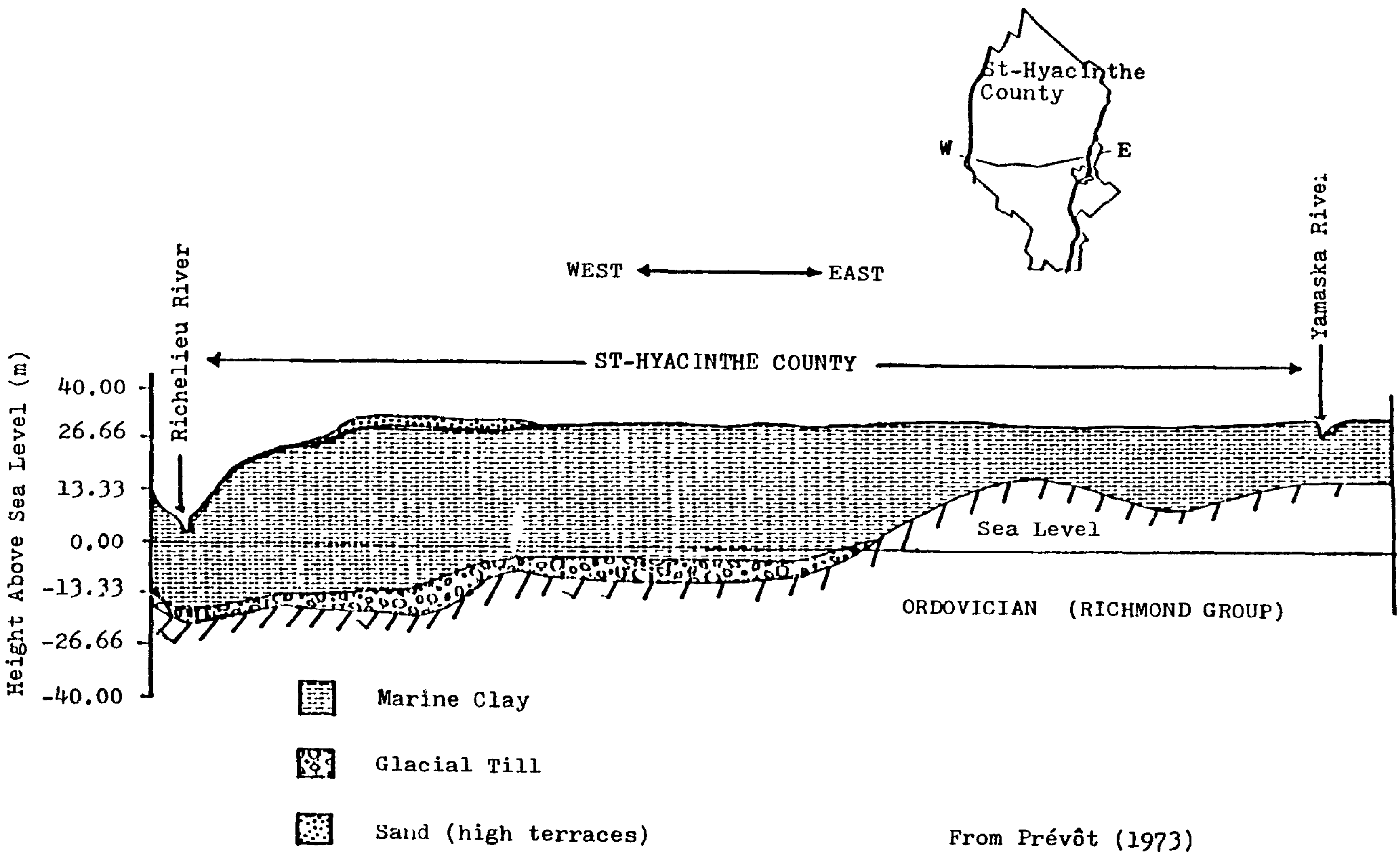
Note:See note in Table 2.1.

(From Massin, 1971)

soils, and thus the soils capacity to retain wate increasing the dependency of the plants on a water supply other than the soil's reserve.

2.1.3 Surface Geology of Richelieu and St-Hyacinthe Counties.

The region's soil deposits are essentially sediments from the Ordovician period (450 million years). Both counties, at that time, were under the Champlain sea. The first deposit consists of very fine marine clay over glacial till over limestone. The thickness is variable. Originally, the bottom of the Champlain sea was a glacial landscape. Clay deposits up to 30 meters deep have been observed in the region (Gadd, 1960). The marine clay deposit is very flat, gently sloping towards the St-Lawrence River. The clay minerals observed are mainly mica-illite and montmorillonite (Karrow, 1965). The permeability of this deposit is very low. In a large part of the region, a fine sandy deposit of variable thickness lies over the marine clay. The sand deposits originated from various phenomena. The sand terraces along the Richelieu and Yamaska rivers are fluvial deposits and consist mainly of coarse sand. A large portion of the sand cover is of deltaic origin. The texture is finer. The thickness of the deposits can reach 5 meters (Karrow, 1965). The soils that are of interest in this study were formed on these sandy deposits. A profile of the St-Hyacinthe county from east to west is found in Figure 2.3. The sand layer, under natural conditions is saturated most of the year because of the restriction of drainage by the underlying clay layer. Also, water does not easily move longitudinally because of the small slopes observed. After installation of subsurface drains for cultivation, the sands become drier.



From Prévôt (1973)

Figure 2.3 Profiles of the Geological Deposits at the Level of St Hyacinthe, In St Hyacinthe County.

Richelieu and Yamaska Rivers were formed by erosion of these deposits. The banks of both rivers are steep as they pass through Richelieu and St-Hyacinthe counties.

2.1.4 Hydrogeology

The soil deposits of both counties do not hold large aquifers except for the sandy high terraces. Water flows at the boundary of the sand and marine clay deposits. Aquifers in the limestone are found at depths ranging from 20 to 65 meters.

Water from the wells, in Richelieu and St-Hyacinthe counties, is saline. During the Champlain sea episode, salty sea water was trapped. The concentration of dissolved solids is higher than 500 mg/l and often above 1000 mg/l. Data on well water quality is found in Table 2.3. Two types of aquifers were observed by Simard and DesRosiers (1979) in Richelieu and St-Hyacinthe counties. The wells located north of St-Louis parish have fresh water with high ferrous iron concentrations. Wells from St-Louis to St-Hyacinthe have saline water. The highest degree of salinity is found in wells around St-Louis. The concentrations of total salt in the water from the aquifer on the experimental site are also found in Table 2.3.

Table 2.3 Water Quality of Sample Wells in St-Hyacinthe and Richelieu counties.

	Well 1[1]	Well 2[2]	Well 3[3]
pH	8.20	7.60	7.1
Chlorides (mg/l)	76.00	1 020.00	7 748.00
Total Hardness (mg/l $CaCo_3$)	80.00	897.00	N/A
Alkalinity (mg/l $CaCo_3$)	328.00	423.00	457.00
Iron (mg/l)	0.31	1.41	4.24
Total Disolved Solids (meq/l)	21.40	189.10	12 713.00
Conductivity (mmho/cm)	1.056	6.236	15.00

1. Around Sorel and along the Richelieu river. (Simard and Des Rosiers, 1979)

2. Along Yamaska river up to Point du Jour. (Simard and Des Rosiers, 1979)

3. Located on Mr. Charbonneau's farm in St-Louis.

2.1.5 Hydrography and Drainage.

Three important drainage basins cover Richelieu and St-Hyacinthe counties: Richelieu river basin, Yamaska river basin, both sub-basins of the St-Lawrence basin. Because the banks along the Richelieu and the Yamaska rivers are steep, the risk of flooding is reduced. Part of the land along the St-Lawrence river is periodically flooded, limiting its agricultural use.

A few small rivers meander through both counties. They are fairly deep and carry low flows. The Laplante, Amyot and Raimbault flow into the Richelieu river. Salvail, Pot-au-Beurre and St-Pierre rivers drain into the Yamaska. Some of these rivers can be located on Figure 2.1. Apart from these naturally occuring rivers, a network of drainage ditches and small watercourses cover Richelieu and St-Hyacinthe counties.

The internal drainage of the land is imperfect to very bad. This is due to the very flat topography and to the marine clay layer lying at about 1.5 meters below surface. On the cultivated land the poor drainage has been corrected by the installation of artificial subsurface drainage pipes. Only the land on the edges of the sand terraces or on the escarpment along the Yamaska river are naturally well drained.

2.1.6 Agricultural Production.

The region's main industry is agriculture. About 55% of the total land area is cultivated. Traditionally, the region was a dairy producer. With the rise in the price of grain corn, the counties' agriculture has shifted towards corn monoculture. In Richelieu, 42% of the total cultivated area is grain corn. In St-Hyacinthe, this proportion is 51 %. Table 2.4 shows how the land is distributed among the various crops. Second in importance are forage crops: cultivated hay, alfalfa and small grains. All of these major crops suffer drought during summer and could benefit from supplemental irrigation.

In summary, the climate and the geology are responsible for many of the cropping problems occuring in the region from St-Hyacinthe to Sorel. The drainage problems have now largely been solved. The subsurface drainage systems have been beneficial, lengthening the growing season and improving conditions for planting and harvesting on the light soils in Richelieu and St-Hyacinthe counties. The dry conditions prevailing in June, July and August in the medium sand soils with high drainable porosity have been accentuated by the subsurface drainage systems. The absence of water sources in proximity of these areas and the low flows available in the watercourses have prevented the use of irrigation. Approximately 25 875 ha of light, flat soils,in Richelieu county alone, could benefit from sprinkler and subirrigation, if the water resources were adequately managed.

Table 2.4 Agricultural Land Use in Richelieu and St-Hyacinthe counties.

Crop	Richelieu (ha)	St-Hyacinthe (ha)
Alfalfa	1 673.53	2 616.80
Barley	2 060.37	3 181.39
Buckwheat	276.08	45.71
Cereals (mixed)	308.03	1 097.36
Corn (silage)	1 114.56	1 952.96
Corn (grain)	10 831.18	25 324.54
Forage	5 353.02	4 445.52
Oat	1 827.79	1 525.05
Oat (silage)	35.05	6.84
Orchard	5.18	165.98
Potatoes	9.92	52.77
Rye	0.00	0.00
Small Fruits	27.69	174.85
Sugar Beats	36.24	1 769.66
Tobacco	0.00	0.00
Wheat	591.40	3 994.57
Others	1 355.90	2 476.65
Total Cultivated	25 817.44	49 493.62

(From MAPAQ, 1986)

2.2 Subirrigation in Québec.

Although subirrigation has been practised for 30 years in the Netherlands and United States, it has just started in Québec. An experimental project has been going on for 5 years in Richelieu county. Many farmers have recently bought control chambers and begun to practise controlled drainage.

Subirrigation consists of using the subsurface drain pipes in place to distribute the irrigation water. In the irrigation mode, water is pumped into a control chamber from which it flows into the lateral pipes and out into the soil. From the saturated subsoil, water rises to the root zone by capillarity. In controlled drainage mode, the subsurface drains are obstructed to retain water in the subsoil and to prevent excessive drainage. No water is added.

In general, Québec has a cool, moist climate. In order to improve planting and harvest conditions and to extend the growing season, most cultivated land in the St-Lawrence lowlands has been artificially drained. The challenge was then to find out if it was possible to use the subsurface drainage systems in place and transform them, at minimum cost, for subirrigation. The first research was conducted by Gallichand and Broughton in 1983, and looked at the water table distribution in the field. They were able to maintain a steady state water table. The head difference between the control chamber and the field varied from 30 to 50 cm. A 50% increase in yield was observed as a result of the experiment. Von Hoyningen Huene (1984) continued the research. He compared water table fluctuations under irrigated and non-irrigated conditions, by measuring water losses in the system and the time required to raise the water table. He found that, under irrigation, the water table had risen by 22 cm in two weeks while, in the same period, the water table had dropped by 10 cm in the non-irrigated plots. He also found that leakage to non-irrigated plots was negligible and was likely to decrease in importance if the area irrigated was increased. He concluded that subirrigation was feasible on the condition that the land be levelled, to give a more uniform water table profile. An appreciable change in the remaining available water after irrigation was observed. The increase was due to capillary rise from the water table. In order to determine the height at which the water should be maintained in the control chamber, Bournival et al. (1986) measured all head losses through the subirrigation system. He found that, for a sandy loam in southern Québec, the volume of irrigation water needed for 1.06 ha was 1890 m^3, an average of 3.3 mm/d. The water in the control chamber had to be kept 55 cm above the drain pipes to maintain the desired water table throughout the field. 75% of the head loss was observed to occur in the first 5 cm from the drain pipe.

In the past three years, farmers have shown a real interest in the concept of subirrigation. Since 1984, improvements have been made to simplify the management of the technique.

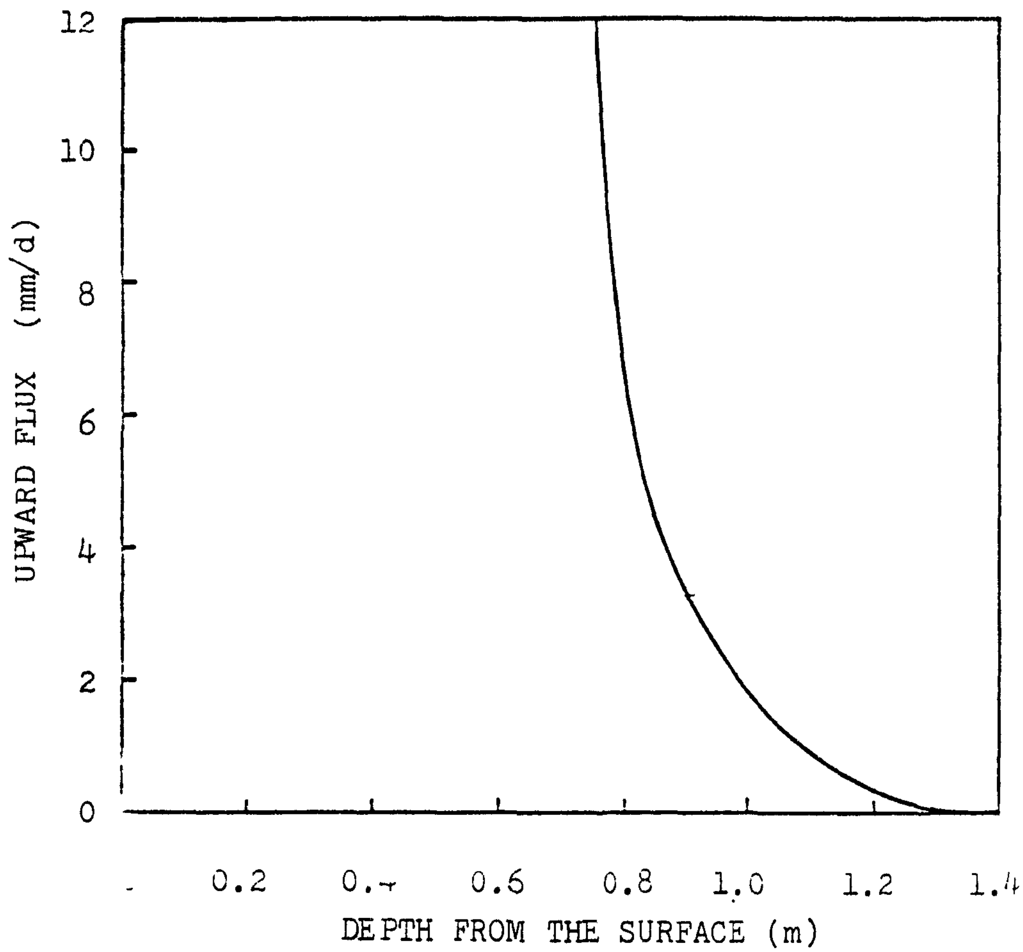
Much research is left to be done, with other crops than corn and other soils than sandy loams. Nothing indicates that subirrigation is unfeasible on heavier soils with good hydraulic conductivity.

2.3 Criteria for the Selection of Land for Subirrigation.

For subirrigation to be efficient, certain requirements must be met. Fox et al. (1955), and Criddle and Kalisvaart (1967) have reviewed the conditions under which subirrigation is feasible.

Subirrigation implies a precise control of the water table. The water table has to be held below the primary root zone, but close enough that the water can reach the plant by capillarity. This is easily achieved if an impervious layer, clay, bedrock or natural water table, exists within 2 or 3 metres from the surface. This layer will restrict the downward movement of water and create a perched water table condition. Harris et al. (1962) said that for corn the optimum water table depth is 100 cm. Memon (1985) indicated that for the St-Samuel sand in Richelieu county, to obtain an upward flux of 3 mm/d, the water table should not be deeper than 90 cm. A graph of the upward flux versus the depth of the water table from the surface is shown in Figure 2.4. Doering et al. (1982) gave results of experiments in North Dakota, U.S.A. showing maximum yields of maize and sugar beets when the water table was between 95 and 115 cm below the surface. If the permanent water table is below 2 meters deep, it will be almost impossible to maintain an upward flux high enough to supply the plants. The upward flux should at least be 2 mm/d.

As for the soil, subirrigation has shown to work best in the sandy type soils found in North Carolina and Florida. But Renfro (1955) reported that subirrigation has also been succesfully implemented in



From Memon (1985)

Figure 2.4 Upward Flux vs. Depth from the Surface, in a St-Samuel Sandy Loam.

peat soils of the San Joaquim valley in California. The capillary conductivity of clay soils is usually not high enough to meet the plant demand. Criddle and Kalisvaart (1967) have reported that silt and clay soils seal after periods of drying and rewetting thus reducing the hydraulic conductivity of the soil. Based on tests, Skaggs (1972) states that, for the water to rise by capillarity sufficiently rapidly to meet the crop needs, the saturated hydraulic conductivity of the soil should be greater than 0.5 m/d. This hydraulic conductivity value is also the lower limit below which subirrigation ceases to be economical (Evans and Skaggs, 1987). Layers of low hydraulic conductivity will impede the upward water flux. Thus subirrigation performs best when the soil above the drain is of uniform texture.

It is mandatory that the topography be relatively flat so the water table is maintained between 60 and 100 cm depth throughout the field. When the water table is closer than 60 cm below the surface, the crop may suffer from lack of air in the root zone. Where the water table is deeper than 110 cm, the field will experience drought. This range allows some storage space for the rain. The drain pipes should be in the permeable zone above the restricting layer. Alternately, if the drains must be put in a layer of low permeability, they should be installed with a trencher and backfilled with sand so that the water can flow up from the drain pipes into the sand in the irrigation mode. Only soils with an important sand layer above the clay, 80 cm at least, could benefit from this type of installation.

If a drainage system is in place, either ditches or subsurface pipes, the parallel drains should be close enough together so the water table at midspacing can be raised at sufficient height. Skaggs (1972) said that a 30m spacing did not respond fast enough while a 19.2 tile spacing was able to keep the water table at 90 cm for potatoes. The rate of rise of the water table depends also on the hydraulic conductivity of the soil, and the soil-water characteristic.

Because of a difference in head, water will leak from the side of irrigated to non irrigated plots. All authors suggest that the larger the area subirrigated, the smaller will the leakage be in proportion to the total water needed. Depth of adjacent ditches will also influence the seepage volumes. Massey et al.(1983) proposed that subirrigation may not be feasible if the ditches along irrigated fields are too deep, unless a tight control is exerted on the water levels in the ditches. Adjacent fields should be leveled to minimize leakage.

In summary, there are three requirements for subirrigation to be successful:

1. Soil texture
2. Topographic features
3. Location of the subirrigation zones

2.4 Subirrigation vs. Sprinkler Irrigation.

Sprinkler irrigation is a versatile means of applying water. It can be used under almost all conditions of topography, soil and climate, for germination, frost protection and manure spreading. By comparison, subirrigation requires a very specific set of conditions found only in a few agricultural regions. Nevertheless, in some cases, where both systems can be used, subirrigation presents net advantages.

If suitable natural conditions are available, and a drainage system exists or is required, the initial investment for subirrigation will clearly be lower than for sprinkler irrigation. Von Hoyningen Huene (1984) has shown that it was possible to adapt a subsurface drainage system to Québec's conditions. Under Québec's climate, where only supplemental irrigation is needed, sprinkler irrigation may not be economically justified. A sprinkler irrigation system probably is economical for high value crops but this remains to be confirmed with more tests for lower value crops. Additional costs linked to an irrigation system are labour, maintenance and energy. The energy requirements of subirrigation are only about 15 % of those associated with sprinkler irrigation when water is available in a watercourse or a well near the field to be irrigated.The pumping head for subirrigation is only about 15 % of that for sprinkler irrigation.

With sprinkler irrigation, the water requirements are affected by evaporation and wind which reduce the application efficiency.

The comparison between sprinkler and subirrigation could be endless. What is important, is to compare how both performed on soil types that suffer most from drought in Richelieu and St-Hyacinthe counties. Subirrigation reduces the stress on the plants by maintaining water available continually to the roots. With sprinklers, water is applied weekly, when the water table has receeded. However, subirrigation cannot be used with all crops. Strawberries, for example, are better irrigated with sprinklers, which provides frost protection and the very high demand needed over a few days during rapid growth of the berries. Also, vegetables are better irrigated by sprinkler because of their shallow rooting system and the need for surface application to help with germination.

The sandy soils of Québec have a very low water holding capacity and cation exchange capacity. Water applied by the sprinkling will percolate rapidly and leach the remaining nutrients in the soil. Maintaining a high water table has been shown to reduce the loss of nitrates and other minerals (Gilian et al.,1978, Skaggs et al.,1972). In muck soils, a high water table could reduce subsidence. Subirrigation, therefore seems better adapted than sprinkler irrigation for these soils.

2.5 Irrigation Requirements In the St-Hyacinthe and Richelieu Counties.

The most common way of estimating water requirements is by doing a water balance of the soil-root zone.

$$AWC = Rain - E.T. + Irrigation\ Water \qquad (2.1)$$

AWC is the water held in the root zone and available to the plan. E.T. is the evapotranspiration. Lake (1968) using equation 2.1, and 30 years of weather data for St-Hyacinthe station calculated the irrigation water needed. He used Thornthwaite's method to calculate evapotranspiration, and found irrigation requirements, for the months of June, July and August to average 2 mm/d. From experiments conducted in 1985, Bournival et al. (1986) calculated that the irrigation requirements were 3.3 mm/d, including seepage losses.

Nolin and Lamontagne (1986) estimated the available water of some soil series found in the Montreal region, for 50 cm rooting depth. These values can be found in appendix B. The rooting depth which controls the amount of water accessible to plants is variable throughout the season. Many authors suggest that the corn rooting depth goes from 1 to 1.6 m. These depths were observed in very deep soils under long vegetative seasons. Hudson (1976) states that the effective rooting depth of corn is more likely 60 cm. In subirrigation, the roots will not need to go very deep for water. Memon (1985) measured the root density at the experimental subirrigated site of St-Louis, in a St-Samuel soil suitable for subirrigation. He found no roots below 50 cm in both the subirrigated and non irrigated plots. Eighty percent of the roots were found in the top 30 cm in both the irrigated and non-irrigated plots.

2.6 Water Quality in the Richelieu and St-Hyacinthe Counties.

Water quality is a factor that affects irrigation. There are three types of problems related to irrigation with poor water quality:

1. Plant toxicity
2. Soil structure deterioration
3. System operation problems.

Plant toxicity is created by the presence of certain minerals in the water. The most common toxic minerals are chloride, sodium and boron. Not all plants are equally sensitive to these minerals. Corn is sensitive to concentrations of boron greater than 2 mg/l and will also be affected by high concentrations of sodium, specially if water is sprayed on a long term basis. (Ayers and Wescot, 1985). These criteria will vary under humid conditions, where no long term accumulations of minerals are likely to occur. Other minerals are toxic to plants but are only occasionally present in river waters.

Some plants are also sensitive to high concentrations of nitrates and ammonia in the irrigation water. This can cause excessive leaf growth of the plants and reduce grain yields. Corn however consumes great amounts of nitrogen. If nitrates and ammonia are available in the irrigation water, the fertilizer requirements could be reduced.

Soil structure deterioration occurs on clay soils irrigated with saline sodic water. Sodium affects the soil structure of clay minerals. Subirrigated soils that contain less than 5 % clay cannot be much affected. No deterioration due to salinity has been observed in the sandy soils of Richelieu county which are seasonnally leached (fall and spring).

The efficiency of the irrigation system can be affected by the quality of the irrigation water. Corrosion, blocking of the pipes by sediments and algal growth deteriorate the system's components. The effect of each parameter depends on the irrigation method.

Subirrigation is very sensitive to high sediment content and presence of iron ochre and algae which can block the envelopes, pores and the pipes (Criddle and Kalisvaart, 1967). Bournival et al. (1986) have observed partial blockage of the filter envelopes by the iron ochre which resulted from the activity of iron loving bacteria using the ferrous iron present in the irrigation water source. However, the water can be treated to avoid the iron ochre problem in the locations where the water has excessive ferrous iron.

The presence of nitrates and ammonia could enhance algal growth in the ditches. Pump intakes need to be provided with very large screen areas.

Ayers and Wescot (1985) and the Canadian Ministry of Environment have produced guide lines for irrigation water quality. The latter are better adapted to Québec's acid soils and humid climate than Ayer's and Wescot's mainly developed for arid conditions . The water in the Yamaska, Richelieu and St-Lawrence rivers is of suitable quality for subirrigation of maize, soya and most of other crops, according to the Ministry of Environment's criteria (McNeely et al., 1982). Water from some of the wells maybe too saline, or require treatment for iron.

CHAPTER 3

IDENTIFICATION OF LAND FOR IRRIGATION

3.1 Mapping Methodology.

The first step in mapping irrigable zones was to define soil and land selection criteria. The soil information maps, for St-Hyacinthe (Cossette, 1983) and Richelieu counties (Nolin, 1983) were important sources of background information . Both surveys were not yet completed at the time this research project was carried out. One part of St-Hyacinthe, south of Highway 20, is not included in the present work. Additional soil information (profile descriptions) was acquired from adjacent counties' soils reports. Soil series suitabilities were assessed from profile descriptions and field observations according to the pre-established criteria. Then the zones, where the major concentration of the appropriate soil series are found, were visited to evaluate visually the general slope, microrelief and surrounding topography.

The information resulting from soil maps and visual observations was organized and mapped on 1 in 20 000 topographical maps. The topographical maps were a good map base since they showed the roads, ditches and river networks and forested areas. Each of the areas identified was given a special code and planimetered. The zones were classified in three categories. The first class is " SI-" for subirrigation zones. The sprinkler irrigation zones are "SP1" and "SP2", depending on the available water capacity of the soils.

In making the blocks, property boundaries were not considered. All soil types selected for one irrigation class behave similarly within their class. Therefore all adjacent zones that answered the same criteria were grouped together, regardless of the soil type. The maps, Figures 3.2 to 3.9 are included and contained in the pockets at the end of this thesis. Figure 3.1 shows the relative position of the maps with respect to each other.

All the information given by the maps should be considered within some limits. The main objective of these maps is to locate the areas that can benefit from subirrigation and sprinkler irrigation. The block boundaries are approximate and depend on the accuracy of the soil maps.

The same can be said about topography. Detailed surveying measurements were not taken. Topographic evaluation was based solely on visual observations of the microrelief. This was sufficient since only qualitative appreciation was needed. Slopes were measured approximately on the 1 in 20 000 topographic map and in the field using a hand level. However, since some fields were unaccessible, classifications were based on slopes calculated from the maps. This could have introduced an error: topographic maps give little information about microrelief. Nevertheless, these approximations do not reduce the informative value of the irrigation maps which have been prepared.

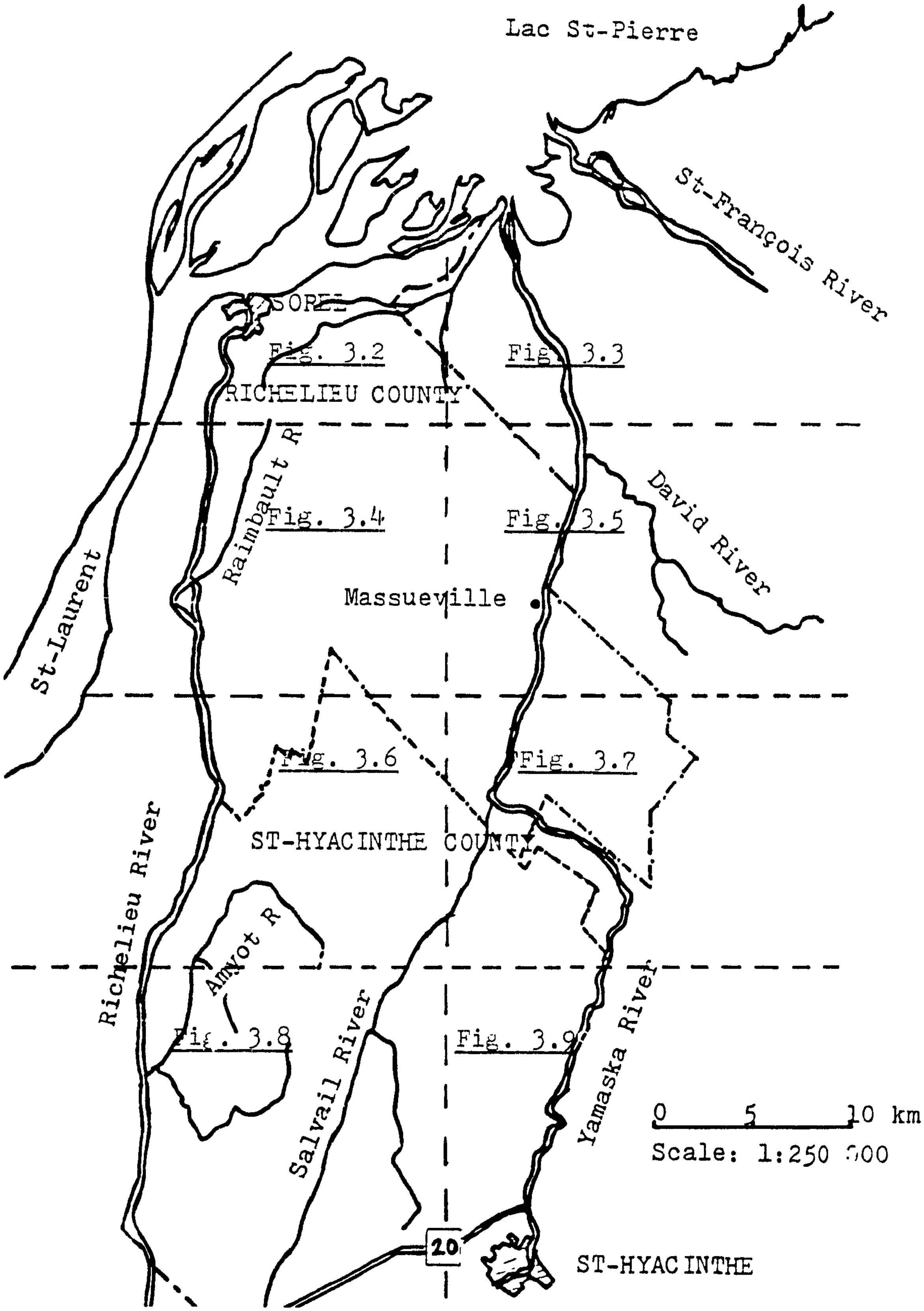


Figure 3.1 Key Maps Indicating the Location of the Irrigation Suitability Maps With Respect to Each Other

3.2 Criteria of Selection of Land for Subirrigation.

Prior to mapping, an analysis of the land resources was conducted. This analysis was done within a set of criteria, established from published work on subirrigation and from the experimental set up in Paroisse St-Louis. Although all defined areas answer all criteria, they are not necessarily of equivalent quality. The criteria chosen are broad to permit a very structured and refined classification. Before designing irrigation systems for individual farms, further local fields investigations should be made. There are two groups of criteria : soils and topography.

3.2.1 Soil Related Criteria.

The soils mostly affected by drought during summer, in St-Hyacinthe and Richelieu counties, have a sandy texture in the top 60 cm. Their ability to retain water in the root zone (50 cm) is extremely low, ranging from 3 to 6 cm of water. The drought is accentuated by overdrainage of the soils. These soils have saturated hydraulic conductivities, from 0.5 to 5 m/d. In their natural state, these soils absorb rainfall and snowmelt. Water infiltrates rapidly and the water table comes to the surface through April and May, and after autumn rains in October and November. Thus these soils need subsurface drainage to allow cultivation and planting in April and May.

Some clay soils are affected by drought, mainly at seed germination time. Subirrigation would not be able to satisfy this need. At this time, because of the heavy traffic of machinery in the fields, the water table must remain low, at a depth that would not permit much water to reach the seeds by capillarity. Because of their low hydraulic conductivities, it is probable that water would not reach the plants fast enough to supply the demand. Besides, these clay soils have a very high water holding capacity, from 9 to 18 cm of water per 50 cm of soil, and they have less need for irrigation water.

Based on the above, the criteria selected for soils pertained to the texture and the hydraulic conductivities of the soils. The soils to be subirrigated, independantly of their texture, should have a hydraulic conductivity of at least 0.5 m/d. The St-Samuel sandy loam, on the experimental site, at St-Louis, has an average hydraulic conductivity of 1.5 m/d. Clay soils with high hydraulic conductivities, if there were sufficient water resources, could also be subirrigated. It is doubtful if much of the clay soil in these two counties has these high hydraulic conductivities.

It was also decided that the subsurface drain pipes should be in a sandy layer of high hydraulic conductivity. The average drain depth in Québec is about 90 cm. Therefore, a sand layer should occur between 85 to 120 cm from the surface. Soils that drain well naturally are not suited for subirrigation. It would be uneconomical to install drains to subirrigate only. If these soils drain well, it means that no barrier exists to restrain the water table, thus rendering a perched water table impossible. For subirrigation to be successfull, it is necessary that permanent or perched water table conditions be present. This situation is common in the sandy soils of Richelieu and St-Hyacinthe counties. These conditions exist if the impermeable layer lies slightly below the drains. Otherwise, the water will drain naturally, through the bottom of the profile. The maximum depth of the impervious layer should be 2 m, according to Skaggs (1981). Therefore, drainage characteristics are a good indication of the suitability of a soil for subirrigation.

There are four types of soil profile descriptions, in Richelieu and St-Hyacinthe counties that fit the criteria selected for subirrigation. Their profiles are found in Figure 3.10.

Profile 8a is layered with alternating sand and clay in the bottom of the profile. These soils usually have a lower hydraulic conductivity because of their clay content. If the drain pipe is in a sand layer, the soil might be suitable for subirrigation. However, another problem arises: the heavier layers could impede the rise of water. The success of subirrigation depends on the rate at which capillary rise occurs. These layered soils are: St-Aimé, Bellevue, Fleury and Michaudville. The first two have a global texture of clay loam in the bottom of the profile, contrary to Fleury and Michaudville where the sand content is dominant. The layers of clay in the Fleury and Michaudville profile are so thin that it was thought that these soils could satisfy subirrigation requirements. Because of the higher clay content of the St-Aimé and Bellevue profiles and the thickness of the layered horizon, these soils were discarded for subirrigation. Still, both St-Aimé and Bellevue series would also need supplemental water because of the 30 cm sand layer in the root zone. These were then classified as suitable for

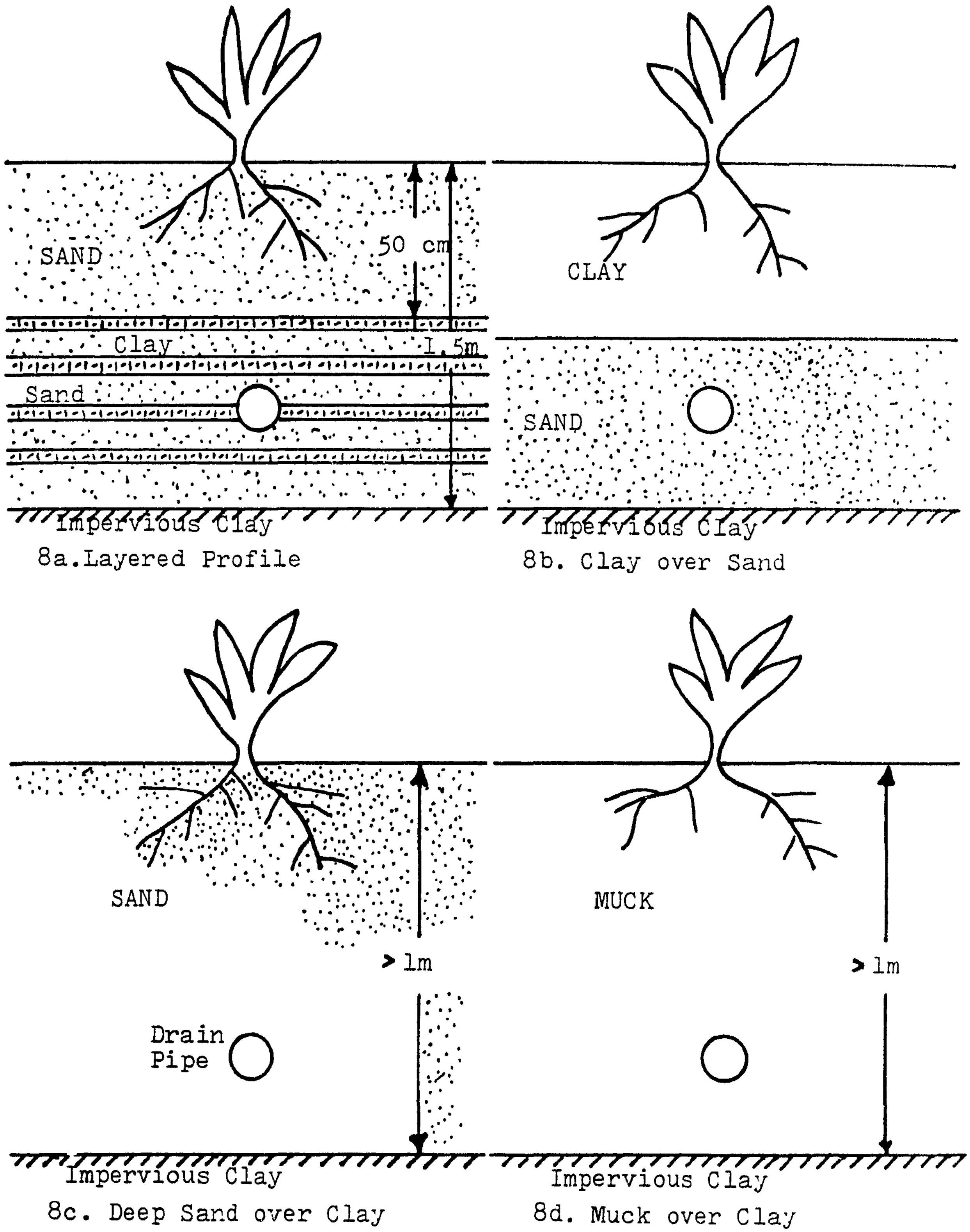


Figure 3.10 Soil Profiles Potentially Suitable for Subirrigation.

sprinkler irrigation. However, this classification is not definitive. If further tests show that the St-Aimé and Bellevue soils have high rates of capillary rise, they could be considered as suitable for subirrigation. All four soil series have poor drainage.

Profile 8b is a deposit of clay over a sand layer. The drain tube is located in the sand layer. If the sand layer is not too thick, about 35 cm, the roots might not be supplied fast enough . In the counties studied, only a few soils are of this type. Among them is the Chaloupe series, located in the northern tip of the Richelieu county. However, the Chaloupe soil, unlike most of the St-Lawrence Lowlands soils, does not lie on a shallow clay layer, but on a very deep sand layer (5m). Subirrigating such a soil would be inefficient because a large portion of the water would percolate. Soils comparable to profile 8b were not selected for subirrigation.

Only a small area of soil such as shown in profile 8d, a muck soil over clay is found in the south of St-Hyacinthe county, near Highway 20. Other organic soils, Tracy, Victoire and Vallières are present in Richelieu county. The thickness of the organic layer is variable. These soils lie over a deep permeable sand layer. They are located at the edge of the Richelieu river delta, and are saturated year long. Pot-au-Beurre soil has a profile of alternating sand and organic matter layers. Unlike the other layered soils described above, the overall hydraulic conductivity of such a soil is high. Also, the rate of capillary rise in the organic matter is important. These soils are not common in Richelieu county, with approximately 200 ha of cleared land. About one half is cultivated. They are suitable for subirrigation.

The last profile, shown in figure 8c, constitutes the bulk of the soils suitable for subirrigation. Lasalle (1962) described these soils as deposits of fine to medium sand, of fluvial origin (deltaic formation), with a maximum depth of 3 m, but usually not more than 1.5 m, and lying on a marine clay deposit of more than 3 m. Soils Aston, St-Damase, Michaudville, Prairie, Fleury, Joseph, Massueville, Ste-Sophie, Achigan and St-Thomas were developed on these deposits. These soils are usually poorly drained, despite their high hydraulic conductivities. The Aston and St-Damase are not suitable for subirrigation because they are shallow sand deposits (70 cm) over heavy clay. Their suitability would be conditional on the hydraulic conductivity of the clay deposit. Because they are poorly drained, it is probable that the clay layer below the thin sand deposit is not very permeable to water. These soils are also affected by drought in summer. They could benefit from controlled drainage or sprinkler irrigation.

The Ste-Sophie and St-Thomas soils are located at the edge of the terraces where the sand is often 3 m deep. Their drainage, on the average is good, and thus fail, in most cases, to meet the subirrigation criteria. They were included in the classification, but only conditionally.

The main soil series suitable for subirrigation are listed in table 3.1, along with their capability index. All the suitable soils have similar agricultural characteristics. They have low clay content (< 5%), low organic matter content, low CEC, low fertility and low water holding capacity. Their agricultural potential depends on the clay and

Table 3.1. Soils Suitable for Subirrigation in Richelieu and St-Hyacinthe Counties

Soil Series	Symbol	Agricultural Soil Capability[1]	Water Holding Capacity[2]
Achigan	AC1	4WF(d)	2
Fleury	FY1	2Wf	2
	FY2	2W	2
Joseph	JS1	3WF	2
	JS2	2Wf	2
	JS2h	3W'	2
St-Jude	JU1	3MF	2
Massueville	MS1	3WF	2
	MS2	3WF	2
Michaudville	MC1	3WF	2
	MC2	2Wf	2
Pierreville	PI2	2Wif	2
	PI3	2Wi	3
	PIT	4W'I	2
Pot-au-Beurre	PO3	3WI	3
	PO3h	4W'I	3
Prairie	PR1	3WF	2
	PR2	2Wf	2
Ste-Rose	RS2	2Wf	2
	RS3	2W	3
Salvail	SL1	3WF	2
	SL10	3Fwmt	2
St-Samuel	SM2	3W'f	2
	SMT	3W'i	2
Ste-Sophie[3]	SP1	5F'M't	2
St-Thomas[3]	TH1	4F'M'	2

1. Soil Capability Classification by Marshall et al. 1979 modified by Nolin (1983). See appendix A.
2. Average Available Water Capacity for the first 50 cm of soil
   Class 2: AWC < 50 mm
   Class 3: 50 mm < AWC < 75 mm
3. Conditional to the depth of the clay layer and drainage conditions.

organic matter content of the arable layer. A large proportion of the suitable soils, mainly the Ste-Sophie and St-Thomas, are forested.

However, all the soils selected for subirrigation have the same geological origin and very similar genetic developement. A profile of a typical soil, suitable for subirrigation, the Joseph series, is described in table 3.2. Detailed descriptions of all the soil profiles suitable for subirrigation are found in the soils reports by Nolin (1983) for Richelieu and Drolet (1984) for St-Hyacinthe.

Table 3.2 Description of a Typical Profile of Joseph Soil Series, Suitable for Subirrigation

Prc^.le of a typical pedon in a cultivated area.

JOSEPH (Orthic Humic Gleysol to Rego Humic Gleysol)

Horizon	Depth from the surface (cm)	Description
Ap	0 - 35	Loamy sand, greyish brown, very dark (2.5Y.3/2h); granular structure, fine weakly developed; very friable; abrupt boundary, regular;medium acidity
Bgl	35 - 60	Veryfine sand, greyish brown (2.5Y5/2h) mottles, brownish yellow (10YR6/6h), common, medium, prominent; amorphous structure; loose; clear boundary, wavy; medium acidity.
Bg2	60 - 75	Fine sand, greyish brown (2.5Y5/2h); mottles strong brown (7.5YR4/6), many, medium, prominent; amorphous structure; loose; clear wavy boundary; weakly acid.
Cg	75 - 100	Fine sand dark greyish brown (2.5Y4/2h) few mottles, fine and medium, prominent, amorphous structure; loose; neutral.

Translated from J.Y. Drolet (1984)

General Characteristics

- Texture of the surface layers of the various phases:

JS1: fine loamy sand to loamy sand.
JS2: fine sandy loam to loam
JS2h: Organic matter very well decomposed on fine sandy loam to loam
JS3: loam

- Similar Soils: Massueville and Prairie series

- Geological Origin: Fluvial deposit (deltaic formation)

- Drainage: Poor

3.2.2 Topographic and Geographic Criteria.

Only the land bearing suitable soils for subirrigation (profiles 8c and 8d) were visited for topographical examination. Because the efficiency of subirrigation depends on a good control of the water table, it is essential that the surface slope be very small. This reduces the number of control chambers and the amount of pumping needed and ensures a sufficiently uniform water table distribution throughout the field. The maximum slope was set at 0.5%. To some people this may seem to be a large slope. However, in Nicolet, Trottier et al. (1987) successfully conducted controlled drainage experiments on such a slope. Subirrigation could be practiced on steeper slopes, providing a special set up is built . This has yet to be tried. Slope and shape of the clay layer below the sand has some effect on the distribution pattern of the water table. The information about the sand and clay layers' boundary was gathered in soil reports. In both counties studied, it is doubtful that any effect due to the shape of this boundary can be seen. The marine clay layer is a sedimentary deposit and lies flat over almost the whole area. The very slow lateral movement along the layers' boundary reinforces the idea that the clay layer is flat and has a small slope. The flatness of the impervious layer seems to be a geological characteristic of the whole region.

The surface microrelief was also observed and added as a criterion. All topographic features were verified by visual observations. It was not necessary to make precise measurements. Most of the land bearing the suitable soils for subirrigation, even the portion under forested cover, is very flat in both counties. Occasionally, large depressions were observed because of the occurence of a small river. Fields near the Yamaska and the Salvail rivers had pronounced microrelief and were rejected. On a few fields in St-Hyacinthe county, some small surface ditches were observed. These fields were very flat. This is perhaps a sign that the soils did not need subsurface drainage. Surface ditches would have to be removed to subirrigate efficiently.

3.3 Results of the Classification of Land for Subirrigation.

After the field observation work for this thesis was carried out and the irrigable zones identified, it was found that a total of 15 697 ha, both forested and cleared, might be suitable for subirrigation, in Richelieu and St-Hyacinthe counties. The suitable land is unequally distributed among the two counties. 53 % of the subirrigable land is located in Richelieu county. Of the total area, 65 % is presently cleared, but not necessarily all under cultivation in any one year.

The subirrigable area is distributed among 43 blocks of size varying from 14 to 4724 ha. Most of the subirrigable blocks are in close proximity, in a band extending from north east to south west. 28 of the 43 blocks are closest to the Richelieu river, at an average distance of 5.4 km.

Table 3.3 summarizes the results of the planimetry. Tables 3.4 and 3.5, give the area of each individual block, and the distance to the closest river.

Table 3.3 Total Area Available for Subirrigation in Richelieu and St-Hyacinthe counties

	Total Area (ha)	Forested Area (ha)	Cleared Area (ha)
Area Available	15697	5497	10 200
% of total		35 %	65 %
Area in Richelieu	8316	2085	6231
% of total	53 %	38 %	61 %
Area in St-Hyacinthe	7381	3412	3969
% of total	47 %	62 %	39 %
Area in vicinity of Richelieu riv.	8421	4107	4314
Area in vicinity of Yamaska riv.	6250	1322	4928
Area in vicinity of the St-Lawrence	1025	68	958
Number of irrigable zones (Richelieu)	27		
Number of irrigable zones (St-Hyacinthe)	16		
Average distance from the Richelieu	5.4 km		
Average distance from the Yamaska	4.6 km		
Average distance from the St-Lawrence	3.1 km		

Table 3.4 Areas of the Individual Subirrigation Blocks in Richelieu County

Block	Total Area (ha)	Forested Area (ha)	Cleared Area (ha)	River in Vicinity	Distance to River (km)
SI-01	74.63	0.00	74.63	Richelieu	3.81
SI-02	93.39	0.00	93.39	Richelieu	2.79
SI-03	16.44	0.00	16.44	Richelieu	2.54
SI-04	18.43	0.00	18.43	Richelieu	0.76
SI-05	342.25	154.01	88.24	Richelieu	7.87
SI-06	102.48	0.00	102.48	Richelieu	5.84
SI-07	217.12	4.34	212.78	Richelieu	8.64
SI-08	65.76	65.76	0.00	Richelieu	7.11
SI-09	3929.26	667.97	3261.29	Yamaska	6.35
SI-10	690.67	55.25	635.42	St-Laurnt	1.02
SI-11	49.41	2.96	46.45	St-Laurnt	1.15
SI-12	185.37	5.56	179.81	St-Laurnt	6.60
SI-13	427.40	128.22	299.18	Yamaska	0.76
SI-14	183.23	31.15	152.08	Yamaska	0.89
SI-15	787.87	401.81	386.06	Yamaska	2.41
SI-16	75.78	0.00	75.78	Yamaska	6.22
SI-17	24.05	0.00	24.05	Yamaska	3.18
SI-18	511.21	439.64	71.57	Richelieu	3.56
SI-19	99.83	3.99	95.84	St-Laurnt	3.56
SI-20	17.24	0.00	17.24	Richelieu	3.05
SI-21	128.30	112.26	16.04	Richelieu	1.78
SI-22	60.54	0.00	60.54	Yamaska	0.51
SI-23	14.03	0.00	14.03	Richelieu	4.19
SI-24	46.11	12.45	33.66	Yamaska	4.95
SI-25	12.02	0.00	12.02	Yamaska	6.35
SI-26	69.95	0.00	69.95	Richelieu	0.76
SI-43	73.37	0.00	73.37	Yamaska	1.27

Table 3.5 Areas of the Individual Subirrigation Blocks in St-Hyacinthe County.

Block	Total Area (ha)	Forested Area (ha)	Cleared Area (ha)	River in Vicinity	Distance to River (km)
SI-27	186.82	24.29	162.53	Yamaska	5.59
SI-28	256.56	17.96	238.60	Yamaska	5.08
SI-29	4724.19	2149.51	2574.68	Richelieu	9.40
SI-30	84.20	20.21	63.99	Richelieu	6.35
SI-31	1652.29	1024.42	627.87	Richelieu	7.37
SI-32	101.84	53.98	47.86	Richelieu	7.87
SI-33	115.47	63.51	51.96	Richelieu	7.87
SI-34	16.03	12.02	4.01	Yamaska	7.87
SI-35	47.71	0.00	47.71	Yamaska	9.65
SI-36	19.24	0.00	19.24	Richelieu	10.92
SI-37	13.60	0.00	13.60	Richelieu	5.34
SI-38	39.29	19.25	20.04	Richelieu	5.58
SI-39	20.04	0.00	20.04	Yamaska	3.56
SI-40	39.69	7.14	32.55	Yamaska	7.62
SI-41	40.95	9.01	31.94	Yamaska	7.62
SI-42	22.85	10.05	12.80	Yamaska	7.62

3.4 Discussion of Criteria and Results

All the results of section 3.3 should be used carefully, with the limitations of the classification in mind. All the land identified in the subirrigation class is, in theory, suitable for this form of irrigation, according to a strict interpretation of the criteria previously established.

However, the classification has the same limitations as the source from which the information was derived, and is subjected to the interpretation of the author. The following discussion will try to analyse firstly the weaknesses of the soil and topographic criteria, and secondly to see the effects on the results, of slight modifications on the criteria. The criteria elaborated in section 3.2 are not absolute, they are based on one interpretation of the reality.

Additional criteria, more precise, would have refined the classification to a point where a degree of suitability could have been given to each block. However, many factors controlling the quality of a suitable zone compared to another are not quantifiable, at least with the information presently available . For example, what is the minimum size of area that could be efficiently and economically managed? No exact figure exists. It is only possible to say, qualitatively, that the larger the area, the more efficient and worthwhile it will be to subirrigate. It is important to at least estimate the quality of the different irrigation zones with respect to each other to maximize the water resources available. This will be done in a third step.

3.4.1 Discussion of the Soil Criteria

3.4.1.1 Limitations of the Soil Classification.

Soils information was gathered from 1 in 20 000 maps. The limitations of the soils maps should be understood. The irrigation maps cannot be more precise than the soil maps. Similarly, the irrigation maps have limitations. Soils may be highly variable. Within one field, many soil series, even very different ones, are found. In a soil delineation all these series cannot be mapped. However, the soil maps units are usually homogeneous, grouping only similar soils. It is still possible that pockets of shallow sand are found in areas defined as deep sand suitable for subirrigation. As indicated in the soils reports, 90 cm deposits were tolerated for soils that usually have one meter deep sand deposits in the top portion of their profile. Under these conditions, the drain pipes might be installed in a clay layer. This occurs only occasionally but would interfere with good functioning of subirrigation in an individual field. These zones could not be identified on the maps, but are probably located in the vicinity of identified shallow sand areas (Aston, St-Damase). This is not considered a serious problem : total uniformity in the water table distribution is not achievable, under any circumstances.

Another weakness of the classification arises from the soils suitable for subirrigation themselves. These are sands with an average depth of 1.5 m . However, in certain circumstances, they attain 3 m in depth. In such cases, the soils are usually well drained. Unfortunately, no information is available in the soil reports to indicate where the deep phases of a series are located. There are two types of geological formation from which the suitable soils for subirrigation originated. The oldest one are fluvial deposits and are shallower. The second deep deposits are also fluvial, but of deltaic formation. They were formed after the first type deposits. The wind has often shaped them in dunes mainly in the Sorel- Tracy area. Subirrigation block SI-10 is located in this region and possibly could have fields bearing very deep sand deposits. Block SI-09 is from the first formation and bears sand deposits of approximately 1.5 m deep. This block is located in Richelieu county, at the center of the terrace formation. The deep phases of the suitable soils are probably located at the edge of the terraces or close to the St-Lawrence river. Only a thorough investigation will indicate to which extent the soils from these zones are irrigable. The farmers who have cultivated the fields are most likely to have some understanding of these variations. The farmers should be questioned carefully prior to making any detailed subirrigation plans on their farms.

3.4.1.2 Modification of the Soil Criteria.

The requirements for soils were the most specific. Still, they were applied arbitrarily, based on soil profile descriptions that are often difficult to interpret because they are general and imprecise for some parameters. This also makes the selection approximate. Some soils were excluded because of the uncertainty about their behaviour under subirrigation. Important physical features such as the hydraulic conductivity and rate of capillary flow are not well represented in the soil reports.

Borderline soils which were excluded from the soil classification were: St-Aimé and Bellevue. Alternating layers of fine sand and loam or silty clay loam are found in the bottom part of the profile at the level of the subsurface drainage pipe. Because of the texture and nature of the layers of both St-Aimé and Bellevue soil series, doubts can arise whether they can conduct water rapidly.(Lake found that at least 2 mm/d were needed to meet the deficits .) Until some tests are conducted on the rate of capillary rise and hydraulic conductivity on these soils, they should remain in the SP1 class. In Richelieu county, if proven suitable, 2000 ha of cleared land bearing these soils, and about the same quantity in St-Hyacinthe county could be added to the subirrigation class.

Another category of soil profiles, widely found in both counties suscitate the same questions. These soils consist of a shallow layer of sand (70 cm) over a deposit whose texture can vary from a clay loam to a heavy clay. These productive soils are very much affected by drought. The use of these soils, Aston and St-Damase mainly, for subirrigation, depends on the hydraulic conductivity of the bottom layer. If it is higher than 0.5 m/d, the soils could be used for subirrigation. They both cover about 2000 ha of Richelieu county. Irrigation of any kind would be essential for improved productivity. If subirrigation was suitable and feasible, it would be even better. Based on the limited information available, the Aston and St-Damase soils have been classified for sprinkler irrigation. If farmers in this region seriously wish to irrigate, the same detailed soil investigations should be made on the St-Aimé, Bellevue, Aston and St-Damase.

3.4.2 Discussion of the Topographical Criteria.

3.4.2.1 Limitations of the Topographical Classification

Visual observations of topography of all cleared land is an approximate method. Many portions of grassland did not appear as flat as adjacent cultivated land. It would not be difficult to level this land which is presently uncultivated. The cleared uncultivated land was classified as suitable when it was felt some improvement could be easily achieved. As an example, the fields on the west side of block SI-10 are slightly undulating, and could easily be levelled. Now, whether levelling makes subirrigation economical depends on the crops grown, and the prevailing costs and prices at the time the work is done.

Very few observations of forested land were possible. However, it was classified as suitable if it was among the irrigable soils on the soil maps. The topography of the forest was approximated from observation of the surrounding cleared land. While touring the counties, the author noticed that tracts of forest had just been cleared and prepared for agriculture. The topography of these new fields was amazingly flat. It should be mentioned that although the forested land is suitable for subirrigation, it may not be agronomically suited (low pH). It may be desirable for environmental reasons to leave most of the forests intact.

3.4.2.2 Modification of the Topographical Criteria.

The topographic features, slope and microrelief were visually observed. This was considered to be sufficient in the case of Richelieu and St-Hyacinthe counties, where the overall topography is characteristically flat.

It is difficult to modify or change this criteria without affecting the efficiency of the system. No farmer is willing to invest in an inefficient irrigation system. It is true that subirrigation is technically feasible on steeper land than the 0.5% suggested. This would require more control chambers, more pumping, and hence more costs and inconvenience. Microrelief on the contrary is an absolute requirement. Some microrelief was tolerated when it was possible to level the land at a low cost. Otherwise, it becomes impossible to control the height of the water table and the uniformity in the distribution of the water throughout the field. Extensive earthmoving and excessive water pumping to maintain the water table despite leakage would increase the costs beyond economic profitability. Thus topography has to be examined very carefully.

When areas with suitable soils were selected for subirrigation, only their own topography was considered. However the topography of the surroundings will influence the amount of leakage that occurs from the irrigated plot. Criddle et al. (1967) suggested that adjacent fields should be in the same plane as the irrigated field. The surrounding topography was verified, after the classification had been made. It was found that, in both counties, most of the land is level in the vicinity of the proposed subirrigation plots. A few blocks, SI-13 and SI-14 located close to the Yamaska River for example, could be affected by the surroundings. At these locations, the banks of the river are very steep, and leakage from these plots to the river could occur. The elevation difference between these fields and the water level in the river is more than 15 m. Since these areas have been found to need subsurface drains, leakage to the river must be so slow that subirrigation could be practical. If it is found that too much seepage will occur, they should be reclassified in the SP1 category. Both blocks have a total surface area of 452 ha (cleared).

3.4.3 Evaluation of Some Physical Parameters on the Results of the Classification

The U.S. Bureau of Reclamation (1953) has included, in its classification system, features such as shape, size, location, land quality and land use. The aim of the US Bureau classification is to decide which land could economically be irrigated. The quantification of such parameters is supported by research and years of field operations. No equivalent exists in Québec. With the information now available, it is not possible to make any statement on the economics of subirrigation. The following evaluation of the subirrigation blocks is merely qualitative. This analysis is included to show how resources could be better used by giving priority to and exploiting first those zones that have a higher degree of suitability.

3.4.3.1 Location of the Subirrigation Blocks with Respect to Each Other.

The proximity of the blocks with respect to each other will influence the water distribution efficiency of the system, by affecting the importance of leakage, and make the construction of required control structures more affordable. It is mainly an economical and organizational problem. Location of the blocks is closely related to the size and shape of the irrigation zones.

Blocks that are isolated or very small (< 5 ha) are less attractive for subirrigation. It becomes costly to bring the water if no source is available on the terrain. The isolated irrigated zones represent a very small proportion of the area identified for subirrigation. This land was not discarded. Research by Bournival et. al (1986) shows that it is quite feasible to successfully subirrigate an area of less than 10 ha.

In Richelieu and St-Hyacinthe, only a few zones are isolated or have an odd shape that would make irrigation less attractive. Blocks SI-6, SI-11, SI-19, SI-20, SI-23, SI-34, SI-35, SI-36, SI-37 are isolated and have an irregular shape. Among these zones, SI-20, SI-23, SI-34, SI-37 have a surface area of less than 17 ha of which it would be impossible to recuperate 10 ha.

Some sections of a block are split in parcels belonging to different owners. This is a major problem. Cadastre was not always considered in the delineation of blocks for subirrigation. Therefore, the true effective area available could be reduced. Some of the area, for administrative reasons, becomes unavailable. In some fields, the subirrigated area is only a fraction of a whole field, not always well located to be able to modify the drainage system. This is the case for some of the blocks listed in the previous paragraph.

Geographic location also means the position of blocks with respect to each other. Most of the blocks are grouped in tracts of land usually larger than 300 ha. This will ease the elaboration of a regional irrigation project.

What is characteristic in both counties is that most of the suitable land for irrigation is part of a narrow strip that extends from north to south. That strip comprises subirrigation and sprinkler irrigation zones. Among all the blocks are 3 that constitute by themselves large tracts of land. They are SI-09 in Richelieu and SI-29 and SI-31 in St-Hyacinthe. Together they cover 5 600 ha of mostly good cultivated land. As for the whole strip, it has an area of 19 000 ha of which 12 000 ha were identified for subirrigation.

3.4.3.2 Location of Water Sources.

The viability of an irrigation project depends on the availability and proximity of the water sources.

About 57% of the blocks are located in the vicinity of the Yamaska River which has its lowest flows in summer. The Richelieu River on the other hand has plenty of water which could be pumped to the irrigation blocks located near the Yamaska River, in the event not enough water is found in this river. The largest distance between a block and a river other than the Yamaska is 20 km, a small distance compared with what is done in major irrigation projects in western Canada and other countries.

Both counties contain a network of small rivers and drainage ditches. Due to their depth and capacity, they could be used as reservoirs and conveyance channels ,if small control structures are built on them. The volume of reservoir needed will be examined in chapter 4.

The major subirrigable zones, SI-09 and SI-29, are well served by drainage ditches. Most of the blocks have at least one ditch that connects to the major rivers. Only the forested areas are deprived of ditches. Blocks SI-09 and SI-29 are also close to small rivers, Laplante and Salvail. These rivers carry no flows in summer, but could be filled with spring runoff and used as reservoirs.

All the blocks are close to at least one source of water. It is only the economics that will justify bringing water to any subirrigable zone, isolated or not.

3.4.3.3 Land Use

The consideration of the land use pattern could make an important difference in the results of the classification of land for subirrigation.

Two types of land use were considered in this classification: forested and cleared. A large portion, perhaps one quarter, is cleared but uncultivated. The land was abandoned because of poor drainage, drought, fertility and land tenure problems. It could easily be put into production if combined subsurface drainage and irrigation systems were installed.

The forested land suitable for subirrigation is class III and IV land. It is acid, infertile, and very sensitive to erosion. It meets all the criteria for subirrigation but, still represents poor value for agriculture. A portion of the forested land is constituted of good quality soil (Ste-Rose) and could be cleared, but at high cost. The forested land represent 35% of the subirrigable land. If it was totally excluded, which is probable, more than 50% of the subirrigable land in St-Hyacinthe would have to be reclassified. In Richelieu county, it is estimated that 200 ha of the 2 000 ha forested have some potential.

The land under forest cover, suitable for subirrigation, are Ste-Sophie, St-Thomas and Achigan soils. These soils have a capability index of 4 (Nolin, 1983) with high restriction on fertility. They are also extremely sensitive to erosion. Corn crops on these soils could not be sustained for many years. The exclusion of these soil types for agriculture in Richelieu county does not affect the classification of the cleared land since 90% of these soils are forested. As for the other soil types, they have a quality index of 2 or 3, as all cultivated Québec land.

3.4.3.4 Soils Agronomic Quality

Most of the land suitable for subirrigation could grow corn, soya beans, alfalfa and other crops. It would be more profitable to spend water resources on blocks which already have good corn and soya bean production potential.

An agricultural capability index already exists in soil reports. However, this index only indicates the deficiency of the soils for agricultural purposes in general. It only gives a broad idea of the potential of a soil to be put into production. All soils listed in table 3.1 are class 2 and 3 soils. They are good agricultural soils but require special conservation practices. All the subirrigable land for example has fertility deficiencies and drainage problems. Ste-Sophie and St-Thomas have extreme fertility deficiencies (4F'M'). They chronically suffer from drought, which is an indication that the sand layer is probably deeper than 2m, and would be unfit for subirrigation. The Ste-Sophie soil, although it suffers from severe drought, should not be put into production even if subirrigation can reduce this problem. These soils are fragile and would erode fast if deforested. Despite all modern techniques to improve soil qualities, Ste-Sophie soils lack the requirement to be a good agricultural soil. St-Thomas, on the other hand, when located at the center of terraces has a top layer of 1.5 m of sand and behaves as the other subirrigable soils.

Denholm (1987) has calculated an index, the Soil Potential Rating Index (SPR), for the soils of the Richelieu county, rating the soils with respect to each other, according to their ability to produce corn.

The SPR indexes for different soils of the Richelieu county are listed in table 3.6. These soils were indexed without the knowledge that they could be subirrigated. The SPR rating for some subirrigable soils would increase appreciably, although the best soils in the county, for corn production, Fleury and Joseph, are already the most suitable for subirrigation. The Massueville and Ste-Rose soils have a medium potential that could certainly increase with subirrigation. The Aston soil, a shallow soil usually, with the best potential for corn production, cannot be subirrigated.

The major concentrations of these good soils are located again in the large tract of irrigable land that extends from one end of Richelieu to Highway 20. They are: SI-9, SI-7, SI-14, SI-22, SI-13, SI-15, SI-29, SI-10, SI-31. More than 50% of the subirrigable land is part of the above blocks.

What is important, before starting irrigation is to determine the long term effect on the soil properties. Major problems associated with surface irrigation are leaching of minerals, translocation of the fine particles down the profile, and salt accumulation. For subirrigation, the nature of the problems are different. The soils used have a low C.E.C. and a high leaching potential. Maintaining a high water table, as done in subirrigation can help these soils by reducing the leaching of mineral.. Hazardous accumulation is not to be feared since the water table is only maintained high temporarily. To improve the fertility of the subirrigated land, the fertilizer inputs should be added when leaching will not occur, ie. during and after planting, when the drain valves are closed. Some of the salts will rise to the topsoil during

Table 3.6 Soil Potential Rating for Corn and Yields, for the Soils of Richelieu County.

Soil Unit	SPR	Yield Drained (t/ha)	Yield Undrained (t/ha)
ASa1	very high	7.60	
PV4	high	6.54	7.47
FY2	high	6.08	4.65
JS2h	high	5.73	6.06
FY2h	high	6.17	
JS1	high	5.38	
JS2	high	5.54	6.69
KI2	high	7.06	7.12
UB4	medium	7.80	5.87
MS2	medium	6.03	
JU1	medium		4.24
BL3	medium	4.15	8.42
RS3	medium	7.07	4.97
FYa1	medium	6.02	
MS1	medium	4.93	

Note: PV4 : Providence soil series
ASa1: Aston soil series
KI2: Kierkosky soil series
UB4: St-Urbain soil series

(From Denholm, 1987)

June, July and August, but they will be leached down again in fall and spring, causing no detrimental effects. Salt affects the structure of the soil by deflocculating the clay minerals. Fortunately, the subirrigable soils have very low clay content in the top layer of the profile. The Fleury, Michaudville and Ste-Rose soils contain more clay in their profile and could be more affected. This problem would not occur if river water was used. The use of saline well water for irrigation might cause a problem. Tests were made in 1985, 1986 and 1987 by Macdonald College students on a St-Samuel sandy loam, using saline water. Detrimental effects on the structure and hydraulic conductivity have not yet been observed . However, the clay content of the St-Samuel soil is lower than that of Fleury, Michaudville and Ste-Rose soils.

3.4.4 Summary of Analysis.

In summary, 4 000 ha of the St-Aimé, Bellevue, Aston and St-Damase soils in Richelieu county and about the same amount in St-Hyacinthe could conditionally benefit from subirrigation. About 4 000 ha of forested land should remain untouched. The other physical factors such as shape and size could affect 500 ha. The extent of the problems caused by cadastral disposition of the land are unknown and is beyond the scope of this thesis. The net total of the above is 2 000 ha of additional flat cleared land that could become available for subirrigation if further investigation is carried out.

It is obvious that the best zone for subirrigation is block SI-09 of Richelieu county.

3.5 Economical Aspects of a Regional Subirrigation Project in Richelieu County.

In Richelieu county, 5 sites have an area larger than 200 ha. They are: SI-07, SI-09, SI-10, SI-13 and SI-15. The total area of these 5 sites is 4 795 ha, 77 % of the total cleared subirrigable area of Richelieu county. The largest site among the five is SI-09 with 3 261 ha. All the 5 sites cover 26.6 % of the cultivated area of the county. An agricultural portrait of the three municipalities included in block SI-09 is given in table 3.7 .

Site SI-09 has definite potential for the establishment of a regional subirrigation project because most of it is cultivated, very flat and bears the soils that have the highest productivity index for corn in the county.

To assess, basically, the profitability of a regional subirrigation project, it was assumed, for purpose of calculating, that 75 % of block SI-09 would be subirrigated and that the increase in production of corn from subirrigation is 2 tonnes/ha. The commercial value of corn is, on the average, $125 per tonne. If $30 per hectare are allocated for amortizing the system and $30 per hectare for maintenance, the net increase in revenue per hectare subirrigated is $190. This would represent, for the 2500 ha of SI-09, a total increase in revenue of $475 000 per year.

If subirrigation is shown to be suitable for soya, the increase in revenue would be more important with soya selling at $270 per ton. On

Table3.7 Agricultural Portrait of the Municipalities Included in Subirrigation Block SI-09.

Cultivated Area of the Municipalities:

St-Aimé:	4942 ha
St-Louis:	3302 ha
St-Robert:	3938 ha
	12 182 ha

Distribution of crops:

Crop	Area	%
Corn	5 756 ha	47 %
Grains	2 145 ha	17 %
Forrages	3 235 ha	27 %
Vegetables	360 ha	3 %
Soya	250 ha	2 %
Other	436 ha	3.5 %

Site SI-09 : 3262 ha, 26.7 % of the cultivated area of the 3 municipalities.

(From Marius Bélanger, 1987)

some sandy soils of the St-Hyacinthe county the use of sprinkler irrigation increased the yield by 70 %. If the price of corn and soya rise again as they have in the past, the benefits of subirrigation will be even greater.

A more extensive feasibility study would evaluate in detail the expected revenue. However, the profitability of a project is not only a measure of the increase in revenue but also of the social and ecological impacts. Farmers of Richelieu county have had for years to apply fertilizers 2 or 3 times per summer, because of leaching. Subirrigation would reduce the leaching by maintaining a high water table, and at the same time, reduce the pollution of the Yamaska River.

3.6 Field Investigations Necessary to make detailed subirrigation plans for farms.

Not all the land identified for subirrigation has the same quality. The scale of the maps gives the extent of the survey: a general map locates the most promising areas. A more detailed survey of the individual farms would indicate the degree of suitability and the priority of development. It is recommended that the land located in the suitable "SI" zones be investigated to ensure that it can be efficiently subirrigated.

The hydraulic conductivity should be measured for the different soil layers, throughout the field to detect the troublesome areas where low conductivity values would prohibit the water from reaching the root zone. The microrelief should be examined before any subirrigation project is started. If the microrelief is not too severe or extended, soil grading can be done. Another way of solving such a problem would be to isolate the problem area, by means of rearranging the drainage system or installing a separate control chamber. Deep depressions should be avoided to reduce the leakage losses. The level of the surrounding non irrigated land should be observed. If the difference in elevation is great, an analysis of possible seepage losses should be done.

The variation of the sand thickness in the field could be measured along the drain pipes to again determine the problem areas.

Existing subsurface drainage systems should be checked before converting them to subirrigation systems. Many of the subsurface drainage systems installed in the St-Hyacinthe and Richelieu counties are old. Some of the pipes were laid without any protective envelopes. If the pipes are blocked with sediments, replacement pipes enrobed with fabric envelopes should be installed.

The hydraulic conductivity of sandy layered soils such as St-Aimé and Bellevue, that are presently classed SP1 (sprinkler) should be checked. In cases where the hydraulic conductivity of a layered soil is greater than 0.5 m/d, subirrigation could be practiced, if all other criteria are met.

3.7 Criteria of Identification of Land for Sprinkler Irrigation

When supplemental irrigation is considered, the cost of equipment seems large . Some farmers are already using portable sprinklers on tobacco, vegetables and small fruit crops. A few farmers are using travelling gun sprinklers to irrigate corn, soya and peas. In a deep flat sandy soil, the economic solution is subirrigation. However, some soils, although not suitable for subirrigation, do suffer from drought. Travelling gun sprinkler irrigation could be a solution.

To some extent, one can say that all land can benefit from irrigation. Sprinkler irrigation is the most versatile among all irrigation methods. It can be practiced on any soil and topography. The soils that would benefit the most from sprinkler irrigation are those with a sandy to loamy surface texture. Due to the climate of southern Québec, clay soils normally only need irrigation for a short period of time at germination. The clay soils of both counties have a sufficiently high water holding capacity, 36 cm/m, to supply most of the crop water needs. Thus the extra yield due to irrigation of the clay soils is rarely enough to pay for the equipment and labour costs. Lake (1969) found that soils with less than 15 cm/m of water holding capacity were likely to suffer from drought 3 out of 5 years. Nolin and Lamontagne (1986) have classified all the soils of the St-Lawrence Lowlands according to their water holding capacities. For the purpose of the classification in this thesis, only soils with moderate to low water holding capacities (AW < 18 cm/m) were selected. Some of the land bearing suitable soils for subirrigation but missing one criterion were classified in SP categories. The St-Aimé and Bellevue soils with layered horizons, were classified in this category also. In the event that these layered soils are found suitable for subirrigation, the land bearing these soils should be reexamined in light of the subirrigation class criteria. A list of the soils satisfying sprinkler irrigation criteria are listed in Table 3.8 . A profile description is found in Table 3.9.

The water holding capacity of soils was used as a criterion to identify land suitable for sprinkler irrigation mainly to save time and work to be done. Most land in any of the two counties is suitable for sprinkler irrigation. However, because the water is not abundant, only the land severely suffering from drought, for many successive months, should be irrigated. Therefore, the land in SP1 and SP2 classes is not the only suitable for sprinkler irrigation, but, the land that will benefit the most. In the classification of land for sprinkler irrigation, a degree was established: SP1 needs irrigation more than SP2. Soils with available water between 12 and 18 cm/m were put in the SP2 category, and soils with available water less than 12 cm/m were classified in SP1. The remaining land that was not mapped could be put in other classes, such as SP3, SP4 according to their water holding capacity in the root zone. Nothing, it should be added, indicates that it is not more profitable to irrigate with sprinklers the unmapped SP3 land than SP1 or SP2 land, although the former might not need the water as much. It depends on the capacity of a soil to produce.

Although topographic features are not as significant as for subirrigation, only relatively flat land was considered. It should be

Table 3.8 Soils That Will Benefit from Sprinkler Irrigation

Soil Series		Irrigation Class	Available Water Capacity Class[1]	Agricultural Capability[2]
St-Aimé	AI2	SP2	3	3DW
	AIb2	SP2	3	2Wd
	AIa3	SP2	3	3DW
Aston	AS2	SP1	2	2Wf
	AS3	SP1	2	2W
	ASa1	SP1	2	2Wf
	Asa2	SP1	2	2W
	ASa3	SP1	2	2W
Bellevue	BL2	SP2	3	2Wd
	BL3	SP2	3	2Wd
Contour	CT2	SP1	2	3Wdf(p)
	CT3	SP1	2	2Wd(p)
St-Damase	DA1	SP1	2	3WF
	DA2	SP2	2	2Wf
Ducoteau	DC1	SP1	2	
	DC2	SP2	3	N/A
	DC3	SP2	3	
Dugoût	DG1	SP1	2	
	DG2	SP1	2	N/A
Duravin	DR2	SP1	2	
	DR3	SP2	3	N/A
Présentation	PS1	SP1	2	3FW
	PS2	SP1	2	
	PSa1	SP1	2	N/A
	PSa2	SP1	2	

1. By Nolin (1986). Class2 : 3 cm < Available Water < 6cm in 50 cm
   Class3 : 6 cm < Available Water < 9cm in 50 cm
   See appendix B.

2. Soil Capability Classification by Marshall et al. (1979), modified by Nolin (1983). See appendix A.

Table 3.9 Description of a Typical Profile St-Damase Soil Series Suitable for Sprinkler Irrigation (SP1)

ST-DAMASE (Gleyed Sombric Brunisol)

Profile of a typical pedon, loamy sand St-Damase, cultivated.

Horizon	Depth (cm)	Description
Ap	0 - 40	Loamy sand, greyish brown, very dark (10YR3/2h), grey (10YR5/1h); granular structure, medium, weakly developed; very friable; distinct undulating boundary; extremely acid.
Bfg	40 - 50	Sand, dark brown (7.5YR3/4h), brown (10YR5/3s); particulate structure; loose; distinct undulating boundary; very acid.
BC	50- 58	Sand, yellowish-brown (10YR5/4h); particulate structure; loose; distinct undulating boundary; very acid.
Cg	58 - 63	Loamy sand, brown (10YR5/3h); mottles; particulate structure; loose; distinct undulating boundary; medium acidity.
IICg	63- 100	Clay, greyish-brown (2.5Y5/2h); yellowish brown mottles (10YR5/6), numerous, fine, prominent; subangular structure, fine, weakly developed; friable; weakly acid.

Translated from J.Y. Drolet, 1984

Surface Texture of the Various Phase:

-DA1 : Loamy Sand
-DA2 : Sandy Loam

Similar Soils : Aston and Présentation

Drainage : imperfect to bad

Land Use: corn, forages, grains and forest.

noted that most of the soil types suitable for sprinkler irrigation are of good agricultural quality, with very flat topography. Visual observations permitted one to discriminate between land unsuited for sprinkler irrigation (hilly, very narrow) and good land.

No limit, except for the available water, has been set for soils. However, soils with extreme fertility deficiencies should be avoided.

3.8 Results of the Classification of Land for Sprinkler Irrigation

The land identified for sprinkler irrigation is distributed among 71 blocks for SP1 and 69 blocks for SP2. A list of the individual blocks for class SP1 for Richelieu and St-Hyacinthe are found in tables 3.12 and 3.13 , while SP2 blocks are listed in tables 3.14 and 3.15 .

There are 8 709 ha suitable for sprinkler irrigation category SP1 and 7 836 ha in SP2. The repartition of suitable land among each county is found in tables 3.10 and 3.11 . The smallest area is 4 ha and the largest 1 030 ha. The average size of an SP block is 118 ha.

Six percent of the total area irrigable with sprinklers is forested. Of the remaining 94 %, only a small portion is not cultivated.

Table 3.10 Total Area Available for Sprinkler Irrigation in Richelieu and St-Hyacinthe counties SP1 category.

	Total Area (ha)	Forested Area (ha)	Cleared Area (ha)
Area Available	8 709	1 598	7 111
% of total		18 %	82 %
Area in Richelieu	3 469	185	3 284
% of total	40 %		
Area in St-Hyacinthe	5 239	1 412	3 826
% of total	60 %		
Number of irrigable zones (Richelieu)	39		
Number of irrigable zones (St-Hyacinthe)	32		

Table 3.11 Total Area Available for Sprinkler Irrigation in Richelieu and St-Hyacinthe counties SP2 category.

	Total Area (ha)	Forested Area (ha)	Cleared Area (ha)
Area Available	7 836	470	7 366
% of total		6 %	94 %
Area in Richelieu	3 146	8	3 138
% of total	40 %		
Area in St-Hyacinthe	4 690	462	4 227
% of total	60 %		
Number of irrigable zones (Richelieu)	34		
Number of irrigable zones (St-Hyacinthe)	35		

Table 3.12 **Areas of the individual Sprinkler Irrigation Blocks in the Richelieu County Category SP1**

Block	Total Area (ha)	Forested Area (ha)	Cleared Area (ha)	River in Vicinity	Distance to River (km)
SP1-01	42.10	0.00	42.10	St-Lawren.	1.0
SP1-02	126.70	0.00	126.70	St-Lawren.	1.5
SP1-03	125.10	7.51	117.59	St-Lawren.	3.8
SP1-04	24.05	0.00	24.05	St-Lawren.	7.1
SP1-05	142.00	0.00	142.00	St-Lawren.	6.4
SP1-06	45.71	0.00	45.71	St-Lawren.	6.1
SP1-07	117.47	0.00	117.47	Richelieu	9.1
SP1-08	181.23	10.87	170.36	Richelieu	5.3
SP1-09	10.02	0.00	10.02	Richelieu	4.9
SP1-10	408.96	122.69	286.27	Yamaska	5.6
SP1-11	58.14	0.00	58.14	Richelieu	8.5
SP1-12	16.03	0.00	16.03	Richelieu	6.6
SP1-13	37.29	0.00	37.29	Richelieu	7.4
SP1-14	546.49	27.32	519.17	Yamaska	5.6
SP1-15	6.01	0.00	6.01	Richelieu	7.9
SP1-16	16.03	0.00	16.03	Richelieu	6.4
SP1-17	49.72	7.96	41.76	Richelieu	4.1
SP1-18	6.81	0.00	6.81	Richelieu	3.1
SP1-19	88.21	0.00	88.21	Richelieu	3.4
SP1-20	12.83	0.00	12.83	Richelieu	2.2
SP1-21	26.06	0.00	26.06	Richelieu	0.8
SP1-22	10.02	0.00	10.02	Richelieu	0.8
SP1-23	4.00	0.00	4.00	Yamaska	3.1
SP1-24	12.03	0.00	12.03	Yamaska	3.1
SP1-25	42.90	0.00	42.90	Yamaska	0.9
SP1-26	20.04	0.00	20.04	Yamaska	1.1
SP1-27	24.06	0.00	24.06	Yamaska	2.7
SP1-28	772.22	0.00	772.22	Yamaska	5.3
SP1-30	46.10	0.00	46.10	Yamaska	3.6
SP1-31	20.04	0.00	20.04	Yamaska	2.4
SP1-33	20.04	0.00	20.04	Yamaska	0.8
SP1-34	55.72	0.00	55.72	Yamaska	5.7
SP1-36	100.23	0.00	100.23	Richelieu	1.3
SP1-37	29.67	0.00	29.67	Yamaska	1.1
SP1-38	49.32	0.00	49.32	Yamaska	3.4
SP1-73	60.54	0.00	60.54	Yamaska	4.5
SP1-39	85.00	7.65	77.35	Yamaska	1.1
SP1-40	12.83	0.00	12.83	Yamaska	3.3

Table 3.13 Areas of the Individual Sprinkler Irrigation Blocks in the St-Hyacinthe County Category SP1

Block	Total Area (ha)	Forested Area (ha)	Cleared Area (ha)	River in Vicinity	Distance to River (km)
SP1-42	35.68	7.85	27.83	Yamaska	8.6
SP1-43	477.13	181.31	295.82	Richelieu	4.9
SP1-44	570.15	85.52	484.63	Richelieu	6.6
SP1-45	209.29	77.44	131.85	Richelieu	5.1
SP1-46	233.59	98.11	135.48	Richelieu	7.6
SP1-47	24.06	0.00	24.06	Richelieu	7.6
SP1-48	15.64	0.00	15.64	Richelieu	3.0
SP1-49	24.06	0.00	24.06	Yamaska	1.3
SP1-50	646.73	12.93	633.80	Yamaska	1.3
SP1-51	25.67	0.00	25.67	Yamaska	4.8
SP1-52	118.28	21.29	96.99	Richelieu	6.4
SP1-53	633.10	316.55	316.55	Richelieu	6.9
SP1-54	138.71	66.58	72.13	Richelieu	6.9
SP1-55	4.01	0.00	4.01	Richelieu	5.8
SP1-56	8.82	0.00	8.82	Richelieu	4.3
SP1-57	724.00	267.88	456.12	Richelieu	6.9
SP1-58	137.12	13.71	123.41	Richelieu	5.1
SP1-59	136.72	24.61	112.11	Richelieu	7.1
SP1-60	31.68	0.00	31.68	Richelieu	8.9
SP1-61	40.89	12.27	28.62	Richelieu	9.6
SP1-62	355.64	49.79	305.85	Yamaska	7.4
SP1-63	24.46	0.00	24.46	Yamaska	10.2
SP1-64	18.44	18.44	0.00	Yamaska	8.9
SP1-65	20.04	0.00	20.04	Yamaska	5.6
SP1-66	120.68	0.00	120.68	Yamaska	4.1
SP1-67	38.89	38.89	0.00	Yamaska	5.1
SP1-68	101.03	8.08	92.95	Yamaska	3.8
SP1-69	43.70	14.86	28.84	Yamaska	5.8
SP1-71	25.66	4.88	20.78	Yamaska	7.4
SP1-72	34.48	0.00	34.48	Yamaska	6.6
SP1-70	201.27	92.58	108.69	Yamaska	8.4
SP1-75	20.00	0.00	20.00	Yamaska	7.1

Table 3.14 Areas of the Individual Sprinkler Irrigation Blocks in the Richelieu County Category SP2

Block	Total Area (ha)	Forested Area (ha)	Cleared Area (ha)	River in Vicinity	Distance to River (km)
SP2-01	34.89	0.00	34.89	St-Lawren.	1.1
SP2-02	46.11	4.15	41.96	St-Lawren.	6.1
SP2-03	673.00	0.00	673.00	St-Lawren.	7.1
SP2-04	21.65	0.00	21.65	St-Lawren.	6.6
SP2-05	43.70	0.00	43.70	St-Lawren.	5.2
SP2-06	49.72	0.00	49.72	St-Lawren.	5.1
SP2-07	36.49	0.00	36.49	Richelieu	4.9
SP2-08	8.01	0.00	8.01	Richelieu	7.9
SP2-09	8.01	0.00	8.01	Richelieu	5.6
SP2-10	69.77	0.00	69.77	Richelieu	6.4
SP2-11	33.28	0.00	33.28	Richelieu	7.1
SP2-12	64.15	0.00	64.15	Richelieu	1.3
SP2-13	24.06	0.00	24.06	Yamaska	5.3
SP2-14	1016.01	0.00	1016.01	Yamaska	4.3
SP2-15	26.46	3.97	22.49	Yamaska	0.9
SP2-16	17.24	0.00	17.24	Yamaska	0.9
SP2-17	36.09	0.00	36.09	Yamaska	0.8
SP2-18	29.27	0.00	29.27	Yamaska	0.6
SP2-19	51.32	0.00	51.32	Yamaska	1.3
SP2-20	20.05	0.00	20.05	Yamaska	5.6
SP2-21	154.36	0.00	154.36	Yamaska	3.0
SP2-22	9.62	0.00	9.62	Yamaska	2.9
SP2-23	22.85	0.00	22.85	Yamaska	3.9
SP2-24	35.28	0.00	35.28	Yamaska	4.5
SP2-25	133.52	0.00	133.52	Richelieu	5.8
SP2-26	71.77	0.00	71.77	Yamaska	3.1
SP2-27	31.27	0.00	31.27	Yamaska	2.5
SP2-28	23.25	0.00	23.25	Yamaska	2.9
SP2-29	60.14	0.00	60.14	Yamaska	3.6
SP2-30	202.07	0.00	202.07	Yamaska	3.9
SP2-31	35.68	0.00	35.68	Yamaska	5.7
SP2-32	6.01	0.00	6.01	Yamaska	3.7
SP2-33	29.67	0.00	29.67	Yamaska	2.5
SP2-70	21.25	0.00	21.25	Richelieu	4.2

Table 3.15 Areas of the Individual Sprinkler Irrigation Blocks in the St-Hyacinthe County Category SP2

Block	Total Area (ha)	Forested Area (ha)	Cleared Area (ha)	River in Vicinity	Distance to River (km)
SP2-34	13.63	0.00	13.63	Richelieu	8.5
SP2-35	99.03	5.94	93.09	Richelieu	8.9
SP2-36	18.04	0.00	18.04	Richelieu	7.9
SP2-37	26.06	0.00	26.06	Richelieu	4.1
SP2-38	42.09	0.00	42.09	Richelieu	3.8
SP2-39	52.52	0.00	52.52	Richelieu	3.6
SP2-40	212.50	59.50	153.00	Richelieu	5.1
SP2-41	56.13	0.00	56.13	Richelieu	6.9
SP2-42	40.09	0.00	40.09	Yamaska	2.5
SP2-43	45.30	4.08	41.22	Yamaska	1.3
SP2-44	16.03	0.00	16.03	Yamaska	0.8
SP2-45	14.43	4.04	10.39	Yamaska	1.8
SP2-46	107.05	16.06	90.99	Yamaska	2.2
SP2-48	98.23	0.00	98.23	Yamaska	5.6
SP2-49	80.59	57.22	23.37	Yamaska	7.1
SP2-50	106.25	9.56	96.69	Yamaska	9.1
SP2-51	22.85	0.00	22.85	Richelieu	9.1
SP2-52	174.81	34.96	139.85	Yamaska	8.6
SP2-53	799.09	103.88	695.21	Yamaska	7.6
SP2-54	154.37	0.00	154.37	Yamaska	10.3
SP2-55	75.78	0.00	75.78	Richelieu	6.4
SP2-56	4.00	0.00	4.00	Richelieu	5.8
SP2-57	96.23	0.00	96.23	Richelieu	4.6
SP2-58	87.80	1.76	86.04	Richelieu	3.3
SP2-59	94.61	57.71	36.90	Richelieu	3.3
SP2-60	83.39	0.00	83.39	Richelieu	0.8
SP2-61	745.76	44.75	701.01	Yamaska	4.3
SP2-62	11.22	0.00	11.22	Yamaska	3.1
SP2-63	40.89	0.00	40.89	Richelieu	5.1
SP2-64	1030.00	41.20	988.80	Yamaska	6.6
SP2-65	104.25	0.00	104.25	Yamaska	8.1
SP2-66	28.87	11.26	17.61	Yamaska	6.1
SP2-67	44.10	2.21	41.90	Yamaska	8.1
SP2-68	40.01	0.00	40.01	Richelieu	0.5
SP2-69	24.00	7.92	16.08	Richelieu	1.5

3.9 Discussion of Results for Sprinkler Irrigation.

An analysis of the land for sprinkler irrigation is important to assess the economic feasibility of the project. However the extent of the data available does not permit a detailed assessment at this time.

3.9.1 Physical Factors Affecting the Classification

3.9.1.1 Geographic location

The sprinkler irrigation blocks are grouped. The larger irrigated surfaces will make a regional project more profitable . The leakage losses will decrease. Most of the sprinkler blocks are in close vicinity of the subirrigation blocks. In the event a regional irrigation project is organized, the zones located near subirrigation blocks would receive priority.

3.9.1.2 Size and Shape of Blocks

Size does not affect the performance of sprinklers but will affect the economic viability of a water supply project. The smallest zones, less than 10 ha, are isolated. These should be avoided for sprinkler irrigation.

Shape is a more pertinent factor, although the sprinkler rotation permits irrigation almost of any field. Zones that cannot be subirrigated because of their odd shape could probably benefit under sprinkler irrigation. Block SI-42, which is a very narrow strip could be irrigated better with sprinklers although it answers all subirrigation criteria.

3.9.1.3 Soil Quality of Sprinkler Irrigation Blocks

The majority of SP1 and SP2 blocks are constituted of Aston and St-Aimé soils. The latter is classified by Denholm (1987) as having the highest corn production potential while the former has a medium potential. On the other hand, as far as capacity to retain water is concerned, the St-Aimé soil performs better. This soil would require less irrigation water. The St- Aimé soil has a structural problem that makes it less appealing to cultivate than the Aston soil. However, sprinkler irrigation on the Aston soil should be done carefully. The Aston and similar soils, such as St-Damase and Présentation have fertility deficiencies that could be accentuated by sprinkler irrigation. It was said previously that subirrigation could reduce the leaching of minerals. Sprinkler irrigation will have the opposite effect on soils with very low C.E.C such as the Aston soil.

It should be added that even if sprinkler irrigation requires an investment 6 times larger than subirrigation, it could be extremely beneficial for certain crops such as vegetables and small fruits. For corn, if subirrigation is suitable, it should be given priority.

Also, if further investigations are made, it is possible that a few soil types, now listed as unsuitable for subirrigation, could be reclassified.

CHAPTER 4

IRRIGATION REQUIREMENTS AND WATER AVAILABILITY IN RICHELIEU, YAMASKA AND ST-LAWRENCE RIVERS.

The main obstacle to an irrigation project in the Richelieu and St-Hyacinthe county is the availability of water. The Yamaska river, near which most irrigable land is located, has low flows during months of June, July and August. On the other hand, the Richelieu and the St-Lawrence have plentiful supplies, but are located farther from most of the land needing irrigation. The well water supply is saline and many farmers are afraid to use it at this point in time. Staff and students from Macdonald College are conducting research on that subject. A comparison of the availability of water from the rivers and irrigation requirements was made, the results are given below.

4.1 Daily Irrigation Water Requirements.

To calculate irrigation requirements, one needs to know:

1. The water deficits in a given period for a certain recurrence interval
2. The amount of land to be irrigated.
3. The overall efficiency of the system.

There is, at this stage, very little irrigation going on. As for subirrigation, it has been operated only for a few years and published information about water requirements, efficiency and irrigation scheduling is not available yet. The following basic calculations will give a good idea of the state of the water availability.

4.1.1 Irrigation Requirements in Southern Québec

To calculate irrigation deficits in one region requires records on weather, evapotranspiration data from crops for at least 10 years, and the available water capacity of the soils. These calculations were made by Lake (1968) for Southwestern Québec which includes both Richelieu and St-Hyacinthe counties. Using 18 years of weather data, he evaluated the irrigation requirements for soils of different available water capacities. Thornthwaite's method was used to calculate the evapotranspiration. Lake compared the total deficit calculated from a frequency analysis on 18 and 30 years of data. He found only a slight difference between the two values. The length of record, 18 years, was considered to be sufficient. What could affect the present calculations to a great extent is that the requirements were calculated only for the St-Hyacinthe weather station which is located at the extreme south of the region under study. If only one station had to be used it should have been at the border between St-Hyacinthe and Richelieu counties. It was seen in section 2.1.2 that the precipitation decreased from the center of the studied region to Sorel. But for the present use, Lake's data are the most readily available to estimate the water requirements. Table 4.1 gives a list of weekly mean irrigation requirements from April to the end of August for different soil water holding capacity. The standard deviation of the mean is given for each week and permits the calculation of the weekly deficit for probabilities other than the mean. For subirrigation, even if the drain valves are closed in May, irrigation is only started in June and carried out till the end of August. In May, water is still available in the soil. Using the values of table 4.1, total monthly deficits were calculated for 50, 80 and 90 %

Table 4.1 Mean Weekly Soil Moisture Deficits Between June 1st and August 31st at the St-Hyacinthe Station.

	Soil Moisture Capacity in Millimeters[3]					
	25.00		50.00		75.00	
Week[1]	Mean	SDM[2]	Mean	SDM	Mean	SDM
1	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.00
5	0.25	0.00	0.00	0.00	0.00	0.00
6	1.52	0.76	0.00	0.00	0.00	0.00
7	1.02	0.51	0.00	0.00	0.00	0.00
8	2.03	0.76	0.00	0.00	0.00	0.00
9	4.06	1.27	0.25	0.25	0.00	0.00
10	8.38	2.03	3.56	1.27	0.00	0.00
11	5.59	1.52	3.30	1.02	0.25	0.25
12	11.68	2.03	5.59	1.78	2.54	1.27
13	9.91	2.29	7.87	2.54	5.59	2.29
14	9.40	2.03	6.86	2.03	5.08	2.03
15	7.87	2.29	6.86	2.03	5.33	2.03
16	11.68	1.78	7.62	1.78	4.83	1.52
17	10.16	2.29	8.64	2.29	7.37	2.29
18	10.16	2.03	8.64	2.03	7.37	2.03
19	11.68	2.29	11.18	2.29	10.16	2.29
20	9.14	2.29	8.89	2.29	8.13	2.29
21	7.37	2.03	6.35	2.03	5.33	2.03
22	6.60	2.03	5.33	1.78	5.08	1.78
23	4.32	1.52	3.05	1.52	2.79	1.27
24	3.30	1.02	1.02	0.51	1.02	0.51
25	2.03	1.02	0.51	0.51	0.51	0.51

(From Lake, 1968)

1. Week 1= 1st week of april
   Week 10 to 13= month of June
   Week 14 to 17= month of July
   Week 18 to 22= month of August

2. SDM: Standard Deviation of the Mean or Standard Error

3. A summary of the soil moisture deficits for 50 %, 80 % and 90 % probability of occurence is found in Table 4.2.

probability of occurrence. These values are found in table 4.2. It should be noted, from these results that the largest irrigation requirement is in August, although the dryest month is July. This could be explained by the state of the soil's water reserve in August which can not be replenished because little rainfall occuring in July.

4.1.2 Available Water Capacity of Richelieu and St-Hyacinthe Soils.

Lake calculated the irrigation requirements for different values of available water capacities in the root zone. It was left to the user to evaluate the effective rooting depth and usable storage capacities of each soil type. The available water is the amount of water held between field capacity and wilting point. Only the water held in the root zone is considered to be available to the plant.

The irrigable soils of Richelieu and St-Hyacinthe counties have been identified in Chapter 3 and classed among three groups: subirrigation (SI), sprinkler irrigation 1 (SP1) and sprinkler irrigation 2 (SP2). The available water capacity was used as a criterion of differentiation between the two sprinkler irrigation categories. The available water storage in the effective root zone was evaluated by Nolin and Lamontagne (1986) for all soils of the St-Lawrence Lowlands. Nolin classified each soil series according to its average water holding capacity. These values, for the soils of St-Hyacinthe and Richelieu counties, are found in appendix B . One can notice that all the soils suitable for subirrigation and SP1 have available water capacity between 6 and and 12 cm per meter of soil. SP2 soils have a moderate available water capacity between 12 and 18 cm per meter of soil. The

Table 4.2 Monthly Water Deficits for Different Probability of Occurrence at the St-Hyacinthe Meteorological Station

Month	Root Zone Available Water (mm)	SDM (mm)	Deficits (mm) Probability of Occurrence[1] 50 %	80 %	90 %
June	25	7.9	35.6	63.5	78.2
July	25	8.4	39.1	69.0	84.6
August	25	10.7	44.9	83.1	102.9
June	50	6.6	20.3	43.9	56.1
July	50	8.1	29.9	58.9	74.2
August	50	10.4	40.3	77.5	97.0
June	75	3.8	8.3	21.8	28.9
July	75	7.9	22.6	50.5	65.3
August	75	10.4	36.0	73.2	92.7

1.The deficits in mm in the table indicate the deficit which can be expected not to be exceeded for the percent of years indicated.

Note: Since Richelieu county receives less rainfall than the city of St-Hyacinthe, deficits in the county could be expected to be as much as 10 mm greater for each month. Only the irrigation requirements of St-Hyacinthe were available.

average values of available water capacities were set at 5 cm and 7.5 cm per 50 cm of soil for the first and second group respectively. All of Nolin's value were based on a root depth of 50 cm.

4.1.3 Total Irrigation Requirements for Richelieu and St-Hyacinthe County

The irrigation period was set to run from June 1 st to August 31st. For sprinkler irrigation the period would be a bit longer in some years.

It was assumed that all calculations should be done for an 80 % probability. Therefore the water requirement calculated would not be exceeded 4 out of 5 years. The 80 % probability was chosen because it corresponds to the recurrence interval of the drought period in Richelieu county. It might not be economic to supply the 4 in 5 years requirement. Only further studies that are out of the scope of this thisis would be needed. Irrigation requirements were also calculated for a 50 % and 90 % probability.

Data for total irrigation efficiencies of systems in Québec were not available. Subirrigation has just started and sprinkler irrigation is not yet practiced extensively. For purpose of this analysis, an efficiency of 75 % was used.

The pumping rate is different whether subirrigation, or sprinkler irrigation are considered. For subirrigation pumping can be continuous thus requiring smaller pipes and less energy. For sprinkler irrigation, it is unrealistic that the same rate could be maintained day and night.

Pumping was assumed to be done 84 hours per week, half the pumping time of subirrigation. Hence the pumping rate requirements for sprinkler irrigation are twice as high as for subirrigation for the same surface area.

4.1.3.1 Sample Calculation of Water Flow Requirements for one Subirrigation Zone of the Richelieu County.

The following sample calculation was done for a subirrigation block. The flow required for an identical sprinkler irrigated block would at least be twice the amount calculated for subirrigation.

<u>General Information</u>:

River in Vicinity: St-Lawrence
Overall efficiency: 75 %
Area of Block: 46.45 ha
Irrigation period: 1^{st} of June to 31^{st} of August
Soil Available Water in the root zone(50 cm): 5 cm
Total Irrigation Requirements: 9.3 cm
(Irrigation requirements= sum of the mean weekly irrigation requirements from week 1 to 22 (Table 4.1) for asoil available water of 5 cm in the root zone.)
Standard Dev. of the Mean(SDM): 0.94 cm (Lake, 1968, Table 43)

$$\text{Mean Water Requirements} = \frac{(\text{Area Irr.})*(\text{Irr.Req.})}{(\text{Efficiency})} \quad (4.1)$$

$$= 57\ 598\ m^3$$

<u>80 % Probability Water Requirements:</u>

$$\text{Deficit}_{(80\%)} = \text{Deficit}_{(50\%)} + Z_{(.2)} * \sqrt{n} * (\text{SDM}) \quad (4.2)$$

Probability: 80%
$Z_{(.2)}$: 0.84 (from statistical tables)
Mean Deficit: 9.3 cm
SDM: 0.94 cm
n: Length of Record: 18 years
Deficit(80 % prob.)= 9.3 + (0.84)*(.94)*(18)
= 12.65 cm
Water Requirements = 78 345 m^3

Flow Requirements at 80 % Probability

Flow = (Wat. Req.) ÷ (Irrigation Period) (4.3)

Irrigation Period= 90 days X 24 hrs/day (Continuous)

Flow = 0.01 m^3/s

The water flow needed to meet the continuous irrigation requirements 4 years out of 5 and a large portion of the need of the 5^{th} year is 0.01 m^3/s. If the irrigation pumping period was reduced to 92 days X 12 hrs/day (half of the subirrigation period), the flow rate required would be multiplied by 2.

4.1.3.2 Results of Flow Requirements Calculations

The water requirements were calculated as in the previous section. All the irrigable land was divided among the three rivers surrounding the counties: Richelieu, Yamaska, St-Lawrence. All blocks were classed according to their proximity to a river. The distance between 1 block and a river was measured from the center of the block, perpendicular to the river. Table 4.3 shows the partitioning of blocks among the three rivers. Of course, the distances measured are not the actual routes water will have to travel, but it is a good approximation. The distances were not used in any calculation, but were an indicator to determine the area that would be irrigated by a given river. The distances of subirrigation blocks from a river are given in Table 3.4 and 3.5.

Water requirements were calculated for 80 % probability for total and cleared areas and are found in Table 4.4 and 4.5. The total

Table 4.3 Areas in Vicinity of the Different Rivers

River	Irrigation Method	County	Area: Total (ha)	Area: Cleared (ha)
Richelieu	SI	Richelieu	1 669.28	895.22
		St-Hyacinthe	6 750.12	3 419.24
		Total	8 419.40	4 314.48
Richelieu	SP1	Richelieu	736.10	717.23
		St-Hyacinthe	2 848.14	1 956.15
		Total	3 584.24	2 673.38
Richelieu	SP2	Richelieu	374.48	374.48
		St-Hyacinthe	876.26	802.93
		Total	1 250.74	1 117.41
Yamaska	SI	Richelieu	5 621.63	4 378.02
		St-Hyacinthe	630.65	550.18
		Total	6 252.28	4 928.20
Yamaska	SP1	Richelieu	2 228.00	2 068.81
		St-Hyacinthe	2 391.47	1 870.67
		Total	4 619.47	3 939.48
Yamaska	SP2	Richelieu	1 902.47	1 898.50
		St-Hyacinthe	3 813.74	3 425.03
		Total	5 716.21	5 323.53
St-Lawrence	SI	Richelieu	1 025.28	957.52
St-Lawrence	SP1	Richelieu	505.66	498.15
St-Lawrence	SP2	Richelieu	869.67	865.52

Table 4.4 Water Flow Requirements for the Total Irrigable Land, According to the Proximity to a River, with an overall irrigation efficiency of 75 % for the once in 5 dry years.

Irrigation Method	River in Proximity	Water Flow Requirements		
		June m^3/s	July m^3/s	August m^3/s
SI	Yamaska	1.41	1.88	2.41
SP1	Yamaska	2.08	2.71	3.56
SP2	Yamaska	1.28	2.87	4.17
Off-Peak Total		1.41	1.88	2.41
On-Peak Total		4.78	7.42	10.14
SI	Richelieu	1.90	2.47	3.43
SP1	Richelieu	1.62	2.10	2.77
SP2	Richelieu	0.28	0.63	0.91
Off-Peak Total		1.90	2.47	3.43
On-Peak Total		3.79	5.19	7.11
SI	St-Lawrence	0.23	0.30	0.39
SP1	St-Lawrence	0.23	0.29	0.39
SP2	St-Lawrence	0.19	0.44	0.63
Off-Peak Total		0.23	0.30	0.39
On-Peak Total		0.66	1.04	1.42

Note: Total Area is 36 242 ha

Table 4.5 Water Flow Requirements for the Cleared Irrigable Area, According to the Proximity to a River, with a total irrigation efficiency of 75 %

Irrigation Method	River in Proximity	Water Flow Requirements		
		June m^3/s	July m^3/s	August m^3/s
SI	Yamaska	1.11	1.45	1.90
SP1	Yamaska	1.78	2.31	3.04
SP2	Yamaska	1.19	2.68	3.88
Off Peak Total		1.11	1.45	2.90
On Peak Total		4.08	6.43	8.82
SI	Richelieu	0.97	1.27	1.67
SP1	Richelieu	1.21	1.57	2.06
SP2	Richelieu	0.26	0.59	0.86
Off Peak Total		0.97	1.27	1.67
On Peak Total		2.45	3.43	4.59
SI	St-Lawrence	0.22	0.28	0.37
SP1	St-Lawrence	0.22	0.29	0.38
SP2	St-Lawrence	0.19	0.43	0.63
Off Peak Total		0.22	0.28	0.37
On Peak Total		0.52	1.00	1.38

Note: Cleared Area is 24 677 ha

irrigable land is 32 242 ha. Total water flows required were divided among the months of June, July and August, even though the irrigation period for sprinklers could extend to September. Lake (1968) showed that the irrigation requirements for September were negligible. In Table 4.4, the flow required for the peak and off peak periods are given separately. Peak periods last 12 hours per day and occur when water is pumped for both subirrigation and sprinkler irrigation. Reducing the area of land that is to be irrigated by sprinkler would considerably reduce the total flow requirements. Of course if the water supply was infinite, there would be no concern about the rate of pumping. The Yamaska, however, has limited flows in the summer months. The flow needed to irrigate all cleared land in vicinity of the Yamaska, at peak, would reach 6.43 m^3/s and only 1.44 m^3/s during off peak period.

All the flowrate values of Table 4.5 were calculated for 75 % irrigation efficiency. Experiments were not done to assess the efficiency of a subirrigation system. But from data gathered at the experimental site of St-Louis, efficiencies ranging from 80 % to 95 % were obtained. As the water table rose, the efficiency decreased: the head difference between the irrigated field and adjacent non-irrigated fields had increased and thus leakage was more important. A value of 75 % seems conservative, but realistic because it also includes the delivery efficiency. Water requirements for subirrigating would decrease if the global efficiency was increased. This can only be done if good control of the water table is achieved and if the level of water in the ditches is monitored . Massey et. al. (1985) think that good efficiencies can be achieved with a subirrigation system if the water table is allowed to recede to a predetermined depth, so the plant can benefit from the rainfall, as it does with sprinkler irrigation.

Water requirements were calculated for both total and cleared areas. It is more realistic, on a short term basis, to consider that only cleared land will be irrigated. The clearing of land for any form of irrigation will depend on the amounts of water available. For the Yamaska, the difference between the water requirements for the total area, 7.415 m^3/s, and the peak needs for cleared area, 6.431 m^3/s, is not very large. This can be explained by the fact that the largest part of the flow requirements come from the sprinkler irrigated land, which is almost all cleared. Most of what is forested near the Yamaska is classified as suitable for subirrigation.

The largest requirement for water occurs in the month of August but fortunately the flow in the river increases enough from July to August. The large amounts of water required in July can usually be supplied by the surplus water from June rainfall. During July, the Yamaska River reaches its lowest flows.

If all the irrigable land was to be supplied from a single river it would require, in the dryest month 18.6 m^3/s for the total area, and 14.82 m^3/s for the total cleared area. The Richelieu and St-Lawrence rivers have ample water.

4.2 Water Availability from the Different Sources

In the previous section, average water requirements were calculated for the once-in-5 dry year. Therefore, frequency analyses were performed on the flows of three rivers to find the minimum and average flows for the once in 5 dry year period. Even if the flows required are not very large compared to large irrigation projects in western Canada, many people have always thought that not enough water would be available, despite the fact that four sources, the Yamaska, the Richelieu, the St-Lawrence and wells are found in the region. The last source will not be examined closely in this report. The main investigation was done for the Yamaska River which, as reported by local farmers, has low flows in summer. More than 50 % of all the irrigable land and about 50 % of all the cleared subirrigable land is located close to the Yamaska River.

4.2.1 Water from Wells

If the quality of the well water had been good, it would have been used for irrigation a long time ago. The salinity of the water has always restricted its use. Table 2.3 of section 2.1.4 gave an overview of the salt content of the well water in the Richelieu and St-Hyacinthe county.

The county is underlain by two types of aquifer. The first one is located in the south of St-Hyacinthe county and has a mean flowrate of 3.18 m^3/hr (Simard et.al., 1979). The second aquifer has a mean flowrate of 2.51 m^3/hr (Simard et. al., 1979). It covers the rest of the

St-Hyacinthe and Richelieu county. It is the water of the first aquifer that is presently used on the experimental site of St-Louis. The possibility of using this water for subirrigation would be an asset: it is the most accessible source. The use of the saline well water would be conditional to the clay content of the soils. Soils as the Aston and St-Damase should not be irrigated with the well water. The subirrigable soils have low clay content in their profile. The first aquifer should be used with care because of its extremely high salinity.

The assessment of the volumes of water available from wells is difficult. Not much information is available at this point as to the volume of the aquifer. It is possible to think that well water could be used as a reservoir to meet extreme conditions, or mixed with the river water. This would reduce the strain on rivers such as the Yamaska, during the month of July.

Yet, the use of this saline water is still experimental. It will be important to evaluate the impact of such a saline water on the soil and watercourses before planning intensive use of the water. The well water may need treatment to remove iron to avoid blocking the subsurface drain perforations and envelopes. The saline water, if used with sprinkler systems could have negative effects on the plant leaves and corrode the equipment.

4.2.2 Water from the St-Lawrence River.

The amount of cleared land located in vicinity of the St-Lawrence river needing irrigation is only about 2 320 ha. The flow required to irrigate the cleared irrigable surface is 0.4 m^3/s. Frequency analyses were not made for the St-Lawrence River, since on the average, the river flow is 9 100 m^3/s. Only the land at the north end of Richelieu county, in the municipalities of Sorel, St-Pierre and St-Robert, could easily have access to the St-Lawrence river. This zone covers an area of 2 321 ha, of which half could be subirrigated. The mean distance of the blocks to the river is 3.1 km. At the present time, most of this land is cleared but uncultivated. It is near the St-Lawrence that the soils are the most sandy.

Pumping water from the St-Lawrence does not represent a problem. It should be inexpensive since the water is abundant and in proximity of the irrigated land. The pumping head is the smallest, less than 5 m. Some of the land may be occasionally flooded.

The St-Lawrence river could supply all the 30 000 ha suitable for irrigation, but this would be costly. The distances to bring the water to some of the parcels are longer than 15 km. This option would be a last resort.

4.2.3 Water from the Richelieu River.

The Richelieu is a river which has an average flow of 380 m^3/s, the lowest average over 10 years being 299 m^3/s. This was measured at Fryers Rapids, just upstream from Chambly. The region of interest in this thesis is located downstream from Chambly and Highway 20. It is not expected that there will be a large variation in flow between Fryers Rapids and the section downstream from Highway 20. Not much water is removed from the river except perhaps at Beloeil, St-Jean de Richelieu and Chambly, which are upstream from Highway 20. The maximum water extracted would be approximately 5 m^3/s, relatively nothing compared with the minimum flow in the river . The 37 year minimum is 40 m^3/s.

A frequency analysis was performed from the data at Fryers Rapids. Flow data gathered by Environment Canada at that location from 1972 to 1986 were used. Two flow duration curves, one for average flows and one for minimum daily flows were produced for each summer month. The recurrence intervals were calculated with Weibull formula and plotted on Gumbel paper. For extreme value distribution, Gringorten's plotting position formula is normally used, and recurrence intervals were also calculated with this method. However, since no differences were noticed for small recurrence intervals (once-in-5 and once-in-10 years), Weibull formula was considered as adequate. This thesis was not concerned with the once-in-50 and ina 100 years events for which Gringorten's formula would have given more accurate results. Curves for the average flow frequency analysis are found in Figure 4.1. The comparison between the one-in-5 years water requirements found in table

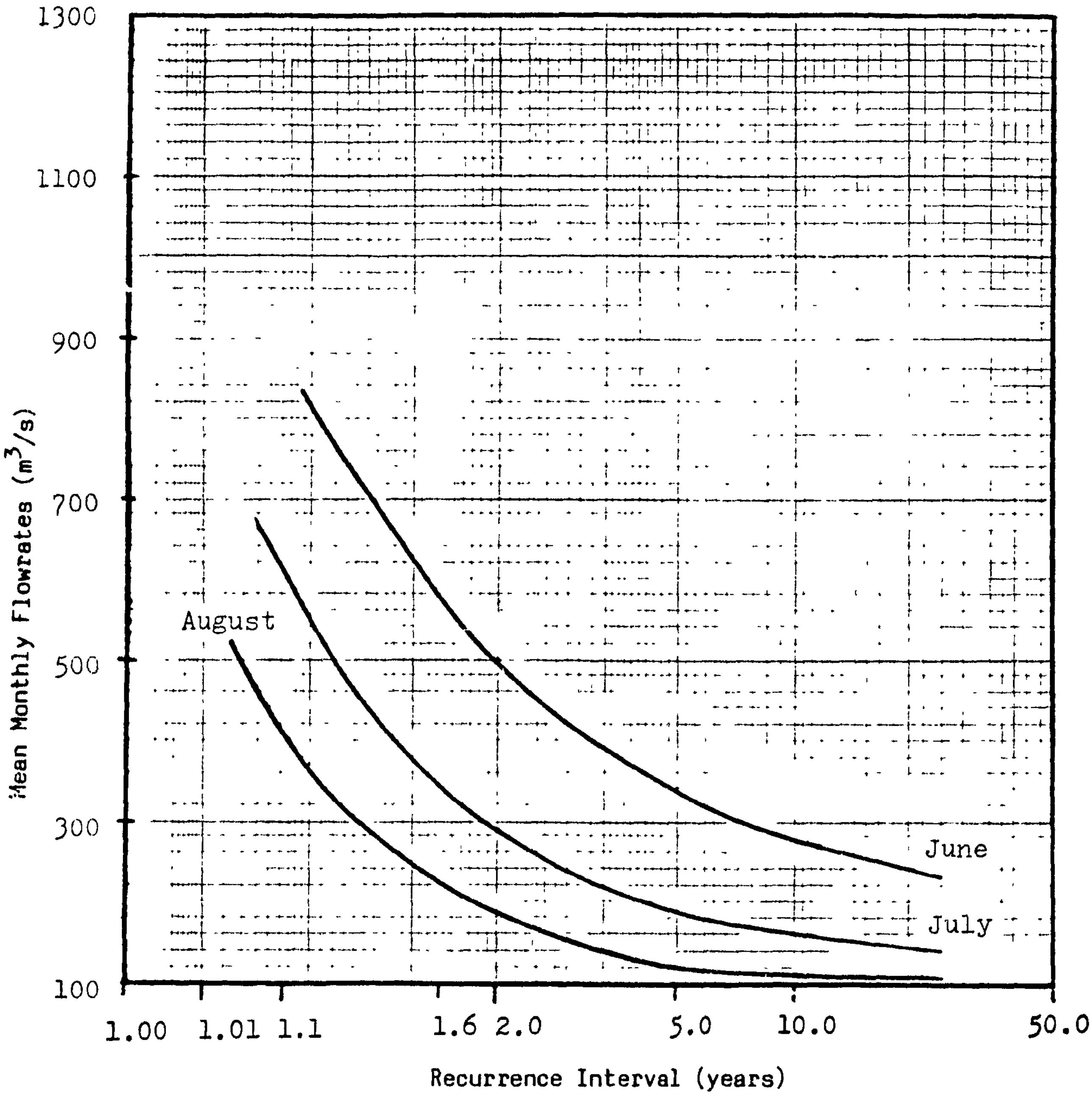


Figure 4.1 Recurrence Interval vs Monthly Average Flows in the Richelieu River, for the Summer Months.

4.5 and the flowrates exceeded 4 out of 5 years shows that the Richelieu River is able to meet the irrigation demand for the land located in its vicinity. However, in performing the analysis, the aim was to find out about the possibility of irrigating all the 30 000 ha of irrigable land in both counties. The minimum day flows, and the average flows for the 1 in 5 and 1 in 10 years were read from the recurrence curve and are listed in table 4.6.

In August, the 1 in 5 year minimum day flow was found to be 105 m^3/s. This is the lowest minimum day flow amongst the three months, for that recurrence interval. For ecological reasons and to supply other users, from 1/2 to 2/3 of the flow should remain in the river, the proportion remains to be determined. Assuming 2/3 of the flow remains in the river, this still leaves 35 m^3/s available for irrigation. The peak flow needed in August to satisfy the demand of the whole 26 000 ha of cleared land is 14.79 m^3/s. Thus, there is still place for development since 20 m^3/s could still be used to irrigate the remaining 7000 ha presently forested. The 37 year minimum could almost meet the demand of the whole area. Some additional storage would be needed. It is obvious that the Richelieu River can supply all the land in its vicinity for at least the once-in-5 dry year probability , which requires a peak flowrate of 3.8 m^3/s.

The pumping head would be about 15 m for any of the blocks identified for subirrigation. Although it is feasible to irrigate the whole surface with water from the Richelieu river, it might not be economical. At least 57 % of the land is located at more than 15 km from the Richelieu. Even if it is economical, it will not be easy to find a path through the agricultural land for the pipelines and canals required

Table 4.6 Average of Monthly Flows And Minimum Day Flows for the Summer Months in the Richelieu River, for Different Recurrence Intervals.

Month		Flow "greater or equal to" (m^3/s)		
		50 %	80 %	90 %
June	Average	500	340	290
	Minimum day	348	255	215
July	Average	290	184	160
	Minimum day	198	140	120
August	Average	182	127	115
	Minimum day	141	105	90

to bring the water to the farthest plots. Also, as the amount of water pumped increases, so does the size of the control structures. It is important to realize that a standard drainage ditch as found in both counties can carry 3.8 m^3/s. Very little needs to be done to accomodate some of the ditches for water delivery. Irrigating from one source would ease the management, but it probably is not economical: the increase in the corn yields may not pay for costly irrigation structures.

4.2.4 Water from the Yamaska River.

About 50 % of the land to be irrigated is located in the vicinity of the Yamaska river. The best land for subirrigation, in block SI-09 mainly, is closer to the Yamaska than to any other river. The flow requirements from the Yamaska are listed in Table 4.5. About 70 % of the irrigable land near the Yamaska is to be irrigated with sprinklers.

4.2.4.1 Frequency Analysis of Monthly Average and Minimum Day Flows in the Yamaska River.

Frequency analyses were performed on the minimum day and average monthly flows, as with the Richelieu River. The flow data were measured by Environnement Québec for La Noire River, Yamaska River at Farnham and Yamaska River at St-Hyacinthe. Twenty years of data, from 1965 to 1985, were used. All frequencies, calculated by the Weibull formula were plotted on Gumbel paper. Frequency analyses could not be done for a station located in the portion of the Yamaska River downstream of St-Hyacinthe, which is close to the subirrigation zones: no guaging stations with a sufficiently long record existed. To approximate the flow at St-Hyacinthe, the monthly average and minimum day flows per unit drainage area of two branches of the Yamaska, the La Noire river and Yamaska River at Farnham were plotted on Gumbel paper. The drainage areas of these two sub basins are almost equal. Also the total drainage area served by these two stations is equivalent to the drainage area of the Yamaska at St-Hyacinthe. The average curve of the flow per unit area, in between the La Noire and Yamaska River at Farnham curves, was assumed to represent the flow per unit area at the St-Hyacinthe station. From this average curve the recurrence interval of various flows per unit area was read. Each value had to be multiplied by the drainage area of the Yamaska at St-Hyacinthe, 3 370 km^2. Figures 4.2 and 4.3 illustrate the resulting frequency curves for the St-Hyacinthe station for both monthly average and minimum daily flows for the summer months. There is usually little inaccuracy in an approximation of this sort. However, in this case, a dam located at St-Hyacinthe could influence the downstream flow by its reservoir effect. The approximation made to calculate the flows at the St-Hyacinthe station and downstream would not reflect the reality if this is true. The dam at St-Hyacinthe is very low and probably has negligible effect on the flow except at very low levels. The flow downstream of St-Hyacinthe depends on the amount of water removed from the river at St-Hyacinthe for domestic and industrial use. If the per capita consumption for all usage is 800 liters per day, the flow needed at St-Hyacinthe to be able to supply this town of 45 000 inhabitants will be 0.42 m^3/s. This does not affect significantly the flow downstream. It was therefore possible to use the approximated flows at St-Hyacinthe to evaluate the flow of the rest of the Yamaska, downstream St-Hyacinthe.

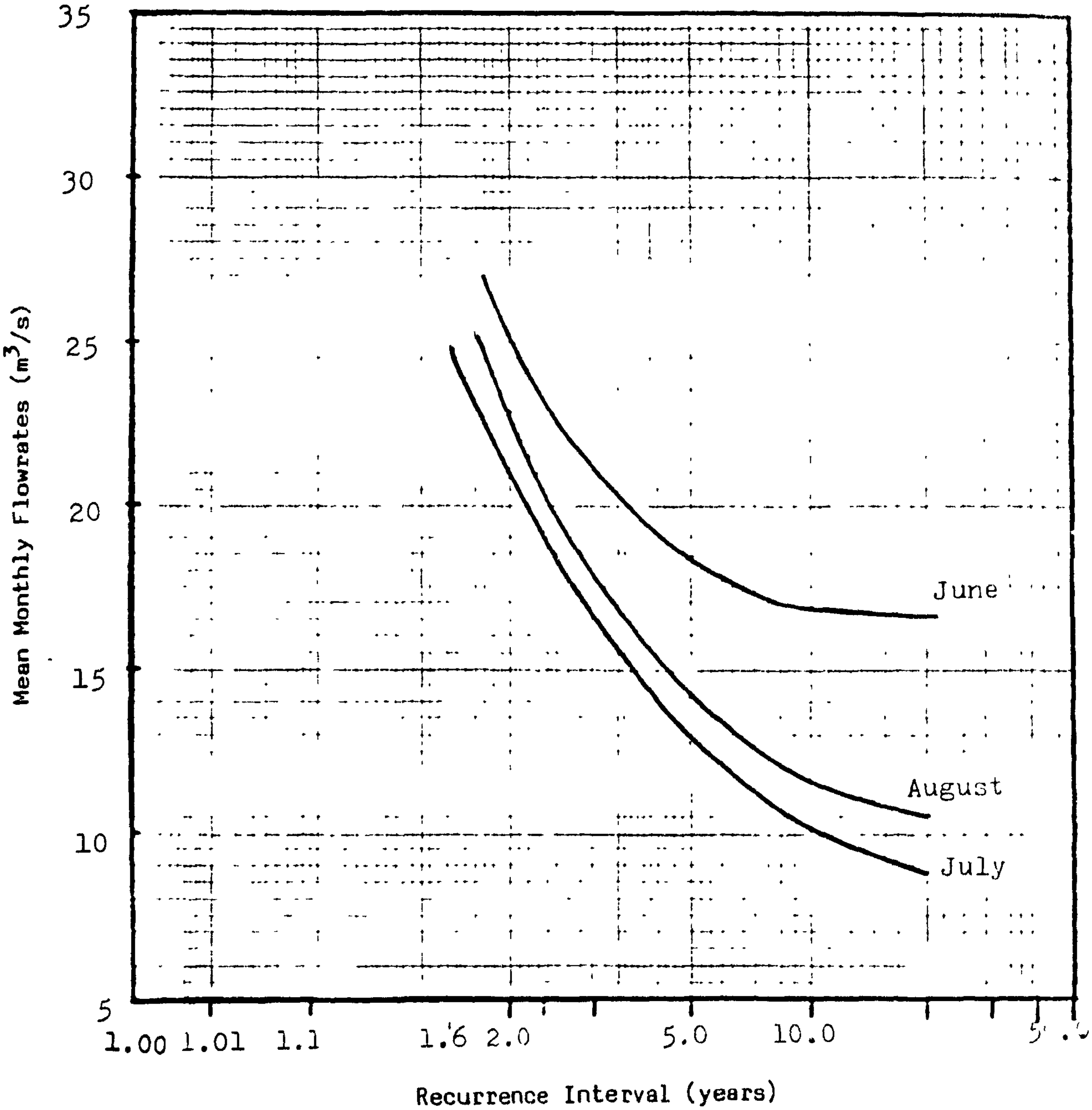


Figure 4.2 Recurrence Interval vs Monthly Average Flows in the Yamaska River, for the Summer Months.

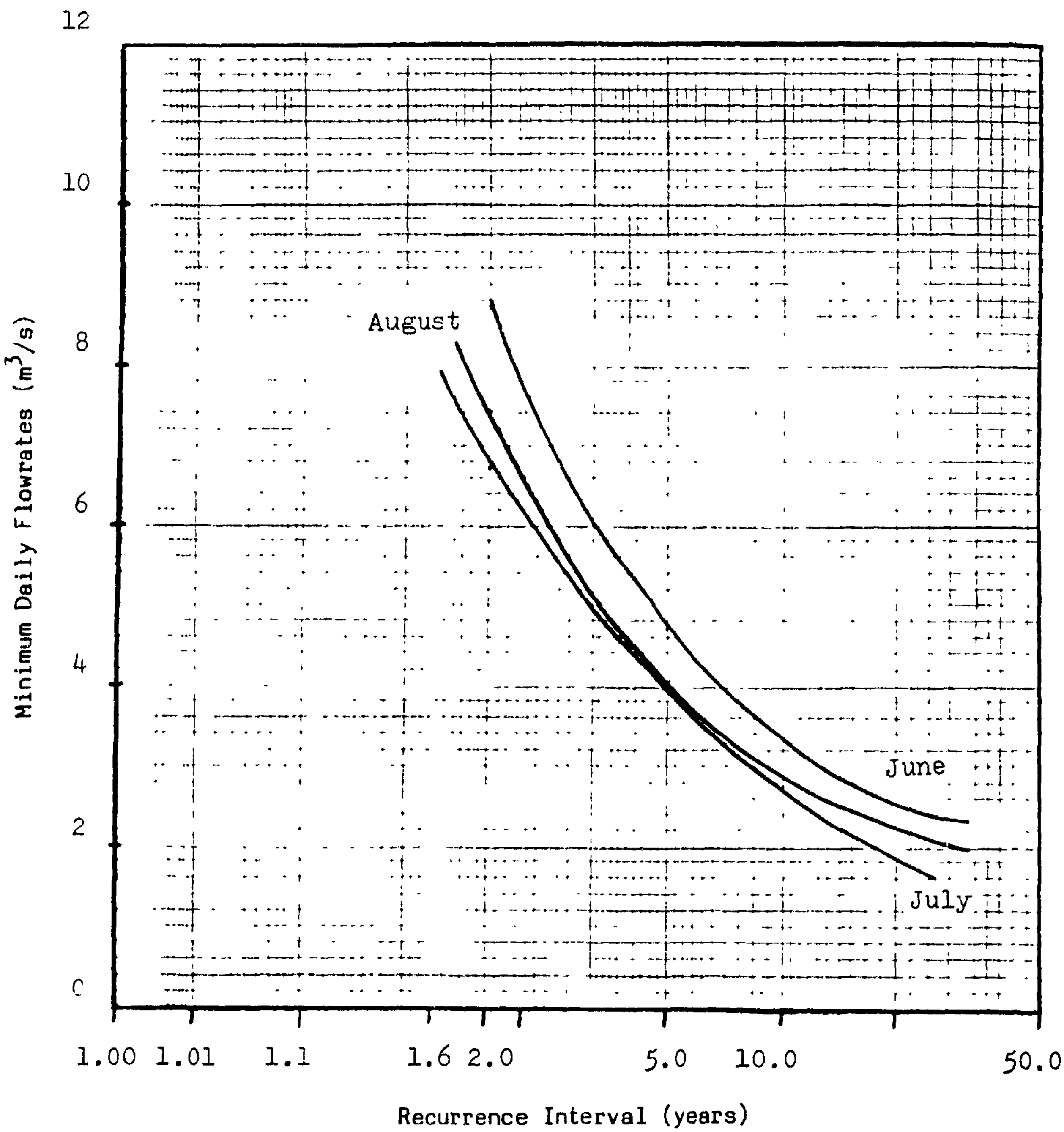


Figure 4.3 Recurrence Interval vs Minimum Day Flows in the Yamaska River, for the Summer Months.

The values of minimum daily and average monthly flows for different recurrence intervals were then read from the frequency graphs for June, July and August, and placed in Table 4.7. The recurrence interval selected on which all further calculations are based, is the once-in-5 dry year. For supplemental irrigation, it is unnecessary to try to supply more than the needs of the once-in-5 dry year. This amount also supplies most of the needs for the once-in-10 or once-in-50 dry year.

4.2.4.2 Minimum Daily and Monthly Average Flows Available in the Yamaska for Subirrigation

It is common practice to assess availability of irrigation supplies based on the minimum daily value at a given recurrence interval. This remains true until some storage can be established to supplement the river. This is what occurs with subirrigation. For this type of irrigation, additional storage sources of water can be found in the ditches and the soil. The water table, if no irrigation water is pumped will be able to supply the plants by capillarity for a few days. In sprinkler irrigation, water can be stored in some ditches, but not in the soil because the water table is too low for water to rise by capillarity. For subirrigation, it is sufficient to base calculation on average flows. On the other hand, sprinkler irrigation flows should be based on the minimum values. The flows in the Yamaska are so low during some period of the year that it is difficult to rely on the values measured. Therefore, in this project a greater importance being given to subirrigation, the average flows were privileged. Using Yamaska's lowest flows to assess the potential of the river as a source would result in an over estimation of the needs for new supplies: due to the

Table 4.7 Average And Minimum Day Flows in the Yamaska River, for Different Recurrence Intervals.

Month		Flow "smaller or equal to" (m^3/s)		
		50 %	80 %	90 %
June	Average	20.22	13.48	11.79
	Minimum	8.76	4.70	3.37
July	Average	15.84	7.75	5.05
	Minimum	6.74	4.04	2.79
August	Average	16.85	9.09	6.74
	Minimum	7.41	4.04	2.86

climate of the region, it is not critical to lack water for a few days, at least for corn. Of course, not all the average flow is available for irrigation.

The minimum flow that has to remain in the river to maintain the wildlife, supply the inhabitants and ensure that enough water is left to dilute the pollutants is an unknown. The minimum flow should normally be determined by some investigation. This was beyond the scope of this thesis. In the Yamaska, because of the low flows encountered, the determination of such a minimum is critical to the evaluation of the potential of the river as a source of water for irrigation. In the Richelieu river, because of the large flows, the determination of this value is of little importance. Three possibilities, to determine a minimum flow that should remain in the Yamaska river were examined:

1. To leave two thirds of the average flow in the river during the dryest month (July) 1 in 5 year. This would leave a flow of 5.16 m^3/s. (Average flow in July exceeded 4 in 5 years: 7.75 m^3/s.)

2. To leave two thirds of the minimum day flow in the dryest month (July), 1 in 5 year. This would leave 2.69 m^3/s in the river. (Minimum average flow in July exceeded 4 in 5 years: 4.04 m^3/s.)

3. To use the minimum flow in the Yamaska 1 in 50 years or 1 in 100 years. This would leave 2.6 m^3/s in the river. (From figure 4.3)

The first proposition is the most conservative but the safest. The 5.16 m^3/s includes the need of all other users. All the flow above the minimum day value is available for irrigation. This implies that no pumping could occur if the flow is lower than 5.16 m^3/s. This would cause the quantity of storage required to increase. The average monthly flow in the Yamaska is at least equal or greater to 5.16 m^3/s 49 out of 50 years (figure 4.3). The minimum day flow will be less than 5.16 m^3/s once in 3 years. This suggests that despite its low flows, the Yamaska could be a good supply, at least for the subirrigated land.

The irrigation requirements that will not be exceeded 4 out of 5 years, for all types of irrigation are found table 4.5. The total flows required from the river, to irrigate all the areas identified were divided in two categories : peak and off peak. Sprinklers are assumed to function 12 hours per day. The period of the day when the river must supply both the subirrigated and sprinkler irrigated land is the peak demand period. The 12 night hours, when only subirrigated land is supplied, is the off peak period. In all the calculations, it was assumed that flow was available for sprinkler irrigation when all subirrigable land had been satisfied. These calculations assumed the worst case, that the sprinklers were supplied directly by pipeline from the Yamaska River. If a regional project is undertaken, it is possible that regional pumping stations would deliver water by pipe to the watercourses from where the farmers could pump. If this is done, the main pumps can operate at a slower rate, 24 hours per day. The ditches can provide the overnight storage.

For the month of July, a continuous flow of 1.45 m^3/s is required to supply 4900 ha. The flow required in the peak time is 6.43 m^3/s. For the same month of July, the average water flowing in the Yamaska River at least 4 years out of 5 is 7.75 m^3/s. Assuming 5.16 m^3/s must remain in the river, this leaves 2.59 m^3/s for irrigation. If the average irrigation requirements over the three month period is 2 mm/d, a continuous flow of 2.59 m^3/s can subirrigate 11 200 ha. For sprinkler irrigation, the requirements being double (the application period is half that of subirrigation), the total area irrigated with the same amount will be divided by two. There is not enough water in the Yamaska River to supply the total of both subirrigated and sprinkler irrigated cleared land. There is however enough flow to supply, on the average, the demand for the subirrigated land.

Some deficit occurs, in July mainly, when the river flow goes below the average. These deficits could be supplied by small reservoirs. Some of the deficit between the demand and the flow available above 5.16 m^3/s can be found in the soil and in the ditches, at least for subirrigation. Because the flows in the Yamaska river are so low, an irrigation method that requires small flows over a long period of time, as subirrigation, will always be better than a method that requires large flows for a shorter period of time, such as for sprinkler irrigation.

4.2.4.3 Deficits in Supply, and Storage Requirements

The deficit in supply is defined as the difference between the irrigation flow requirements of an area and the water flow available in the river for irrigation. The maximum deficit occurs when the flow is at its minimum value, for a given probability. The storage required or storage capacity is the volume of water to be added to the river flow to meet the irrigation needs of an area, for a given period of time. Because priority was given to subirrigation, all its water demand must be met first, before any water is allocated for sprinkler irrigation. This increases the importance of the deficit in supply for this form of irrigation. In reality, the allocation of water in the case of a limited supply would be done based on the economics: the most productive land would get more water. It was thought, in making the above assumption, that subirrigation should be privileged since it is the most economical and accessible for the farmer. An in depth analysis would be required, but is beyond the scope of this thesis.

Deficits and storage supplies were calculated from the average and minimum flows available in the Yamaska river, 4 years out of 5, for two values of minimal flow, 5.16 and 2.6 m^3/s. All the monthly deficits and storage capacities meeting those deficits are found in Table 4.8 and 4.9. The irrigation requirements were presented previously in Table 4.5.

It was calculated for both minimal flow that no deficits would occur for subirrigated land demand. In other words, on the average, all the demand for the 4 900 ha of subirrigated land can be supplied by the Yamaska River. The maximum deficit, 4 years out of 5, should not exceed 1.91 m^3/s in August. This represents a volume equal to 10 000 000 m^3 storage capacity, over the irrigation period of 92 days. The true deficit, in that recurrence interval is probably a value between the average, 0 and the maximum. It is , in any case, very low, closer to the average than to the maximum. In subirrigation, because water is available from the ditches and the soil, no extra reserve would be needed in theory. From a water table at 90 cm depth up to 100 cm, the capillary conductivity is 2 mm/d in a sandy soil, about equal to the mean summer irrigation deficit of the St-Hyacinthe area (Lake, 1968).

Table 4.8 Storage Capacity Required to Supplement the Yamaska River Flows to Supply theIrrigation Demand. Calculations are Based on the Monthly Average Flows 4 out of 5 years.

1 Month	2 Irrigation Method	3 Minimum Flow	4 Average Flow	5 Available Flow	6 Irrigation Demand	7 Storage Needed
		(m^3/s)				($10^6 m^3$)
June	SI	5.16	13.48	8.32	1.11	0
	SP	5.16	13.48	7.20	2.97	0
July	SI	5.16	7.75	2.59	1.45	0
	SP	5.16	7.75	1.15	4.98	5
August	SI	5.16	9.09	3.93	1.90	0
	SP	5.16	9.09	2.02	6.92	7

Col. 3 : Minimum flow designated to remain in the river.
Col. 4 : From Table 4.7.
Col. 5 = Col. 4 - Col. 3
Col. 6 : From Table 4.5 (SP= SP1 + SP2)
Col. 7 = (Col. 6 - Col. 5)* Area * Irrigation Period

Note: Irrigation Period for Sprinkler is 12 hrs/dayX 30 days per month, in drier years.

Table 4.9 Storage Capacity Required to Supplement Yamaska River Flows to Supply the Irrigation Demand. Calculation are Based on the Minimum Daily Flows 4 out of 5 years.

1 Month	2 Irrigation Method	3 Minimum Flow	4 Average Flow	5 Available Flow	6 Irrigation Demand	7 Storage
		(m^3/s)				($10^6 m^3$)
June	SI	5.16	4.7	0.00	1.13	2.92
	SP	5.16	4.7	0.00	2.97	3.90
July	SI	5.16	4.04	0.00	1.45	3.90
	SP	5.16	4.04	0.00	4.98	6.70
August	SI	5.16	4.04	0.00	1.90	5.10
	SP	5.16	4.04	0.00	6.92	9.30

Col. 3 : Minimum flow designated to remain in the river.
Col. 4 : From Table 4.7.
Col. 5 = Col. 4 - Col. 3
Col. 6 : From Table 4.5 (SP= SP1 + SP2)
Col. 7 = (Col. 6 - Col. 5)* Area * Irrigation Period (12hrs/day)

Note: Irrigation period for sprinkler irrigation is 12 hrs/day X 30 days per month.

Failing to irrigate for a few days would cause the water table to recede, but, water would still be able to rise by capillarity, until the water table reaches a 100 cm. In such a case, the water source is the water table. The fluctuation of the water table is not detrimental to corn growth.

The soil can serve as a water reservoir as long as the water table does not fall below 100 cm. Past that depth, the capillary conductivity is almost 0 mm/d.

Even if no storage capacity is needed, in theory, the fluctuations of the flow below the mean and the minimum flow, in July mainly, would cause a small reservoir capacity to be desirable. The dry spell in July usually lasts for a few days when flows in the river may drop below the 5.16 m^3/s minimum. Plants can obtain water by capillarity without replenishment for a few days only. The month of July is the most critical period in the growth season of corn. It is the time when water in adequate quantity can make the difference between a fair and an excellent crop, by reducing the stress on the plant during flowering, and ear filling. The volume of the reservoir would be relatively small. The size would depend on what the soil can supply and for how long, and what remains in the ditches. If subirrigation was started early in June, so the water table is approximately at 60 cm below the surface in July, the danger of a shortage of water would be reduced.

The storage capacity needed for sprinkler irrigation 4 out of 5 years is more important, 11 000 000 m^3 on the average, 20 000 000 m^3 maximum, based on maintaining a minimal flow of 5.16 m^3/s in the Yamaska

River. Of course, both values would be notably smaller if 2.6 m^3/s was used as a minimum. Then, the average storage requirements would fall to 5 000 000 m^3. Perhaps it is too conservative to set the minimum flow to 5.16 m^3/s. But, it was said previously that some flow must remain in the river to maintain wildlife, and to supply domestic and industrial needs. One could argue that most of the area downstream of St-Hyacinthe does not have many inhabitants or industries. Still, since well water is not suitable for consumption, the river remains the main source of water for the population of the basin below St-Hyacinthe. In the 5.16 m^3/s is a provision to cover future development, domestic or industrial, that could result in increased needs.

The storage capacities previously calculated were for the whole irrigable area. Another approach would have constituted in evaluating the flow and then decide which area should be irrigated, based on the land quality. This approach is more restrictive, and perhaps more economical since no storage has to be provided. The use of land would depend on its agricultural quality and on its proximity of water source. In a democratic society, such restrictions are not well received. Perhaps it is more beneficial to build a reservoir to store water from excess in March and April, for release in July, and increase the yield on a greater area. The large storms in July and August would refill part of the reservoir and meet the needs for August. Under the restrictive approach, in July, 4 900 ha could be subirrigated and another 2 400 ha irrigated with sprinklers. If all the land was to be subirrigated, 4 900 ha of additional land could be subirrigated (from another county), based on flows available, with no storage. The values of Tables 4.8 and 4.9 are based on land available if storage capacity exists. The storage needed is conditional on the daily variation of flows between the minimum and the average. To illustrate this concept hydrographs were plotted for years 1979 and 1982.

4.2.4.4 Storage Requirements from 1979 and 1982 Hydrographs.

To illustrate the variation of storage required from the calculated mean and maximum storage capacities, the hydrograph of the Yamaska river, in the months of June, July and August was plotted for years 1979 and 1982.

Year 1979 is representative of a hydrograph which is equalled or exceeded 4 years out 5, at least for the months of June and July, with an average of 6.6 m^3/s and a minimum of 4.95 m^3/s for July. On the other hand, 1982 was an extremely dry year with a minimum of 1.01 m^3/s in July It is doubtful that this recording is accurate since the flows at La Noire and Yamaska at Farnham, a few days before this minimum occured, had higher flows. It is expected that the flow at St-Hyacinthe is at least equal to the sum of the two branches and not much less downstream. It is possible, because the water level was so low, that the dam at St-Hyacinthe acted as a reservoir. In such a year, it would be difficult to remove any water in the river for irrigation, without a large storage supply available to meet the whole demand. But most of the years, sufficient flows are available. It would be rather unrealistic to try and supply the demand for a 1 in 100 year. Both hydrographs are found in Figures 4.4 and 4.5.

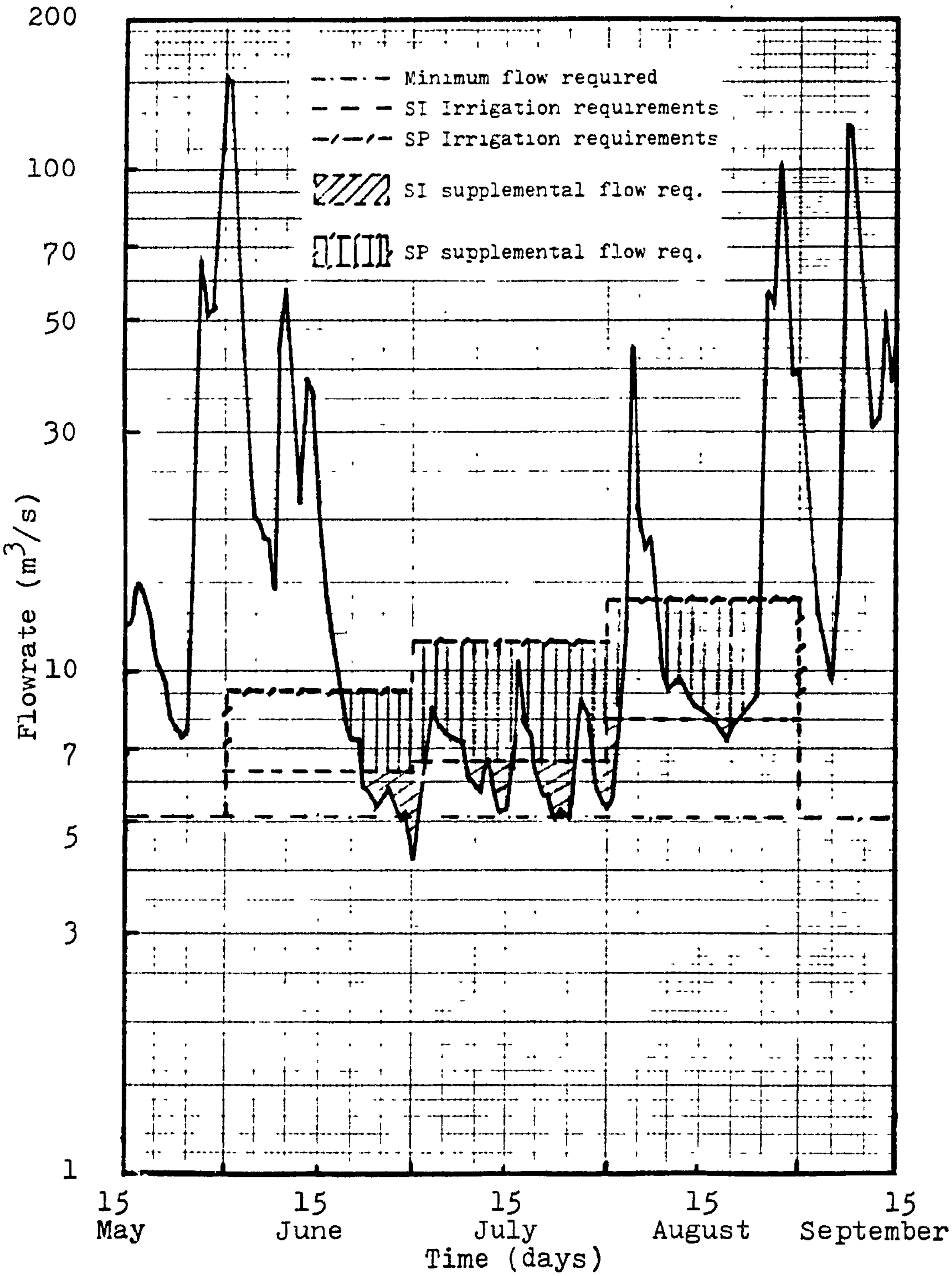


Figure4.4 Flow Hydrograph and Storage Requirements of the Yamaska River in the Summer Months of 1979

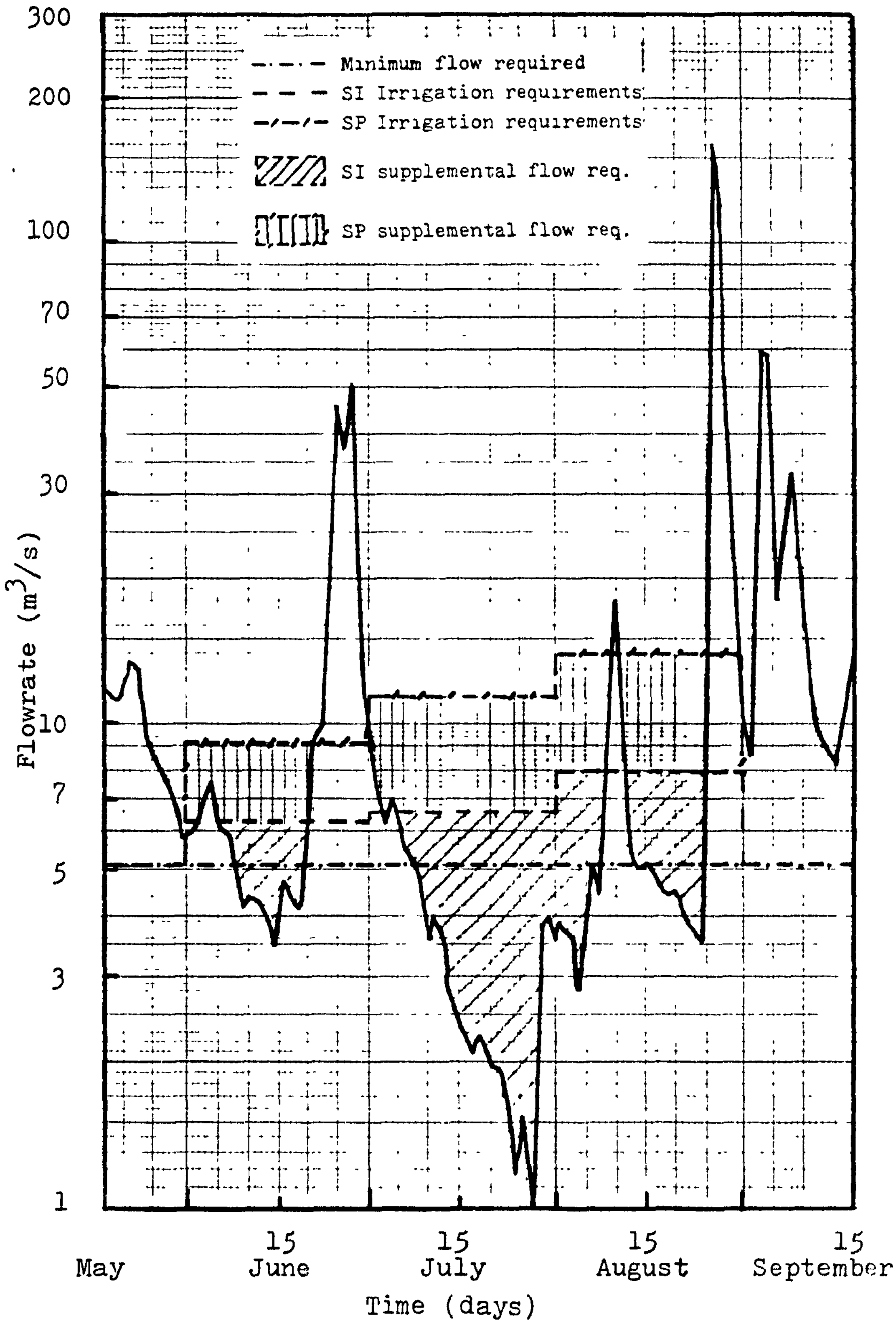


Figure 4.5 Flow Hydrograph and Storage Requirements of the Yamaska River in the Summer Months of 1982

On the hydrograph of Figures 4.4 and 4.5 were plotted the minimum flow to remain in the river, 5.16 m^3/s, and the flowrates required to meet the crop demands on the cleared area identified for irrigation. On a hydrograph, the area under the curve represents a volume of water flowing in the river over a period of time. The deficit between the flow available and the requirements was calculated by measuring the area above the hydrograph line and below the rectangular limits. Values of the storage volume measured on both hydrographs are found in table4.10.

In 1979, there would have been insufficient water to meet the complete subirrigation demand 25 days out of the 92 days of the irrigation period. Seventeen of the 25 days occured in July. The average flow could not have supplied these 25 days, unless some storage was found. The total volume of water to meet the demand was 125 280 m^3, if the minimum flow in the river had to be kept at 5.16 m^3/s. This volume, if distributed on the 25 days of deficit, would represent a flow of 0.06 m^3/s released from a reservoir. It is possible to think that, even if a deficit occured, as in 1979, that no reservoir would have to be built. Such a small volume of water could easily be supplied by the ditches and the water table in the soil. Also, the month of July 1979 was drier than a once-in-5 dry year month of July, and the volume of water required to supply the deficit larger than it would be in 4 out of 5 years. This is true if water is pumped for subirrigation only.

For sprinkler irrigation, in 1979, most of the deficit from mid June to mid July would have required a reservoir, as was expected from the calculations for the average flows. To meet the demand of sprinkler

Table 4.10 Deficit in Volume of Water Available in Yamaska River for years 1979 and 1982.

Type of Irrigation	Minimum Flow[1] Required m^3/s	Deficits[2] millions of m^3			
		1979	1982	Average[3]	Maximum[4]
Subirrigation	5.6	0.13	14.86	0.00	11.92
Sprinklers	5.6	11.60	15.68	11.00	19.86
Subirrigation	2.6	0.00	4.10	0.00	2.50
Sprinklers	2.6	6.13	13.20	4.80	17.20

1. Minimum flow designated to remain in the river.

2. Deficit: Volume of water not available from the Yamaska at a given time to satisfy the irrigation requirements of 24 677 ha of cleared land for the three summer months.

3. Deficits were calculated considering the average monthly flows occurring 4 out of 5 years in the Yamaska River at St-Hyacinthe. (Refer to Table 4.8)

4. Maximum deficits refer to those calculated using the minimum flow available in the Yamaska at St-Hyacinthe 4 years out of 5. (Refer to Table 4.9)

irrigated land, 11 000 000 m^3 of water would have had to be supplied in addition of what was available in the river. The average storage required to irrigate the SP1 and SP2 land also equalled 11 000 000 m^3. It seems that the measured deficit volumes of 1979 agree with the average volumes calculated for a constant river flow of 7.75 m^3/s. This would indicate that the average deficits, in Table 4.10, are sufficient in evaluating the 4 in 5 year additional water volume required to meet the crop needs, and to eventually size reservoir capacity.

Year 1982 was examined by curiosity. The potential of the Yamaska river cannot be determined from the hydrograph of the dry once-in-100 year. Deficits in 1982 were observed 16 days in June, the whole month of July and 12 days in August, a total of 59 days out of 92. The water volume deficit, just for subirrigation is 14 000 000 m^3, and the same for sprinkler irrigation. The reason is that all the flow required to satisfy the demand either for subirrigation or sprinkler irrigation cannot be supplied by the river. If the design of the reservoir was made to maintain a flow equal or greater than the once-in-5 dry year average, in a year like 1982, all the needs for subirrigated land would be met. There would also be 1 m^3/s left for sprinkler irrigation, enough to supply only part of the sprinkler irrigated land which, in 1982, would have required an additional river flow of 3.08 m^3/s (15 000 000 m^3 over 59 days).

4.3 Global Availability of Water for Irrigation in the Richelieu and St-Hyacinthe Counties.

Of the three sources available, the first two, Richelieu and St-Lawrence provide adequate supplies for the land located in their vicinity but also for all the area to be irrigated in both counties. However, a great proportion of the land identified is located relatively far from these two sources.

The Yamaska river is able, 4 years out of 5, to supply on the average, the demand of all the subirrigated land in its vicinity, a total of 4900 ha of cleared land. On the average, there is also water left to supply 1000 ha of sprinkler irrigated land. In the event that no water is used for sprinklers, the surplus could subirrigate an additional 4900 ha, from another county. If the 24 677 ha of cleared land in Richelieu and St-Hyacinthe counties are irrigated from the Yamaska River, there will be no water left for irrigable land in other riparian counties. Before a decision on required reservoir capacity can be reached, it is desireable to evaluate the irrigation needs of some additional counties bordering the Yamaska River.

It is obvious that a storage of water is needed for subirrigation to meet the needs in the dry month of July. A large portion of that storage is already available in the ditches and in the soil, enough to meet the needs for a few days. However one should make sure that sufficient water is available in the last half of July, when corn is flowering. At that period, the plant is very sensitive to water deficiencies. To supply adequately the plant at that time would take full advantages of the subirrigation system potential. A reservoir could easily be built to supply the subirrigation deficits of July.

A dam on the Yamaska River near Massueville could create a reservoir. Small rivers like the Salvail that are deep could also be used. These small rivers have no flow in the summer and are located in uninhabited zones. Also the spillway required for a dam on the Salvail, for example, would be much smaller. Further field and map work would be necessary to properly evaluate the potential for reservoirs in this region.

The storage of water in some ditches could be difficult to realize. Québec's legislation is clear about control structures on ditches. If the ditch is the property of a sole owner, he can use it as he wishes. If the ditch belongs to the municipality or is at the border between the properties of two farmers, care should be taken not to restrain the drainage of the fields and not to cause flooding upstream. A farmer that builds a small dam on a ditch must leave enough water in it to serve its downstream neighbour. If all parties cannot agree, another source of water will have to be found.

The most available source of water is well water. In both counties, all zones located above St-David, along the Richelieu and St-Lawrence rivers can use the well water without much problem. For the subirrigated zones located near Ste-Victoire down to St-Hyacinthe, the well water should be mixed with the fresh water supply. It would help meet the deficit in July and maintain the water table. This water should never be used with sprinklers because of its high salinity.

All the land identified for subirrigation could be supplied from the rivers in their vicinity. Of the lands identified for sprinkler irrigation, only the land located near the Richelieu and the St-Lawrence rivers could be supplied totally. Still, even if enough water is available, it will not be easy to bring it to the irrigated sites. It will constitute an administrative challenge to organize a regional irrigation project.

CHAPTER VI

SUMMARY AND CONCLUSIONS

1. Criteria were defined for the identification of land for both subirrigation and sprinkler irrigation. These criteria are:

-Soils should be deep, uniform, from a sand to a loam, at least in the layer where the drain is located, and have a hydraulic conductivity of at least 0.5 m/d. An impervious layer should lie below the drains, but at less than 2 m of the surface.

-The topography of the terrain should be flat. The general slope should be 0.5 % or less. No significant mounds and depressions should be apparent.

Only land satisfying all these criteria was classified as suitable for subirrigation.

Criteria were also defined for sprinkler irrigation. These criteria are less restrictive than those of subirrigation.

-The available water holding capacity of the soil should be equal or less than 75 mm. Soils with greater water holding capacities suffer less from drought and thus were not selected, although they could physically be irrigated.

-Topography should be as flat as possible.

2. Three classes of irrigable land were established:

- SI for subirrigation
- SP1 for sprinkler irrigation on soils with available water capacity of 50 mm or less.
- SP2 for sprinkler irrigation on soils with available water capacity between 50 and 75 mm.

3. All zones were plotted on 1 in 20 000 topographical maps. It can be seen from the maps that the blocks are grouped in a large band that extends from north east to south west, through Richelieu and St-Hyacinthe counties. This grouping of the irrigable zones makes a regional irrigation project attractive.

4. 15 000 ha of land were identified as potentially available for subirrigation. 10 000 ha of the 15 000 are cleared. The zones were distributed among 49 blocks.

5. It was difficult to assess the quality of the individual zones because of the extensive amount of data needed. Only blocks that are grouped with other irrigation zones or larger than 10 ha, if isolated, should be considered. The best zones for subirrigation are block SI-09 and SI-39. These two blocks should be given priority in development.

6. It is unrealistic to think that of all the 5 000 ha of forested land suitable for subirrigation could be brought into cultivation. Except for those bearing very good agricultural quality soils, the area should remain forested. The forested areas are mainly composed of Achigan, Ste-Sophie and St-Thomas soil series, which are not considered to be prime soils for agriculture.

7. Further research, experiments and detailed investigation could result in the modification of the block boundaries. Hence, layered soils, St-Aimé and Bellevue series, could perhaps be used for subirrigation, despite the presence of clay in the layer near the drain level. It is necessary to measure the hydraulic conductivity of the profile to find if it is greater than 0.5 m/d.

8. 8700 ha, of which 7100 ha is unforested, were found suitable for sprinkler irrigation category SP1. 7836 ha were classified in the SP2 category. 366 ha of this land is forested. Most of the land in these categories is good quality agricultural land.

9. Irrigation requirements were calculated for the once-in-5 dry year. The maximum flow needed for subirrigation, on a continuous base, was 1.909 m^3/s, and occured in August. The sprinkler irrigation period being only 12 hours per day, the irrigation flow requirement was doubled. The flow necessary from the Yamaska in August, for sprinkler irrigation alone was 6.92 m^3/s. The peak rate in August was the sum of both values, 8.82 m^3/s.

10. Either the Richelieu or St-Lawrence rivers could easily, supply the whole 35 000 ha of irrigable land of both Richelieu and St-Hyacinthe counties.

11. It is possible, with 7.75 m^3/s, to subirrigate 10 000 ha of land in this region. Presently, only 4 900 ha near the Yamaska River have been identified for subirrigation. Or, on the average, enough water flows in the Yamaska River to irrigate all the SI land in its vicinity, but only part of the land suitable for sprinkler irrigation (1 000 ha). Because of fluctuations in the flow, below the average, a small storage capacity would be needed for subirrigation. A large portion of the subirrigation water, in times of deficit, can be found in the soil and ditches, but for a few days only. It would be important to have an adequate supply available to meet the crop needs in July, the most critical period for corn.

12. There appears to be a good opportunity for a regional irrigation project. There are large blocks of flat, stone free, good quality land, in the region with the best crop climate. There is a need for irrigation for the maize, soya beans, and some other high value crops, and there is enough water in the nearby rivers.

CHAPTER VII

RECOMMENDATIONS FOR FUTURE RESEARCH

1. Investigations, as suggested in section 3.6 should be made anytime a piece of land is considered for irrigation.

2. Research should be done on the St-Aimé and Bellevue soils to assess their potential for subirrigation. Hydraulic conductivity tests should be conducted.

3. Maps of the potential of counties adjacent to the Richelieu and St-Hyacinthe counties namely Nicolet, Yamaska, Rouville, Verchères, L'Assomption and Joliette should be produced.

4. In the event new areas near the Yamaska, in adjacent counties other than the Richelieu or St-Hyacinthe counties, were suited for irrigation, studies on the availability of water should be carried out.

5. The amount of water that can possibly be stored in the ditches adjacent to the subirrigation plots should be measured. This information is important to evaluate the reserve available for non constant pumping and to estimate the benefits of catching runoff from summer rains.

6. A study should be made on the possibility of using the drainage ditches to convey the water from the rivers. This would imply the construction of many small control structures. If this solution is not possible, a route for a new canal or pipeline will have to be found.

7. Preliminary investigation should be carried out to determine possible locations of dams, to create reservoirs. Possible locations are on the Yamaska at Massueville and on the Salvail riverand other tributaries of the Yamaska River.

8. The water quality of the river, mainly for the Yamaska should be analysed, to determine if it is proper for irrigation.

9. An economic analysis on the use of subirrigation should be performed to determine the actual costs and benefits of irrigating.

10. It will be necessary to develop a regional water development plan and have a concerted approach with the farmers. It is important that cooperation of all parties concerned is achieved.

11. The effects of water withdrawal for irrigation on downstream water quantity, over the long term will have to be analysed by computer models.

APPENDIX A: Agricultural Soil Capability Classification From Inventaire des Terres du Canada, 1972 and Marshall et.al., 1979.

Extrait du rapport no. 2 de l'Inventaire des Terres du Canada (1972) intitulé "Classification des sols selon leurs aptitudes à la production agricole", pp 3-11.

Le present expose portant sur une methode de classement des sols selon leurs possibilites agricoles fait partie d'une série de rapports concernant les methodes de travail et les resultats obtenus par l'Inventaire des terres du Canada. Les objectifs, la portee et l'organisation de l'Inventaire figurent au rapport nº 1, que l'on peut se procurer aupres du ministere des Forêts du Canada.

L'Inventaire des terres du Canada est une etude complète des possibilites et des utilisations des sols a des fins diverses. Il comprend l'estimation des possibilites qu'offrent les sols pour l'agriculture, la foret, la recreation et la faune, des renseignements sur l'utilisation actuelle des terres, et l'evaluation des facteurs d'ordre social et économique qui influent sur l'utilisation des terres. L'Inventaire est une entreprise conjointe federale-provinciale dont la mise en œuvre releve de la Loi sur la remise en valeur et l'amenagement des terres agricoles (ARDA), promulguee en juin 1961.

La presente methode de classement des sols selon leurs possibilites agricoles peut s'appliquer à toutes les regions du Canada, elle a ete elaboree par le Comite national de la classification des sols, en collaboration avec l'administration féderale ARDA et celle des provinces. Grâce a l'assistance financiere de l'ARDA, les organismes affectes à l'etablissement de releves pedologiques ont adapte cette methode a tous les secteurs agricoles du Canada, ainsi qu'aux regions contigues a ces secteurs et situes en bordure des forêts.

La methode de classement est utilisee à diverses échelles, mais surtout à l'échelle de un mille au pouce. Les cartes serviront a la delimitation et a l'étude des aires pedologiques, en conjonction avec les autres renseignements recueillis par l'Inventaire. On publiera une serie de cartes en couleur a l'échelle de 1:250,000, suivant le Systeme de reference cartographique national, ces cartes offriront une vue d'ensemble des donnees recueillies au cours de ces etudes. On pourra se les procurer aupres de l'Imprimeur de la Reine, a Ottawa, au fur et à mesure que le ministere des Mines et des Releves techniques les imprimera.

Le classement des sols selon leurs possibilités

Le classement des sols selon leurs possibilites de production agricole n'est qu'une des façons d'interpreter les donnees obtenues d'études pedologiques. Comme tout groupement interpretatif, il s'elabore a partir d'unites cartographiques des sols. Dans le present classement, les sols mineraux se subdivisent en sept classes, selon leurs aptitudes ou leurs limitations en matiere de production agricole. Les sols des trois premieres classes se prêtent aux cultures ordinaires à rendement continu, ceux de la quatrième classe sont de fertilite mediocre pour l'agriculture a rendement continu, ceux de la cinquième classe se prêtent uniquement au pâturage permanent des herbages et du foin, ceux de la sixieme, uniquement au pâturage naturel, tandis que les sols et les terrains de la septieme classe (qui comprend des affleurements rocheux et des etendues d'eau trop petites pour apparaître sur les cartes) se prêtent ni a l'agriculture ni a la culture permanente des herbages. Les sols des quatre premieres classes conviennent non seulement aux cultures de labour, mais aussi a la culture des plantes fourrageres vivaces. Dans toutes les classes, les sols peuvent convenir a la forêt, a la faune et à la recreation. Pour les besoins du classement, n'entrent pas dans la definition des grandes cultures ordinaires ou des plantes cultivees, les arbres fruitiers, les arbres ordinaires, les atocas, les bleuets et les plantes d'ornement qui exigent peu ou pas de culture.

Le classement employé au Canada pour designer les possibilites agricoles des sols comprend deux categories principales, soit: 1) la classe, et 2) la sous-classe.

La *classe*, qui est la categorie la plus generale dans le classement, est un groupement de sous-classes comportant le même *degre relatif de limitation ou de risque*. Cette limitation ou ce risque s'accroit progressivement à mesure que l'on passe de la premiere a la septieme classe. La classe indique donc l'aptitude generale des sols a la production agricole.

La *sous-classe* est un groupement de sols où l'on retrouve des *limitations ou des risques de meme genre*. Elle renseigne sur le genre du problème de conservation ou de la limitation. Ensemble, la classe et la sous-classe fournissent a l'utilisateur de la carte des renseignements sur le degre et le genre de limitation, qui permettent d'établir un plan general pour l'utilisation des terres et pour l'appreciation des besoins en matiere de conservation.

Le present classement s'applique aussi bien aux terres vierges qu'aux terres presentement cultivees, a l'exception des sols organiques. Les sols sont places dans l'une ou l'autre des categories de classes ou de sous-classes a l'aide de donnees fondees sur la recherche, l'experience, et sur des observations. Dans les regions ou de tels renseignements ne sont pas disponibles, on juge des possibilites des sols à partir des caracteristiques et des observations faites en d'autres endroits sur des sols semblables. L'échelle des cartes indique le niveau de generalisation du classement des sols.

Le classement n'entend pas indiquer quelle est l'exploitation la plus avantageuse des terres, il s'agit plutôt d'un inventaire de nos ressources en terres arables et d'un guide pour le meilleur usage des terres du Canada.

Postulats

Le classement des sols se fonde sur certains postulats qui doivent être bien compris de ceux qui comptent utiliser les cartes des possibilites agricoles des sols, et qui tenteraient d'interpreter les donnees statistiques qui en découlent. Ils pourraient alors profiter pleinement des renseignements que renferment ces cartes et eviter de tirer des conclusions erronees.

1. Le classement, qui est de nature interpretative, se fonde sur la combinaison des particularites du climat et des sols, sur les limitations que les sols imposent à l'agriculture et sur la capacite generale des sols de produire de grandes cultures. On ne considere pas les arbustes, les arbres ou les souches comme etant des restrictions a moins qu'il ne soit impossible de les faire disparaitre.
2. En ce qui concerne la gestion des sols, on presuppose le recours a de bonnes methodes de gestion praticables dans une agriculture tres mecanisee.
3. Les sols compris dans une classe sont semblables pour ce qui est du degre, mais non pas du genre de limitations. Chaque classe embrasse des sols de différents genres, parmi lesquels plusieurs necessitent une gestion et des traitements differents. La sous-classe indique le genre de limitation, tandis que la classe definit l'intensite de cette limitation. La premiere classe de possibilites ne comprend aucune sous-classe. Les informations particulieres a chaque sol sont contenues dans les etudes pedologiques et autres sources de renseignements.

4. Les sols dont l'amélioration est jugée réalisable soit par le drainage, l'irrigation, l'enlèvement des pierres, la modification de leur structure ou l'érection d'ouvrages de protection contre les crues, sont classés d'après les limitations ou les risques que comporte leur usage une fois l'amélioration complétée. Le terme «réalisable» implique que le cultivateur a, dans la conjoncture économique actuelle, les moyens d'exécuter de telles améliorations, vu que ces dernières n'exigent pas la mise en œuvre de travaux importants. Dans les endroits où de telles améliorations ont été effectuées, on groupe les sols d'après les limitations qu'imposent les facteurs climatiques et pédologiques persistants. La règle générale à observer pour établir si les travaux sont d'une importance majeure, c'est que les travaux en question exigent l'action concertée de tous les cultivateurs, ou des cultivateurs et des gouvernements. Ceci ne comprend pas les petits barrages ou petites digues, ni les pratiques normales de conservation.
5. Les sols d'une région donnée peuvent changer de classe lorsque de grands travaux modifient de façon permanente les limitations imposées à l'usage des terres pour l'agriculture.
6. N'entrent pas en ligne de compte dans l'établissement des groupes de classe, la distance des marchés, l'état des routes, l'emplacement et les dimensions des fermes, le régime foncier, les modes de culture et les aptitudes ou les ressources personnelles des cultivateurs.
7. Le classement est susceptible de modifications à la suite de nouvelles données sur le comportement des sols et leurs réactions aux traitements.

Classes

Classe 1—*Les sols de la classe 1 ne comportent aucun facteur limitatif.*

Les sols de la classe 1 sont plats ou à pente très douce, profonds, bien drainés à imparfaitement drainés et dotés d'une bonne capacité de rétention de l'eau. Ils sont faciles à maintenir en culture et en productivité, étant peu endommagés par l'érosion. Leur rendement est moyennement élevé à élevé, pour une vaste gamme de grandes cultures adaptées à la région.

Classe 2—*Les sols de la classe 2 présentent des limitations modérées qui réduisent la gamme des cultures possibles ou exigent l'application de mesures ordinaires de conservation.*

Les sols de cette classe sont profonds et dotés d'une bonne capacité de rétention de l'eau. Les limitations à la culture sont d'intensité moyenne et les sols sont de gestion et de culture assez faciles. Leur rendement est moyennement élevé à élevé, pour une assez vaste gamme de grandes cultures adaptées à la région.

Dans les sols de cette classe, les limitations à la culture sont attribuables à l'un ou l'autre des facteurs suivants: climat régional défavorable, désavantages mineurs résultant de l'effet cumulatif de facteurs indésirables; dommages mineurs dus à l'érosion; mauvaise structure du sol ou défaut de perméabilité; basse fertilité pouvant être corrigée par des applications régulières de modérées d'engrais et, ordinairement, de chaux; pentes douces à modérées; crues occasionnelles nuisibles, et excès d'humidité pouvant être corrigé par le drainage, mais persistant comme limitation modérée.

En général, les sols de cette classe ne se prêtent pas à une aussi grande variété de cultures que ceux de la première classe. Ils peuvent aussi exiger de la part de l'exploitant des mesures de conservation plus intensives, des labours plus fréquents ou des techniques particulières de conservation. L'ensemble de ces techniques varient d'un endroit à l'autre en fonction du climat, des sols et des méthodes de culture adoptées dans chaque région.

Classe 3—*Les sols de la classe 3 présentent des facteurs limitatifs assez sérieux qui réduisent la gamme des cultures possibles ou nécessitent des mesures particulières de conservation.*

Les sols de cette classe comportent des limitations plus sérieuses que ceux de la deuxième classe et les mesures de conservation et d'entretien qu'il faut leur appliquer sont d'exécution plus difficiles. Si leur exploitation est bien organisée, leur rendement est moyennement ou assez élevé, pour une gamme plutôt vaste de grandes cultures adaptées à la région.

Dans cette classe, les limitations à la culture, au labour, au plantage et à la récolte, au choix des cultures, ainsi qu'à l'exécution et à la perpétuation des mesures de conservation, proviennent soit de la réunion de deux des facteurs décrits sous la deuxième classe, soit de l'un des facteurs suivants: conditions climatiques modérément défavorables, dont la susceptibilité au gel; dommages assez sérieux causés par l'érosion; sol difficile à travailler ou ayant une très lente perméabilité; fertilité médiocre nécessitant des applications de fortes quantités d'engrais et, ordinairement, de chaux; pentes modérées à raides; fréquents dommages aux récoltes causés par les crues; mauvais drainage causant, certaines années, le manque de récoltes; faible capacité de rétention de l'eau ou lenteur à fournir l'eau aux plantes; sols pierreux au point de nuire gravement à la culture et de nécessiter l'enlèvement des pierres; zone d'enracinement restreinte; salinité moyenne.

Chaque sol de cette classe peut avoir un ou plusieurs usages facultatifs ou exiger différentes techniques de culture, mais les possibilités qu'ils offrent à la culture sont moins nombreuses que celles des sols de la deuxième classe.

Classe 4—*Les sols de la classe 4 comportent des facteurs limitatifs très graves qui restreignent la gamme des cultures ou imposent des mesures spéciales de conservation ou encore présentent, à la fois, ces deux désavantages.*

Les facteurs limitatifs des sols de la classe 4 réduisent le nombre de cultures possibles, diminuent le rendement des diverses cultures et, parfois, nuisent considérablement au succès des récoltes. Ces limitations peuvent rendre plus difficiles et retarder certains travaux agricoles tels que le labour, l'ensemencement et la récolte; elles peuvent nuire aussi à l'application et à la perpétuation des mesures de conservation. Le rendement des sols de cette classe s'échelonne de faible à moyen pour une gamme restreinte de cultures, mais il se peut qu'une récolte particulièrement bien adaptée procure un rendement plus élevé.

Les limitations de cette classe sont attribuables soit aux effets défavorables de la combinaison d'au moins deux des facteurs figurant dans les deuxième et troisième classes, soit à l'une ou l'autre des causes suivantes: climat moyennement rigoureux; très faible capacité de rétention de l'eau, faible fertilité, difficile ou impossible à corriger; pentes raides; forte érosion antérieure; sol très difficile à travailler ou de perméabilité extrêmement lente; crues fréquentes, grandement nuisibles aux récoltes, forte salinité provoquant la perte de certaines récoltes, forte proportion de pierres nécessitant des travaux considérables d'épierrement pour permettre l'exploitation agricole tous les ans; zone d'enracinement très restreinte, mais plus d'un pied de sol reposant sur le roc ou sur un horizon imperméable.

Les sols de cette classe qui se trouvent dans des régions subhumides et dans certaines régions arides, peuvent donner de bonnes récoltes dans le cas de cultures propres à la région, au cours des années de forte précipitation; une récolte médiocre dans les années de précipitation moyenne, et aucune récolte lorsque la précipitation annuelle est inférieure à la moyenne. Au cours des années de faible précipitation, même si aucune récolte n'est prévue, il faut exécuter des travaux d'aménagement spéciaux afin de réduire au minimum les effets de l'érosion éolienne, de maintenir la productivité et de retenir l'humidité. Ces travaux comprennent des labours d'urgence et la culture de plantes servant surtout à empêcher les sols de se détériorer. Les sols de cette classe nécessitent de tels traitements, et d'autres encore, plus fréquents et plus intensifs que ceux de la troisième classe.

Classe 5—*Les sols de la classe 5 comportent des facteurs limitatifs tres serieux qui en restreignent l'exploitation à la culture de plantes fourrageres vivaces, mais permettent l'execution de travaux d'amelioration.*

Les sols de la classe 5 comportent des facteurs de sol, de climat et autres, tellement limitatifs qu'ils ne sauraient se prêter à la production continue de recoltes annuelles de grande culture. Toutefois, ils peuvent être ameliores par l'usage judicieux de l'outillage agricole pour la production d'especes indigenes ou domestiques de plantes fourrageres vivaces. Les travaux d'amelioration qu'on peut y executer comprennent notamment le debroussaillement, la culture, l'ensemencement, la fertilisation des terres et la regularisation de l'humidite.

Parmi les facteurs limitatifs de la classe 5 on trouve une ou plusieurs des conditions suivantes: climat rigoureux; faible capacite de retention de l'eau; forte erosion anterieure; pentes raides; mauvais drainage; crues tres frequentes; forte salinite qui ne permet que la croissance des plantes fourrageres tolérantes au sel; terrain pierreux ou sol mince surjacent au roc, au point de rendre la culture impraticable.

Certains sols de cette classe peuvent servir à la production de grandes cultures, à condition de faire l'objet de travaux agricoles plus pousses qu'à l'ordinaire; d'autres peuvent être adaptes a des cultures particulieres, telles que les bleuets, les fruits de verger ou autres cultures semblables qui exigent du sol des conditions différentes de celles qui sont necessaires aux cultures ordinaires. Là où le climat est le principal facteur limitatif, il est certes possible de faire de la grande culture sur les sols de la classe 5, mais, dans la plupart des cas, on obtient de pietres resultats.

Classe 6—*Les sols de la classe 6 sont aptes uniquement à la culture de plantes fourrageres vivaces, sans possibilite aucune d'y realiser des travaux d'amelioration.*

Les sols de cette classe comportent une certaine aptitude naturelle a la production continue de fourrage pour les animaux de ferme, mais aussi de graves limitations dues au sol, au climat ou a d'autres facteurs, lesquelles rendent impraticable la realisation des travaux d'amelioration que l'on peut executer pour les sols de la cinquième classe. La sixieme classe peut comprendre des sols dont la nature physique constitue un empechement a l'execution de travaux au moyen des machines agricoles, des sols qui ne repondent pas aux travaux d'amelioration, ou des sols comportant une breve saison de pâturage et ou les commodites pour l'abreuvage du betail sont insuffisantes. Même s'il est possible d'ameliorer ces sols par l'ensemencement et la fertilisation, soit a la main, soit en utilisant un avion, ces mesures ne sauraient modifier le classement.

Les facteurs limitatifs dans la classe 6 se rapportent à un ou plusieurs des desavantages suivants: climat tres rigoureux; tres faible capacite de retention de l'eau; pentes tres raides; terrains tres gravement erodes ou l'outillage agricole ne saurait s'employer a cause des ravins trop nombreux et trop profonds; terrains fortement salins, uniquement propres a la culture de plantes indigenes comestibles et tolerantes au sel; crues tres frequentes qui limitent la saison reelle de pâturage a moins de dix semaines; eau a la surface du sol durant la majeure partie de l'annee; terrain pierreux ou sol mince surjacent au roc, au point de rendre toute culture impraticable.

Classe 7—*Les sols de la classe 7 n'offrent aucune possibilite pour la culture ou pour le pâturage permanent.*

Les sols et les terrains de cette classe comportent des limitations si graves qu'ils ne sauraient se prêter a l'agriculture ni à l'etablissement de pâturages permanents. Toutes les etendues classees (à l'exception des sols organiques) non comprises dans les six premieres classes devront entrer dans la presente classe. On doit y faire entrer aussi toutes les etendues d'eau trop petites pour apparaitre sur les cartes.

Peu importe si les sols de cette classe offrent ou non de grandes possibilites pour la croissance des arbres, des fruits indigenes, ou pour l'amenagement de terrains propices à la faune et a la recreation. Il n'est donc pas question de tirer des conclusions sur les possibilites que presentent ces sols et categories de terrains, à part leurs aptitudes pour l'agriculture.

Sous-classes

Les sous-classes sont des subdivisions au sein des classes, qui comportent les memes facteurs limitatifs en ce qui concerne l'agriculture. On reconnait treize sortes de facteurs limitatifs se rapportant a autant de sous-classes, lesquelles se definissent et sont indiquees sur les cartes de la façon suivante

Climat défavorable (C): Cette sous-classe indique la presence d'un climat nettement defavorable a la production agricole, en regard d'un climat «median», lequel comporte par definition, au cours de la saison de croissance, des temperatures suffisamment elevees pour faire murir les grandes cultures, ainsi qu'une precipitation annuelle suffisante pour permettre aux cultures de croitre tous les ans au même emplacement sans qu'il y ait risque grave de perdre la recolte en partie ou en entier

Structure indesirable et (ou) lente permeabilite du sol (D) Cette sous-classe s'emploie dans le cas de sols difficiles a labourer, ou qui absorbent l'eau tres lentement, ou dans lesquels la zone d'enracinement est limitee en profondeur par d'autres facteurs que la presence d'une nappe phreatique elevee ou de roc solide.

Érosion (E). Cette sous-classe comprend les sols ou les dommages infliges par l'érosion constituent une limitation a la culture. On evalue les dommages selon la perte de rendement des sols et les difficultes eprouvees a cultiver des terrains ravines.

Basse fertilite (F)· Cette sous-classe denote des sols peu fertiles ou tres difficiles a ameliorer, mais pouvant etre remis en valeur grâce a l'emploi judicieux d'engrais et d'amendements. Cette limitation peut etre attribuable a une carence de substances nutritives des plantes, a la forte acidite ou alcalinite du sol, a une faible capacite d'echange, a une forte teneur en carbonate ou a la presence de composes toxiques.

Inondations causees par des cours d'eau ou des lacs (I)· Cette sous-classe comprend des sols exposes aux inondations, lesquelles causent des degâts aux recoltes ou imposent des limitations a la culture.

Manque d'humidite (M): Cette sous-classe represente des sols ou les recoltes sont affectees par la secheresse du sol en raison des particularites inherentes a ce dernier Ces sols sont generalement dotes d'une faible capacite de retention de l'eau.

Salinite (N): Cette sous-classe comprend des sols ou la teneur en sels solubles est suffisamment elevee pour affecter la croissance des cultures ou pour diminuer la diversite des recoltes qui peuvent y pousser De tels sols appartiennent au mieux a la troisieme classe.

Sols pierreux (P): Cette sous-classe comporte des sols assez pierreux pour qu'ils puissent gener sensiblement les labours, les semailles et la recolte Les sols pierreux sont ordinairement moins productifs que des sols semblables, mais non pierreux.

Roc solide (R)· Cette sous-classe s'entend des sols ou la presence de la roche solide pres de la surface en restreint l'usage pour la culture. Le roc solide gisant a plus de trois pieds de profondeur n'est pas juge nuisible a l'agriculture, sauf dans les terrains irrigues ou une couche plus profonde de sol sur le roc est souhaitable.

Caracteres défavorables des sols (S): Sur les cartes des possibilites agricoles a l'echelle de 1:250,000 la sous-classe «S» est employee pour remplacer, individuellement ou collectivement, les sous-classes «D», «F», «M» et «N». Sur les cartes a plus grande echelle, «S» peut aussi être utilise pour designer collectivement deux ou plus de ces quatre sous-classes. (Voir directives)

Relief (T): Cette sous-classe se rattache aux sols ou le relief constitue une limitation a la culture. La denivellation, ainsi que la frequence ou le mode de disposition des pentes en diverses directions, sont d'importants facteurs qui entrainent l'accroissement des frais de production agricole en regard d'un terrain plat, abaissent l'uniformite de croissance, retardent la maturation des recoltes et accroissent le danger d'érosion pluviale.

Surabondance d'eau (W): Cette sous-classe se compose de sols ou la surabondance d'eau, de provenance autre que les crues, constitue une importante limitation a la culture. Ce surplus d'eau peut être attribuable au drainage impropre des sols, a la presence d'une nappe phreatique a faible profondeur, a l'infiltration ou au ruissellement d'eau provenant des environs.

Effet cumulatif de plusieurs désavantages mineurs (X): La sous-classe «X» comprend des sols qui offrent une restriction moderee resultant de l'effet cumulatif de plusieurs desavantages qui, pris individuellement, ne sont pas assez serieux pour motiver un déclassement.

Règles à observer pour l'emploi des symboles de sous-classe et des symboles cartographiques

1. Tout symbole de sous-classe n'est utilise que si la limitation qu'il represente influe sur la determination de la classe. Cependant, deux sous-classes au plus doivent figurer sur les cartes destinees a la publication.
2. Sur les cartes, les classes sont indiquees en gros chiffres arabes; les sous-classes, au moyen de petites majuscules placees apres le chiffre de classe. Dans les unites cartographiques comportant plus d'une classe, on exprime en dixieme l'etendue relative de chaque classe. Cette proportion est indiquee par des petits chiffres arabes places en sureleve a droite du numero representant la classe.

Sols organiques*

Le classement interpretatif des sols selon leurs possibilites agricoles ne s'applique pas aux sols organiques, vu que, en general, l'insuffisance de donnees ayant trait aux regions dotees de tels sols ne permet pas de les juger sous ce rapport.

*Selon la definition adoptee par le Comite national de classification des sols, les sols organiques sont des sols qui renferment 30 p. 100 ou plus de matieres organiques et possedent une couche consolidee de debris organiques d'au moins 12 pouces de profondeur.

Table A1 Limiting Pedological Factors.

MAJEUR	MODERE	MINEUR
D': Sol massif, faible structure et/ou consistance ferme à très ferme dans la couche du labour et dans le sous-sol causant une aération insuffisante, une absorption et une distribution lente de l'humidité. Le sol de surface est difficile à cultiver, la préparation du lit de semence requiert des travaux spéciaux et en conditions humides, la trafficabilité pour les instruments aratoires est faible	D: Sol massif, faible structure, et/ou consistance ferme causant une aération et une pénétration des racines faible, principalement dans le sous-sol.	d: Structure indésirable causant des problèmes d'aération et de perméabilité de l'eau, mineurs.
F': Bilan nutritif et capacité d'échange cationique très faible dus à une très faible quantité de matière organique et/ou à un faible contenu en argile; débalancement nutritif très sévère résultant de la forte acidité (pH < 4.5) ou alcalinité (pH > 7.6) dans la couche de labour.	F: Taux de matière organique faible et/ou faible contenu en argile induisant un bilan nutritif faible et/ou un débalancement nutritif modéré; acidité (4.5 à 5.5) ou alcalinité (7.4 - 7.6) de la couche de labour restreignant la croissance de certaines plantes.	f: Débalancement nutritif mineur, manque de matière organique et réaction (pH) légèrement acide (5.5 - 5.8) ou alcaline (6.8 - 7.4) affectant seulement quelques plantes. Besoin en chaux modéré.
I': Inondation fréquente de durée prolongée (> 5 jours) durant la saison de végétation; les inondations dues aux débordements printaniers dans la plaine d'inondation ne sont pas considérées ici.	I: Inondation occasionnelle de courte durée (< 5 jours) résultant en une nappe phreatique élevée de longue durée (> 5 jours).	i: Inondation occasionnelle, très brève (1 jour) et nappe phréatique très élevée et affectant seulement les plantes à racines profondes comme la luzerne. Souvent utilisé avec W' pour indiquer la possibilité d'inondation locale.

Table A1 Limiting Pedological Factors. (cont'd)

MAJEUR	MODÉRÉ	MINEUR
M': Manque d'humidité du sol dans les sols sableux à graveleux bien à excessivement drainés exigeant de l'irrigation pour la production normale de culture sous des conditions de température moyenne. De tels sols sont exposés à l'érosion éolienne lorsque non irrigés et non protégés par de la végétation, des brise-vents ou une culture en bande.	M: Manque d'humidité du sol dans les sols bien à excessivement drainés, constitués de sable loameux et de loam sableux grossier, de même que dans les sols constitués de loam sableux fin et loam sus-jacent à un matériel sableux ou graveleux. Sans irrigation, les rendements des cultures peuvent être économiquement acceptables en saison normale à humide, mais non en saison sèche.	m: Manque d'humidité du sol dans les sols bien drainés constitués de loam sableux fin ou loam, spécialement ceux ayant un substratum de texture fine. De bonnes pratiques de conservation de l'humidité du sol résultent en rendements acceptables sous des conditions climatiques moyennes.
P': Sols suffisamment pierreux (3 à 15% de la surface) pour augmenter suffisamment les difficultés de travail du sol, de semis et de récolte.	P: Sols de pierrosité 2 (0.1 à 3% de la surface) causant une nuisance mineure aux opérations de préparation du sol, semis et récolte.	p: Sols de pierrosité 1 (0.1 % de la surface). Ceci s'applique principalement aux sols pierreux sur lesquels des travaux d'épierrement ont été réalisés mais dont l'enlèvement des pierres doit être continué occasionnellement.
R': Le roc consolidé et dur est rencontré à moins de 0.5 m avec des affleurements couvrant plus de 10% de la surface.	R: Le roc consolidé et dur est rencontré entre 0.5 m et 1.0 m, avec des affleurements couvrant moins de 10% de la surface, ou le roc tendre et faiblement consolidé (schiste argileux et métamorphique) est rencontrée entre 30 cm et 1 m avec des affleurements couvrant moins de 20% de la surface.	r: Le roc consolidé et dur est rencontré à plus de 1.0 m, ou le roc non consolidé et tendre (schiste argileux et métamorphique) est rencontré entre 50 cm et 1 m affectant la distribution de l'humidité, la pierrosité, etc.

Table A1 Limiting Pedological Factors. (cont'd)

MAJEUR	MODERE	MINEUR
T': Pentes (< 100 m) plus abruptes que 9% affectant la capacité du travail de la machinerie et nécessitant des mesures de protection contre l'érosion hydrique.	T: Pentes (< 100 m) moins abruptes que 9%, interférant légèrement avec l'utilisation de machinerie agricole et nécessitant quelques pratiques spéciales anti-érosives.	t: Pentes de 3 à 6% n'interférant pas avec l'utilisation de la machinerie agricole mais causant une érosion hydrique légère et/ou un manque d'uniformité dans la distribution de l'humidité, la germination de la semence et la croissance des plantes. Lorsqu'utilisé entre parenthèses (t), les pentes ne sont pas considerées dans le classement.
V': Variations répétitives dans le drainage de deux ou plusieurs classes de drainage à l'intérieur d'un cycle de moins de 50 m et ayant une amplitude de 1 m et plus. Le drainage varie généralement de rapide au sommet des ondulations à pauvre dans les dépressions. Dans les sols sableux, l'érosion éolienne est quelquefois un problème au sommet de l'ondulation.	V: Variations répétitives dans le drainage d'une classe de drainage à l'intérieur d'un cycle de plus de 50 m et ayant une amplitude de moins de 1 m du sommet de l'ondulation au creux de la dépression. Le drainage varie généralement de bas à imparfait.	v: Toute variation (répétitive ou non) du drainage à l'intérieur de très courtes distances (< 100 m) résultant en un manque d'uniformité visible de la culture. Utilisé avec W', W et w ou M', M et m comme modificateur pour indiquer des variations de drainage à l'intérieur des unités cartographiques.
W': Humidité excessive ou drainage très pauvre généralement dû à la formation d'étang, au suintement ou à un sous-sol imperméable. L'humidité excessive peut atteindre la surface et persister suffisamment pour asphyxier les plantes. Des dommages mortels aux plantes sont fréquents dus à la formation de glace en surface durant la saison froide.	W: L'humidité ou le drainage mauvais à imparfait sur des terrains plats à légèrement ondulés. Se rencontre normalement sur des sols argileux ou sur des sols poreux reposant sur un substratum plat imperméable.	w: Humidité périodique ou drainage imparfait sur des terrains en pente. Se rencontre au milieu et en bas de pente des sols morainiques avoisinant les crêtes morainiques.

APPENDIX 8: Available Water Holding Capacities of Mineral Soils of the St-Lawrence Lowlands

by Nolin and Lamontagne, 1986.

Table B1 Available Water in the Root Zone of Soils in the St-Lawrence Lowlands (Nolin and Lamontagne, 1986).

SYMBOLE DE L'UNITE DE LA CARTE	SURFACE (0-25 cm) HUMIDITE POND. (%)			SOUS-SOL 1 HUMIDITE POND. (%)			MATERIAU HOMOGENE PROFOND EAU UTILE TOTALE (cm)			CLASSIFICATION		
	MIN.	MAX.	MOY.	MIN.	MAX.	MOY.	MIN.	MAX.	MOY.	MIN.	MAX.	MOY.
MV1CPM	6.0	9.0	7.5	3.0	7.0	5.0	2.25	4.00	3.13	1	2	2
RG1B	4.0	9.0	6.5	3.0	7.0	5.0	1.75	4.00	2.88	1	2	1
HE2	9.0	14.0	11.5	2.0	8.0	5.0	2.75	5.50	4.13	1	2	2
HE2GP	6.0	12.0	9.0	2.0	8.0	5.0	2.00	5.00	3.50	1	2	2
RG2	10.0	12.0	11.0	3.0	7.0	5.0	3.25	4.75	4.00	2	2	2
AI2	12.0	16.0	14.0	12.0	24.0	18.0	6.00	10.00	8.00	2	4	3
AIA2	12.0	16.0	14.0	12.0	24.0	18.0	6.00	10.00	8.00	2	4	3
BL2	12.0	16.0	14.0	11.0	20.0	15.5	5.75	9.00	7.38	2	3	3
BR2	12.0	16.0	14.0	12.0	16.0	14.0	6.00	8.00	7.00	2	3	3
BR2W	12.0	16.0	14.0	12.0	16.0	14.0	6.00	8.00	7.00	2	3	3
RS2	12.0	16.0	14.0	11.0	20.0	15.5	5.75	9.00	7.38	2	3	3
AI3	16.0	24.0	20.0	12.0	24.0	18.0	7.00	12.00	9.50	3	4	4
AIA3	16.0	24.0	20.0	12.0	24.0	18.0	7.00	12.00	9.50	3	4	4
AIA3B	16.0	24.0	20.0	12.0	24.0	18.0	7.00	12.00	9.50	3	4	4
AIA3W	16.0	24.0	20.0	12.0	24.0	18.0	7.00	12.00	9.50	3	4	4
BL3	16.0	24.0	20.0	11.0	20.0	15.5	6.75	11.00	8.88	3	4	3
BR3	16.0	24.0	20.0	12.0	16.0	14.0	7.00	10.00	8.50	3	4	3
BR3W	16.0	24.0	20.0	12.0	16.0	14.0	7.00	10.00	8.50	3	4	3
BR3M	16.0	24.0	20.0	12.0	16.0	14.0	7.00	10.00	8.50	3	4	3
CE3	16.0	24.0	20.0	11.0	20.0	15.5	6.75	11.00	8.88	3	4	3
CM3	16.0	24.0	20.0	11.0	20.0	15.5	6.75	11.00	8.38	3	4	3
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
PO3	16.0	24.0	20.0	11.0	18.0	14.5	6.75	10.50	8.63	3	4	3
RS3	16.0	24.0	20.0	11.0	20.0	15.5	6.75	11.00	8.38	3	4	3
RS3B	16.0	24.0	20.0	11.0	20.0	15.5	6.75	11.00	8.88	3	4	3
RS3M	16.0	24.0	20.0	11.0	20.0	15.5	6.75	11.00	8.88	3	4	3
RS3W	16.0	24.0	20.0	11.0	20.0	15.5	6.75	11.00	8.88	3	4	3
AIA4	24.0	28.0	26.0	12.0	24.0	18.0	9.00	13.00	11.00	3	5	4
CM4	24.0	28.0	26.0	11.0	20.0	15.5	8.75	12.00	10.38	3	4	4
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
AIA3H	14.0	20.0	17.0	12.0	24.0	18.0	6.50	11.00	8.75	3	4	3
BL3H	14.0	20.0	17.0	11.0	20.0	15.5	6.25	10.00	8.13	3	4	3
PO3H	14.0	20.0	17.0	11.0	18.0	14.5	6.25	9.50	7.88	3	4	3
DJA3	13.0	28.0	20.5	15.0	27.0	21.0	7.00	13.75	10.38	3	5	4
JI3	13.0	28.0	20.5	7.0	20.0	13.5	5.00	12.00	8.50	2	4	3
JI3M	13.0	28.0	20.5	7.0	20.0	13.5	5.00	12.00	8.50	2	4	3
JI3PM	13.0	28.0	20.5	7.0	20.0	13.5	5.00	12.00	8.50	2	4	3
DJA4	21.0	29.0	25.0	15.0	27.0	21.0	9.00	14.00	11.50	3	5	4
JI4	21.0	29.0	25.0	7.0	20.0	13.5	7.00	12.25	9.63	3	5	4
JI4M	21.0	29.0	25.0	7.0	20.0	13.5	7.00	12.25	9.63	3	5	4

Table B1 Available Water in the Root Zone of Soils in the St-Lawrence Lowlands (Nolin and Lamontagne, 1986). (cont'd)

SYMBOLE DE L'UNITE DE LA CARTE	SURFACE (0-25 cm) HUMIDITE POND. (%)			SOUS-SOL 1 HUMIDITE POND. (%)			SOUS-SOL 2 HUMIDITE POND. (%)			MATERIAU CONTRASTANT PROFOND (LEGER/LOURD) EAU UTILE TOTALE (cm)			CLASSIFICATION		
	MIN.	MAX.	MOY.	MIN.	MAX.	MOY.	MIN.	MAX.	MOY.	MIN.	MAX.	MOY.	MIN.	MAX.	MOY.
AS1	8.0	14.0	11.0	4.0	8.0	6.0	20.0	28.0	24.0	3.00	8.50	4.25	1	3	2
ASA1	8.0	14.0	11.0	4.0	8.0	6.0	20.0	28.0	24.0	3.00	8.50	4.25	1	3	2
DG1	8.0	14.0	11.0	4.0	8.0	6.0	20.0	28.0	24.0	3.00	8.50	4.25	1	3	2
DA1	8.0	14.0	11.0	4.0	10.0	7.0	20.0	28.0	24.0	3.00	8.70	4.50	1	3	2
DA1W	8.0	14.0	11.0	4.0	10.0	7.0	20.0	28.0	24.0	3.00	8.70	4.50	1	3	2
PS1	8.0	14.0	11.0	8.0	12.0	10.0	20.0	28.0	24.0	4.00	8.90	5.25	2	3	2
PS1W	8.0	14.0	11.0	8.0	12.0	10.0	20.0	28.0	24.0	4.00	8.90	5.25	2	3	2
AS2	12.0	16.0	14.0	4.0	8.0	6.0	20.0	28.0	24.0	4.00	9.00	5.00	2	3	2
ASA2	12.0	16.0	14.0	4.0	8.0	6.0	20.0	28.0	24.0	4.00	9.00	5.00	2	3	2
DG2	12.0	16.0	14.0	4.0	8.0	6.0	20.0	28.0	24.0	4.00	9.00	5.00	2	3	2
DA2	12.0	16.0	14.0	4.0	10.0	7.0	20.0	28.0	24.0	4.00	9.20	5.25	2	4	2
PS2	12.0	16.0	14.0	8.0	12.0	10.0	20.0	28.0	24.0	5.00	9.40	6.00	2	4	2
AS3	16.0	18.0	17.0	4.0	8.0	6.0	20.0	28.0	24.0	5.00	9.50	5.75	2	4	2
ASA3	16.0	18.0	17.0	4.0	8.0	6.0	20.0	28.0	24.0	5.00	9.50	5.75	2	4	2
DG3	16.0	18.0	17.0	4.0	8.0	6.0	20.0	28.0	24.0	5.00	9.50	5.75	2	4	2
AIB2	12.0	16.0	14.0	12.0	24.0	18.0	20.0	28.0	24.0	6.00	10.60	8.00	2	4	3
CBA2	12.0	16.0	14.0	11.0	20.0	15.5	20.0	28.0	24.0	5.75	10.20	7.38	2	4	3
YK2	12.0	16.0	14.0	12.0	16.0	14.0	20.0	28.0	24.0	6.00	9.80	7.00	2	4	3
YK2W	12.0	16.0	14.0	12.0	16.0	14.0	20.0	28.0	24.0	6.00	9.80	7.00	2	4	3
AIB3	16.0	24.0	20.0	12.0	24.0	18.0	20.0	28.0	24.0	7.00	12.60	9.50	3	5	4
AIC3	16.0	24.0	20.0	12.0	24.0	18.0	20.0	28.0	24.0	7.00	12.60	9.50	3	5	4
CB3	16.0	24.0	20.0	11.0	20.0	15.5	20.0	28.0	24.0	6.75	12.20	8.88	3	5	3
CBA3	16.0	24.0	20.0	11.0	20.0	15.5	20.0	28.0	24.0	6.75	12.20	8.88	3	5	3
PC3	16.0	18.0	17.0	11.0	20.0	15.5	20.0	28.0	24.0	6.75	10.70	8.13	3	4	3
YK3	16.0	24.0	20.0	12.0	16.0	14.0	20.0	28.0	24.0	7.00	11.80	8.50	3	4	3
YK3W	16.0	24.0	20.0	12.0	16.0	14.0	20.0	28.0	24.0	7.00	11.80	8.50	3	4	3
AIB4	24.0	28.0	26.0	12.0	24.0	18.0	20.0	28.0	24.0	9.00	13.60	11.00	3	5	4
AIC4	24.0	28.0	26.0	12.0	24.0	18.0	20.0	28.0	24.0	9.00	13.60	11.00	3	5	4
CB4	24.0	28.0	26.0	11.0	20.0	15.5	20.0	28.0	24.0	8.75	13.20	10.38	3	5	4
CBA4	24.0	28.0	26.0	11.0	20.0	15.5	20.0	28.0	24.0	8.75	13.20	10.38	3	5	4
PC3H	14.0	20.0	17.0	11.0	20.0	15.5	20.0	28.0	24.0	6.25	11.20	8.13	3	4	3
CL2GP	8.0	14.0	11.0	4.0	11.0	7.5	20.0	28.0	24.0	3.00	8.80	4.63	1	3	2
CT2	10.0	16.0	13.0	5.0	14.0	9.5	20.0	28.0	24.0	3.75	9.60	5.63	2	4	2
CT2GP	8.0	14.0	11.0	4.0	12.0	8.0	20.0	28.0	24.0	3.00	8.90	4.75	1	3	2
DR2	10.0	16.0	13.0	5.0	14.0	9.5	20.0	28.0	24.0	3.75	9.60	5.63	2	4	2
DC2	10.0	16.0	13.0	5.0	16.0	10.5	20.0	28.0	24.0	3.75	9.80	5.88	2	4	2
DC2B	10.0	16.0	13.0	5.0	16.0	10.5	20.0	28.0	24.0	3.75	9.80	5.88	2	4	2
CL3GP	10.0	18.0	14.0	4.0	11.0	7.5	20.0	28.0	24.0	3.50	9.80	5.38	2	4	2
CT3	13.0	23.0	18.0	5.0	14.0	9.5	20.0	28.0	24.0	4.50	11.35	6.88	2	4	3
CT3GP	10.0	18.0	14.0	4.0	12.0	8.0	20.0	28.0	24.0	3.50	9.90	5.50	2	4	2
DR3	13.0	23.0	18.0	5.0	14.0	9.5	20.0	28.0	24.0	4.50	11.35	6.88	2	4	3
DC3	13.0	23.0	18.0	5.0	16.0	10.5	20.0	28.0	24.0	4.50	11.55	7.13	2	4	3
DC3B	13.0	23.0	18.0	5.0	16.0	10.5	20.0	28.0	24.0	4.50	11.55	7.13	2	4	3
DJ3	13.0	28.0	20.5	22.0	28.0	25.0	20.0	28.0	24.0	8.75	14.00	11.38	3	5	4
DJ3B	13.0	28.0	20.5	22.0	28.0	25.0	20.0	28.0	24.0	8.75	14.00	11.38	3	5	4
DJC3	13.0	28.0	20.5	22.0	28.0	25.0	20.0	28.0	24.0	8.75	14.00	11.38	3	5	4
DJ4	21.0	29.0	25.0	22.0	28.0	25.0	20.0	28.0	24.0	10.75	14.25	12.50	4	5	5
DJ4B	21.0	29.0	25.0	22.0	28.0	25.0	20.0	28.0	24.0	10.75	14.25	12.50	4	5	5
DJ4P	21.0	29.0	25.0	22.0	28.0	25.0	20.0	28.0	24.0	10.75	14.25	12.50	4	5	5

Table B1 Available Water in the Root Zone of Soils in the St-Lawrence Lowlands (Nolin and Lamontagne, 1986). (cont'd)

SYMBOLE DE L'UNITE DE LA CARTE	SURFACE (0-25 cm) HUMIDITE POND. (%)			SOUS-SOL 1 HUMIDITE POND. (%)			SOUS-SOL 2 HUMIDITE POND. (%)			MATERIAU CONTRASTANT PROFOND (LOURD/LEGER) EAU UTILE TOTALE (cm)			CLASSIFICATION		
	MIN.	MAX.	MOY.	MIN.	MAX.	MOY.	MIN.	MAX.	MOY.	MIN.	MAX.	MOY.	MIN.	MAX.	MOY.
HU3	16.0	24.0	20.0	18.0	28.0	23.0	4.0	8.0	6.0	6.40	13.00	10.75	3	5	4
HU3P	16.0	24.0	20.0	18.0	28.0	23.0	4.0	8.0	6.0	6.40	13.00	10.75	3	5	4
LGR3M	16.0	24.0	20.0	18.0	28.0	23.0	7.0	20.0	13.5	6.85	13.00	10.75	3	5	4
SB3	16.0	24.0	20.0	18.0	28.0	23.0	12.0	28.0	20.0	7.60	13.00	10.75	3	5	4
SBA3	16.0	24.0	20.0	18.0	28.0	23.0	12.0	28.0	20.0	7.60	13.00	10.75	3	5	4
SV3	16.0	24.0	20.0	18.0	28.0	23.0	6.0	11.0	8.5	6.70	13.00	10.75	3	5	4
SVA3	16.0	24.0	20.0	18.0	28.0	23.0	6.0	11.0	8.5	6.70	13.00	10.75	3	5	4
HU4	24.0	28.0	26.0	18.0	28.0	23.0	4.0	8.0	6.0	8.40	14.00	12.25	3	5	5
HU4M	24.0	28.0	26.0	18.0	28.0	23.0	4.0	8.0	6.0	8.40	14.00	12.25	3	5	5
HUA4	24.0	28.0	26.0	18.0	28.0	23.0	4.0	8.0	6.0	8.40	14.00	12.25	3	5	5
LGB4	24.0	28.0	26.0	18.0	28.0	23.0	7.0	20.0	13.5	8.85	14.00	12.25	3	5	5
LGB4M	24.0	28.0	26.0	18.0	28.0	23.0	7.0	20.0	13.5	8.85	14.00	12.25	3	5	5
SB4	24.0	28.0	26.0	18.0	28.0	23.0	12.0	28.0	20.0	9.60	14.00	12.25	4	5	5
SB4M	24.0	28.0	26.0	18.0	28.0	23.0	12.0	28.0	20.0	9.60	14.00	12.25	4	5	5
SBA4	24.0	28.0	26.0	18.0	28.0	23.0	12.0	28.0	20.0	9.60	14.00	12.25	4	5	5
SV4	24.0	28.0	26.0	18.0	28.0	23.0	6.0	11.0	8.5	8.70	14.00	12.25	3	5	5
SV4M	24.0	28.0	26.0	18.0	28.0	23.0	6.0	11.0	8.5	8.70	14.00	12.25	3	5	5
SVA4	24.0	28.0	26.0	18.0	28.0	23.0	6.0	11.0	8.5	8.70	14.00	12.25	3	5	5
SB5	22.0	28.0	25.0	18.0	28.0	23.0	12.0	28.0	20.0	9.10	14.00	12.00	4	5	4
SB5M	22.0	28.0	25.0	18.0	28.0	23.0	12.0	28.0	20.0	9.10	14.00	12.00	4	5	4
SV5	22.0	28.0	25.0	18.0	28.0	23.0	6.0	11.0	8.5	8.20	14.00	12.00	3	5	4
HU3H	14.0	20.0	17.0	18.0	28.0	23.0	4.0	8.0	6.0	5.90	12.00	10.00	2	4	4
SB3H	14.0	20.0	17.0	18.0	28.0	23.0	12.0	28.0	20.0	7.10	12.00	10.00	3	4	4
SV4HM	24.0	36.0	30.0	18.0	28.0	23.0	6.0	11.0	8.5	8.70	16.00	13.25	3	5	5
DF5	22.0	28.0	25.0	20.0	28.0	24.0	16.0	30.0	23.0	9.90	14.00	12.25	4	5	5
DF5H	24.0	36.0	30.0	20.0	28.0	24.0	16.0	30.0	23.0	10.40	16.00	13.50	4	5	5
DU3	16.0	24.0	20.0	20.0	28.0	24.0	12.0	24.0	18.0	7.80	13.00	11.00	3	5	4
DUA3	16.0	24.0	20.0	20.0	28.0	24.0	12.0	24.0	18.0	7.80	13.00	11.00	3	5	4
DU4	24.0	28.0	26.0	20.0	28.0	24.0	12.0	24.0	18.0	9.80	14.00	12.50	4	5	5
DM4	24.0	28.0	26.0	20.0	28.0	24.0	8.0	12.0	10.0	9.20	14.00	12.50	4	5	5
RH4	24.0	28.0	26.0	20.0	28.0	24.0	4.0	8.0	6.0	8.60	14.00	12.50	3	5	5
RH5	22.0	28.0	25.0	20.0	28.0	24.0	4.0	8.0	6.0	8.10	14.00	12.25	3	5	5

Table B1 Available Water in the Root Zone of Soils in the St-Lawrence Lowlands (Nolin and Lamontagne, 1986). (cont'd)

SYMBOLE DE L'UNITE DE LA CARTE	SURFACE (0-25 cm) HUMIDITE POND. (%)			SOUS-SOL 1 HUMIDITE POND. (%)			SOUS-SOL 2 HUMIDITE POND. (%)			MATERIAU CONTRASTANT PROFOND (LEGER/LOURD) EAU UTILE TOTALE (cm)			CLASSIFICATION		
	MIN.	MAX.	MOY.	MIN.	MAX.	MOY.	MIN.	MAX.	MOY.	MIN.	MAX.	MOY.	MIN.	MAX.	MOY.
FY1	8.0	14.0	11.0	4.0	8.0	6.0	12.0	24.0	18.0	3.00	7.90	4.25	1	3	2
FYA1	8.0	14.0	11.0	4.0	8.0	6.0	12.0	24.0	18.0	3.00	7.90	4.25	1	3	2
MC1	8.0	14.0	11.0	4.0	10.0	7.0	12.0	24.0	18.0	3.00	8.10	4.50	1	3	2
SL1	8.0	14.0	11.0	8.0	12.0	10.0	12.0	24.0	18.0	4.00	8.30	5.25	2	3	2
FY2	12.0	16.0	14.0	4.0	8.0	6.0	12.0	24.0	18.0	4.00	8.40	5.00	2	3	2
FYA2	12.0	16.0	14.0	4.0	8.0	6.0	12.0	24.0	18.0	4.00	8.40	5.00	2	3	2
MC2	12.0	16.0	14.0	4.0	10.0	7.0	12.0	24.0	18.0	4.00	8.60	5.25	2	3	2
MC2N	12.0	16.0	14.0	4.0	10.0	7.0	12.0	24.0	18.0	4.00	8.60	5.25	2	3	2
SL2	12.0	16.0	14.0	8.0	12.0	10.0	12.0	24.0	18.0	5.00	8.80	6.00	2	3	2
FY3	16.0	18.0	17.0	4.0	8.0	6.0	12.0	24.0	18.0	5.00	8.90	5.75	2	3	2
MC3	16.0	18.0	17.0	4.0	10.0	7.0	12.0	24.0	18.0	5.00	9.10	6.00	2	4	2
CT82	10.0	16.0	13.0	5.0	14.0	9.5	12.0	24.0	18.0	3.75	9.00	5.63	2	3	2
CL826P	8.0	14.0	11.0	4.0	11.0	7.5	12.0	24.0	18.0	3.00	8.20	4.63	1	3	2
DJ83	13.0	28.0	20.5	22.0	28.0	25.0	12.0	24.0	18.0	8.75	13.40	11.38	3	5	4

Table B1 Available Water in the Root Zone of Soils in the St-Lawrence Lowlands (Nolin and Lamontagne, 1986). (cont'd)

SYMBOLE DE L'UNITE DE LA CARTE	SURFACE (0-25 cm) HUMIDITE POND. (%)			SOUS-SOL I HUMIDITE POND. (%)			MATERIAU HOMOGENE PROFOND EAU UTILE TOTALE (cm)			CLASSIFICATION		
	MIN.	MAX.	MOY.	MIN.	MAX.	MOY.	MIN.	MAX.	MOY.	MIN.	MAX.	MOY.
JS1	8.0	14.0	11.0	4.0	8.0	6.0	3.00	5.50	4.25	1	2	2
MO1	8.0	14.0	11.0	4.0	8.0	6.0	3.00	5.50	4.25	1	2	2
MS1	8.0	14.0	11.0	4.0	10.0	7.0	3.00	6.00	4.50	1	2	2
PR1	8.0	14.0	11.0	4.0	12.0	8.0	3.00	6.50	4.75	1	3	2
TH1	8.0	14.0	11.0	4.0	10.0	7.0	3.00	6.00	4.50	1	2	2
TH18	8.0	14.0	11.0	4.0	10.0	7.0	3.00	6.00	4.50	1	2	2
SP1	8.0	14.0	11.0	4.0	10.0	7.0	3.00	6.00	4.50	1	2	2
SP18	8.0	14.0	11.0	4.0	10.0	7.0	3.00	6.00	4.50	1	2	2
AC1	8.0	14.0	11.0	8.0	16.0	12.0	4.00	7.50	5.75	2	3	2
JU1	8.0	14.0	11.0	8.0	12.0	10.0	4.00	6.50	5.25	2	3	2
JS2	12.0	16.0	14.0	4.0	8.0	6.0	4.00	6.00	5.00	2	2	2
MO2	12.0	16.0	14.0	4.0	8.0	6.0	4.00	6.00	5.00	2	2	2
MS2	12.0	16.0	14.0	4.0	10.0	7.0	4.00	6.50	5.25	2	3	2
PR2	12.0	16.0	14.0	4.0	12.0	8.0	4.00	7.00	5.50	2	3	2
TH2	12.0	16.0	14.0	4.0	10.0	7.0	4.00	6.50	5.25	2	3	2
PI2	12.0	16.0	14.0	8.0	12.0	10.0	5.00	7.00	6.00	2	3	2
SM2	12.0	16.0	14.0	4.0	8.0	6.0	4.00	6.00	5.00	2	2	2
JU2	12.0	16.0	14.0	8.0	12.0	10.0	5.00	7.00	6.00	2	3	2
JS2H	14.0	18.0	16.0	4.0	8.0	6.0	4.50	6.50	5.50	2	3	2
JS3	16.0	18.0	17.0	4.0	8.0	6.0	5.00	6.50	5.75	2	3	2
PI3	16.0	18.0	17.0	8.0	12.0	10.0	6.00	7.50	6.75	2	3	3
PIT	14.0	18.0	16.0	8.0	12.0	10.0	5.50	7.50	6.50	2	3	3
SMT	14.0	18.0	16.0	4.0	8.0	6.0	4.50	6.50	5.50	2	3	2

Table B1 Available Water in the Root Zone of Soils in the St-Lawrence Lowlands (Nolin and Lamontagne, 1986). (cont'd)

SYMBOLE DE L'UNITE DE LA CARTE	SURFACE (0-25 cm)			SOUS-SOL 1			MATERIAU HOMOGENE PROFOND					
	HUMIDITE POND. (%)			HUMIDITE POND. (%)			EAU UTILE TOTALE (cm)			CLASSIFICATION		
	MIN.	MAX.	MOY.	MIN.	MAX.	MOY.	MIN.	MAX.	MOY.	MIN.	MAX.	MOY.
KI2	12.0	16.0	14.0	20.0	28.0	24.0	8.00	11.00	9.50	3	4	4
KIB2	12.0	16.0	14.0	20.0	28.0	24.0	8.00	11.00	9.50	3	4	4
BHA3	16.0	24.0	20.0	20.0	28.0	24.0	9.00	13.00	11.00	3	5	4
KI3	16.0	24.0	20.0	20.0	28.0	24.0	9.00	13.00	11.00	3	5	4
KIB3	16.0	24.0	20.0	20.0	28.0	24.0	9.00	13.00	11.00	3	5	4
BH4	24.0	28.0	26.0	20.0	28.0	24.0	11.00	14.00	12.50	4	5	5
CH4	24.0	28.0	26.0	20.0	28.0	24.0	11.00	14.00	12.50	4	5	5
KI4	24.0	28.0	26.0	20.0	28.0	24.0	11.00	14.00	12.50	4	5	5
LR4	24.0	28.0	26.0	20.0	28.0	24.0	11.00	14.00	12.50	4	5	5
LR4B	24.0	28.0	26.0	20.0	28.0	24.0	11.00	14.00	12.50	4	5	5
CH5	22.0	28.0	25.0	20.0	28.0	24.0	10.50	14.00	12.25	4	5	5
LR5	22.0	28.0	25.0	20.0	28.0	24.0	10.50	14.00	12.25	4	5	5
HY2	12.0	16.0	14.0	20.0	28.0	24.0	8.00	11.00	9.50	3	4	4
KIA2	12.0	16.0	14.0	20.0	28.0	24.0	8.00	11.00	9.50	3	4	4
MA2	12.0	16.0	14.0	20.0	28.0	24.0	8.00	11.00	9.50	3	4	4
HY3	16.0	24.0	20.0	20.0	28.0	24.0	9.00	13.00	11.00	3	5	4
HYB3	16.0	24.0	20.0	20.0	28.0	24.0	9.00	13.00	11.00	3	5	4
KIA3	16.0	24.0	20.0	20.0	28.0	24.0	9.00	13.00	11.00	3	5	4
HY4	24.0	28.0	26.0	20.0	28.0	24.0	11.00	14.00	12.50	4	5	5
HYB4	24.0	28.0	26.0	20.0	28.0	24.0	11.00	14.00	12.50	4	5	5
KIA4	24.0	28.0	26.0	20.0	28.0	24.0	11.00	14.00	12.50	4	5	5
KIA4W	24.0	28.0	26.0	20.0	28.0	24.0	11.00	14.00	12.50	4	5	5
MA4	24.0	28.0	26.0	20.0	28.0	24.0	11.00	14.00	12.50	4	5	5
MA5	22.0	28.0	25.0	20.0	28.0	24.0	10.50	14.00	12.25	4	5	5
RO3	16.0	24.0	20.0	20.0	26.0	23.0	9.00	12.50	10.75	3	5	4
UB3	16.0	24.0	20.0	20.0	26.0	23.0	9.00	12.50	10.75	3	5	4
RO4	24.0	28.0	26.0	20.0	26.0	23.0	11.00	13.50	12.25	4	5	5
UB4	24.0	28.0	26.0	20.0	26.0	23.0	11.00	13.50	12.25	4	5	5
UBS4	24.0	28.0	26.0	20.0	26.0	23.0	11.00	13.50	12.25	4	5	5
RO5	22.0	28.0	25.0	20.0	26.0	23.0	10.50	13.50	12.00	4	5	4
UB5	22.0	28.0	25.0	20.0	26.0	23.0	10.50	13.50	12.00	4	5	4
UB5P	22.0	28.0	25.0	20.0	26.0	23.0	10.50	13.50	12.00	4	5	4
UBS5	22.0	28.0	25.0	20.0	26.0	23.0	10.50	13.50	12.00	4	5	4
UBSH	24.0	36.0	30.0	20.0	26.0	23.0	11.00	15.50	13.25	4	5	5
LG3M	16.0	24.0	20.0	18.0	28.0	23.0	8.50	13.00	10.75	3	5	4
LG3PM	16.0	24.0	20.0	18.0	28.0	23.0	8.50	13.00	10.75	3	5	4
PV3	16.0	24.0	20.0	20.0	26.0	23.0	9.00	12.50	10.75	3	5	4
RI3	16.0	24.0	20.0	20.0	26.0	23.0	9.00	12.50	10.75	3	5	4
CY4	24.0	28.0	26.0	20.0	28.0	24.0	11.00	14.00	12.50	4	5	5
CYA4	24.0	28.0	26.0	20.0	28.0	24.0	11.00	14.00	12.50	4	5	5
LG4	24.0	28.0	26.0	20.0	28.0	24.0	11.00	14.00	12.50	4	5	5
LG4BM	24.0	28.0	26.0	18.0	28.0	23.0	10.50	14.00	12.25	4	5	5
LG4M	24.0	28.0	26.0	18.0	28.0	23.0	10.50	14.00	12.25	4	5	5
LG4PM	24.0	28.0	26.0	18.0	28.0	23.0	10.50	14.00	12.25	4	5	5
PV4	24.0	28.0	26.0	20.0	26.0	23.0	11.00	13.50	12.25	4	5	5
PV4B	24.0	28.0	26.0	20.0	26.0	23.0	11.00	13.50	12.25	4	5	5
PV4W	24.0	28.0	26.0	20.0	26.0	23.0	11.00	13.50	12.25	4	5	5
PVB4	24.0	28.0	26.0	20.0	26.0	23.0	11.00	13.50	12.25	4	5	5
PVC4	24.0	28.0	26.0	20.0	26.0	23.0	11.00	13.50	12.25	4	5	5
RI4	24.0	28.0	26.0	20.0	26.0	23.0	11.00	13.50	12.25	4	5	5
CY5	22.0	28.0	25.0	20.0	28.0	24.0	10.50	14.00	12.25	4	5	5
CYA5	22.0	28.0	25.0	20.0	28.0	24.0	10.50	14.00	12.25	4	5	5
LG5M	22.0	28.0	25.0	18.0	28.0	23.0	10.00	14.00	12.00	4	5	4
LG5PM	22.0	28.0	25.0	18.0	28.0	23.0	10.00	14.00	12.00	4	5	4
PV5	22.0	28.0	25.0	20.0	26.0	23.0	10.50	13.50	12.00	4	5	4
PV5B	22.0	28.0	25.0	20.0	26.0	23.0	10.50	13.50	12.00	4	5	4
PV5P	22.0	28.0	25.0	20.0	26.0	23.0	10.50	13.50	12.00	4	5	4
PV5W	22.0	28.0	25.0	20.0	26.0	23.0	10.50	13.50	12.00	4	5	4
PVB5	22.0	28.0	25.0	20.0	26.0	23.0	10.50	13.50	12.00	4	5	4
PVC5	22.0	28.0	25.0	20.0	26.0	23.0	10.50	13.50	12.00	4	5	4
RI5	22.0	28.0	25.0	20.0	26.0	23.0	10.50	13.50	12.00	4	5	4
CY3H	14.0	20.0	17.0	20.0	28.0	24.0	8.50	12.00	10.25	3	4	4
LG3H	14.0	20.0	17.0	18.0	28.0	23.0	8.00	12.00	10.00	3	4	4
LP4H	24.0	36.0	30.0	20.0	26.0	23.0	11.00	15.50	13.25	4	5	5
LPT	16.0	30.0	23.0	20.0	26.0	23.0	9.00	14.00	11.50	3	5	4

Table 81 Available Water in the Root Zone of Soils in the St-Lawrence Lowlands (Nolin and Lamontagne, 1986). (cont'd)

SYMBOLE DE L'UNITE DE LA CARTE	SURFACE (0-25 cm) HUMIDITE FOND. (%)			SOUS-SOL 1 HUMIDITE FOND. (%)			MATERIAU HOMOGENE PROFOND EAU UTILE TOTALE (cm)			MATERIAU HOMOGENE PROFOND CLASSIFICATION		
	MIN.	MAX.	MOY.	MIN.	MAX.	MOY.	MIN.	MAX.	MOY.	MIN.	MAX.	MOY.
ALC2P	10.0	16.0	14.0	4.0	8.0	24.0	8.00	11.00	9.50	3	4	4
BGA2M	10.0	16.0	14.0	6.0	11.0	24.0	8.00	11.00	9.50	3	4	4
CN2	12.0	16.0	20.0	4.0	10.0	24.0	9.00	13.00	11.00	3	5	4
AL3	13.0	23.0	20.0	4.0	8.0	24.0	9.00	13.00	11.00	3	5	4
AL3P	13.0	23.0	20.0	4.0	8.0	24.0	9.00	13.00	11.00	3	5	4
ALC3	13.0	23.0	26.0	4.0	8.0	24.0	11.00	14.00	12.50	4	5	5
BG3	13.0	23.0	26.0	6.0	11.0	24.0	11.00	14.00	12.50	4	5	5
BG3M	13.0	23.0	26.0	6.0	11.0	24.0	11.00	14.00	12.50	4	5	5
BG3P	13.0	23.0	26.0	6.0	11.0	24.0	11.00	14.00	12.50	4	5	5
BG4	21.0	29.0	26.0	6.0	11.0	24.0	11.00	14.00	12.50	4	5	5
BGA3	13.0	23.0	26.0	6.0	11.0	24.0	11.00	14.00	12.50	4	5	5
BGA3P	13.0	23.0	25.0	6.0	11.0	24.0	10.50	14.00	12.25	4	5	5
LIC3	13.0	28.0	25.0	12.0	28.0	24.0	10.50	14.00	12.25	4	5	5
LIC3P	13.0	28.0	25.0	12.0	28.0	24.0	10.50	14.00	12.25	4	5	5
LIC4	21.0	29.0	14.0	12.0	28.0	24.0	8.00	11.00	9.50	3	4	4
LIG3	13.0	28.0	14.0	12.0	28.0	24.0	8.00	11.00	9.50	3	4	4
ALC3HM	14.0	20.0	14.0	4.0	8.0	24.0	8.00	11.00	9.50	3	4	4
BC3	13.0	28.0	20.0	12.0	28.0	24.0	9.00	13.00	11.00	3	5	4
BC3M	13.0	28.0	20.0	12.0	28.0	24.0	9.00	13.00	11.00	3	5	4
BC3P	13.0	28.0	20.0	12.0	28.0	24.0	9.00	13.00	11.00	3	5	4
BCA3	13.0	28.0	26.0	12.0	28.0	24.0	11.00	14.00	12.50	4	5	5
LI3	13.0	28.0	26.0	12.0	28.0	24.0	11.00	14.00	12.50	4	5	5
LIA3	13.0	28.0	26.0	12.0	28.0	24.0	11.00	14.00	12.50	4	5	5
BC4	21.0	29.0	26.0	12.0	28.0	24.0	11.00	14.00	12.50	4	5	5
BC4M	21.0	29.0	26.0	12.0	28.0	24.0	11.00	14.00	12.50	4	5	5
BC4P	21.0	29.0	25.0	12.0	28.0	24.0	10.50	14.00	12.25	4	5	5
LI4	21.0	29.0	20.0	12.0	28.0	23.0	9.00	12.50	10.75	3	5	4
LI4M	21.0	29.0	20.0	12.0	28.0	23.0	9.00	12.50	10.75	3	5	4
LA4PM	21.0	29.0	26.0	12.0	28.0	23.0	11.00	13.50	12.25	4	5	5
BC3H	14.0	20.0	26.0	12.0	28.0	23.0	11.00	13.50	12.25	4	5	5
BC3HM	14.0	20.0	26.0	12.0	28.0	23.0	11.00	13.50	12.25	4	5	5

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