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GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF MINES AND TECHNICAL SURVEYS

BULLETIN 112

112

GROUNDWATER RESOURCES OF THE LACHINE—SAINT-JEAN AREA, QUEBEC (SOUTH OF ST. LAWRENCE RIVER)

31 H/5 (part of) and 31 H/6 W½

R. A. Freeze

+ 2 cartes

1964

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PREFACE

The rapid industrial and residential expansion of suburban Montreal along the south shore of the St. Lawrence River has created a demand for increased water supplies. In order to satisfy this demand many municipalities and industries are turning to groundwater.

The author of this bulletin has compiled and interpreted the well inventory data collected by the Geological Survey of Canada for the region concerned, and correlated this with geological information and the available hydrologic records. The result is a practical description of the principal aquifers, outlining the quantity and quality of water available from each; an estimate of the annual recharge and basin-wide safe yield; and a more theoretical treatment of the reasons for artesian flow in the region. As a result, therefore, this valuable resource may be properly and economically developed.

J. M. HARRISON,
Director, Geological Survey of Canada

OTTAWA, April 12, 1962

Bulletin 112 — Die Grundwasservorräte des Kartengebiets von Lachine — St. Jean in Quebec (südlich des St.-Lorenz-Stroms).

Von R. A. Freeze

Unmittelbar südlich der Insel Montreal ist genügend Grundwasser von brauchbarer Beschaffenheit vorhanden, um die gegenwärtige Bevölkerung zu versorgen. Das Bulletin enthält Angaben über die Verteilung, Menge und Beschaffenheit der Grundwasservorräte in dieser Gegend.

Бюллетень 112 — Запасы грунтовой воды в Ляшин. Район карты Св. Жона в провинции Квебэк (На юг от реки Святого Лаврентия).

Автор: Р. А. Фриз

Запасы грунтовой воды находящейся сразу же к югу от Монтреальского острова достаточны для удовлетворения потребностей современного населения. Качество этой грунтовой воды удовлетворительно. Бюллетень содержит данные о распределении, количестве и качестве запасов грунтовой воды в данном районе.

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GROUNDWATER RESOURCES OF THE LACHINE—SAINT-JEAN AREA, QUEBEC (SOUTH OF ST. LAWRENCE RIVER)

Abstract

Sufficient groundwater of suitable quality exists throughout the Lachine–Saint-Jean area to supply the domestic, agricultural, and industrial needs of the present population. There is approximately 5 inches of groundwater recharge each year, giving rise to a basin-wide safe yield of 140 gallons per minute per square mile. Salt, hydrogen sulphide, and excessive iron occur in the water in localized areas, but for the most part water quality is good. Hardness, total dissolved solids, and the nature of the major chemical constituents can be correlated with the source aquifer.

Alluvial, glacio-fluvial, and buried valley deposits constitute excellent sand and gravel aquifers, which are too often overlooked in the location of high-capacity wells. The bedrock can be divided into three aquifers, which in order of decreasing transmissibility are: (a) Sandstone, (b) Carbonate, and (c) Shale aquifer.

The groundwater occurs under artesian head and is probably part of an unconfined artesian system. Groundwater flow is toward and into the St. Lawrence River and its tributaries.

Résumé

Il existe suffisamment d'eaux souterraines de qualité convenable dans la région de Lachine–Saint-Jean pour les besoins domestiques, agricoles et industriels de la population actuelle. Les bassins d'eaux souterraines se rechargent chaque année à raison d'environ cinq pouces, ce qui permet de tirer en toute sécurité et en tout point de la région 140 gallons d'eau par minute par mille carré. En certains endroits, l'eau contient du sel, de l'hydrogène sulfuré et une quantité excessive de fer, mais, dans l'ensemble, l'eau est de bonne qualité. La dureté, la quantité totale des matières solides en solution et la nature des principaux constituants chimiques peuvent être rattachées à la nappe aquifère.

Les gisements alluviaux et glacio-fluviaux, de même que les dépôts d'anciennes vallées constituent d'excellentes nappes aquifères à base de sable et de gravier dont on ne tient pas suffisamment compte lorsque l'on cherche des puits à gros rendement. La roche de fond peut se subdiviser en trois nappes aquifères, qui sont, suivant l'ordre de transmissibilité décroissante: *a*) du grès, *b*) de la roche carbonatée et *c*) du schiste argileux.

Les eaux souterraines sont sous pression artésienne et font probablement partie d'un réseau artésien non captif. Les eaux souterraines coulent vers le fleuve St-Laurent et ses affluents où elles se déversent.

INTRODUCTION

Location of Area

This report is a study of the groundwater resources of an area of about 400 square miles on the south shore of the St. Lawrence River near the Island of Montreal. The area is bounded by latitudes 45°15′N and 45°30′N and longitudes 73°15′W and 74°00′W, and consists of the west half of Saint-Jean area (31 H/6) and that part of Lachine area (31 H/5) south of St. Lawrence River. The whole of Laprairie county is included as well as parts of Beauharnois, Chateauguay, Napierville, Chambly, and Saint-Jean counties. No information was collected on the Caughnawaga Indian Reserve, which is also located within the boundaries.

Purpose and Method of Investigation

As this region is undergoing a period of rapid industrial and residential expansion a report outlining the major aquifers together with the quality and quantity of water available should be valuable in the selection of well sites for industrial and municipal use.

This report, prepared in the autumn of 1961, is an interpretation of the well inventory data collected by E. I. K. Pollitt of the Geological Survey in the summers of 1955, 1956, and 1958. The bedrock geology of the region is based on the work of Clark (1952, 1955) and the surficial geology has been adapted from Quebec Department of Agriculture soils maps.

Topography and Drainage

The area is in the St. Lawrence Lowland, a narrow band of land exhibiting relatively low relief and underlain by flat-lying sedimentary rocks. A flat clay plain slopes gently toward the St. Lawrence River disturbed only by isolated till knobs and bedrock outcrops. Elevations range from 30 feet above sea-level (just below Lachine Rapids) to 225 feet (at the south of the area near St-Remi). The plain is cut by several shallow river valleys, which lead to the St. Lawrence River. These are the St. Louis, Chateauguay, La Tortue, St. Lambert, and St. Regis-St. Pierre River systems. Richelieu River at the extreme east edge of the area accepts the waters of L'Acadie River before it continues toward the St. Lawrence River. Run-off records of Chateauguay River are presented later in this report under *Hydrology*.

GENERAL GEOLOGY

An understanding of the geology of the region is necessary before an intelligent appraisal of the groundwater resources can be made. The geology controls the distribution of water in the surficial deposits and the quality of the water in both the drift and the bedrock. The following table of formations is designed to acquaint the reader with the geological terminology and with the age relations of the various formations.

Table I

Table of Formations[1]

Era	Period	Rock unit	Lithology	Thickness (feet)	Aquifer
Cenozoic	Pleistocene and recent		Alluvial sand and gravel	0 – 100	Excellent
			Champlain Sea clay		Poor
			Glacio-fluvial sand and gravel		Excellent
			Glacial till and sandy till		Fair
			Unconformity		
Mesozoic	Cretaceous	Monteregian intrusions	Essexite, nepheline syenite dykes, breccia		
			Intrusive Contact		
Palaeozoic	Ordovician	Lorraine Group	Shale; minor sandy shale	1,000 +	Fracture flow-fair to good aquifer
		Utica Group	Shale	300 ±	
		Trenton Group	Limestone; shaly partings	800 ±	
		Black River Group	Limestone; minor shale and dolomite at base	60 ±	
		Chazy Group	Limestone; minor shale	280 ±	
		Beekmantown Group	Dolomite; dolomitic limestone at top, dolomitic sandstone at base	1,060 ±	
	Cambrian	Potsdam Formation	Sandstone; conglomerate at base	0 – 1,700	
			Unconformity		
Precambrian			Igneous and metamorphic rocks		

[1] After Clark (1952) with modifications.

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ickness (feet)	Aquifer
	Excellent
	Poor
0 – 100	Excellent
	Fair
000 +	Fracture flow-fair to good aquifer
300 ±	
800 ±	
60 ±	
280 ±	
060 ±	
0 – 700	

Bedrock Geology

The area is entirely underlain by flat-lying Cambrian and Ordovician sedimentary rocks with the exception of the Monteregian intrusive rocks, which are of Cretaceous age. Precambrian igneous and metamorphic rocks do not outcrop, but form the basement upon which all the later sediments have been deposited. They are not close enough to the surface to be tapped as an aquifer.

The Potsdam Formation, which covers about 10 per cent of the area, is the lowest member of the Palaeozoic succession, and consists of conglomerate at the base grading upward to a pure quartz sandstone. The sandstone is very hard, but is easily fractured and extremely susceptible to weathering, which has led to the development of numerous fracture zones throughout the rock, especially near the surface.

The Beekmantown Group, which covers about 20 per cent of the area, is a thick series of beds consisting of dolomitic sandstone at the base, pure dolomite in the middle, and dolomitic limestone at the top, with minor amounts of limestone, shale and sandstone throughout. The Chazy Group, a succession of fossiliferous limestone beds interbedded with shale, overlies the Beekmantown Group and is in turn overlain by the Black River Group, some 60 feet of predominately limestone. The Trenton Group is a thick, well-bedded, fossiliferous limestone characterized by abundant shaly partings. Together, the Chazy, Black River, and Trenton Groups have a thickness of over 1,100 feet consisting almost entirely of limestone. Both the dolomite of the Beekmantown Group and the overlying limestones exhibit abundant bedding planes and a well-developed fracture pattern. Near the bedrock surface the joints have become larger owing to processes of weathering. Groundwater is thus afforded excellent passage through these rocks.

A thick section of shale overlies the carbonate rocks, the lowest unit of which is the black shale of the Utica Group, 300 feet thick. This is overlain by the Lorraine Group, grey to fawn shales with some interbedded sandy shales and shaly sandstones, and minor amounts of pure limestone and sandstone. The thickness of the Lorraine Group in the area is unknown, but is 2,500 feet along the Nicolet River, 100 miles to the northeast. Shales of the Utica and Lorraine Groups underlie about 40 per cent of the map-area. Bedding planes and joints are not well developed, but they are sufficient to allow groundwater flow.

In Cretaceous time, plug-like intrusions forced their way up through the Palaeozoic sediments and formed what are now the Monteregian Hills, of which Mount Royal is the most well known. They also occur as sills in the sedimentary rocks. One such sill, which is composed of nepheline syenite, outcrops near St-Luc. It does not seem to have affected the distribution of groundwater nearby.

The Trenton, Black River, Chazy, and Beekmantown Groups and the Potsdam Formation lie conformably on one another with a regional dip of 1 degree to 2 degrees to the east. These formations are separated from the overlying shales of the Utica and Lorraine Groups by the Delson fault. There is no evidence of a fracture zone associated with this fault. Several fold axes trend in a northeasterly direction across the area, but have no effect on the groundwater characteristics of the bedrock.

It should be remembered that a deep well drilled near the up-dip boundary of a formation may go through that formation and enter the underlying one.

Surficial Geology

Most of the area is mantled with unconsolidated drift, commonly 50 to 100 feet thick. The following four major types of surficial deposit are recognized. each one representing a different phase in the glacial and post-glacial history of the region.

Glacial till (commonly referred to as 'hardpan') is an unstratified, unsorted mixture of boulders, pebbles, sand, silt, and clay, which was laid down beneath the continental ice-sheet. The variety in the area is a fairly massive clay till with scattered lenses of coarse sand and fine gravel. The sand and gravel lenses form a network of water-bearing zones throughout the till. The surface of the till shows considerable relief, as evidenced by the numerous 'till knobs' exposed in the area.

Glacio-fluvial deposits or outwash were deposited by streams flowing from a melting ice-sheet, and thus represent a period of receding glaciation. Outwash consists of irregularly stratified sands and gravels. It commonly overlies glacial till, but where the till is absent it occurs directly above the bedrock. Interbedded glacial till and glacio-fluvial sands may result from alternating advances and retreats of the ice-sheet during Pleistocene time.

The Pleistocene epoch of glacial activity was followed by a period of submergence which led to the deposition of a thick layer of marine (Champlain Sea) clay. This clay now covers more than 95 per cent of the area, in places extending right to bedrock, but more commonly concealing till or glacio-fluvial deposits beneath it.

Recent alluvial silt, sand, and gravel are being laid down by almost all the rivers in the area, but only along the St. Lawrence River have the deposits reached aquifer dimensions.

The surficial geology has been interpreted from soils maps and not from an actual field survey. Other types of deposits such as marine sands, dune sands, and ancient beaches are undoubtedly present, but these smaller deposits are probably of minor importance in terms of groundwater recovery.

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HYDROLOGY

The basic hydrological equation is

$$P = R + E \pm \Delta S$$

where

P = precipitation
R = run-off
E = evapotranspiration
ΔS = change in storage (soil moisture, groundwater and surface water).

Precipitation is a measure of the total amount of water deposited on the earth's surface in any form. Run-off is the total outflow from a drainage basin by way of groundwater discharge and stream-flow. Evapotranspiration is the loss of water to the atmosphere by the combined actions of evaporation and plant transpiration. For sufficiently long periods, ΔS becomes insignificantly small.

Records of precipitation and stream run-off are available and a suitable method exists by which the amount of potential evapotranspiration can be calculated. With this information it is possible to outline the effect of hydrologic conditions on the groundwater storage in a given region. The basic assumption is that the surface and underground watersheds are identical. Throughout the following analysis, records for the 10-year period from 1947 to 1957 are used.

Precipitation

Precipitation records from the Dorval Meteorological Station indicate a mean annual precipitation of 37.42 inches (*see* Table II).

Table II

Annual Precipitation

Year	Precipitation (inches)	
1948	33.64	Station: Montreal airport, Dorval, Que.
1949	34.06	
1950	39.47	
1951	42.49	Note: 10 inches snow equal 1 inch rain
1952	46.19	
1953	33.55	
1954	47.65	Mean annual precipitation over 10-year period is 37.42 inches
1955	29.56	
1956	33.43	
1957	34.15	

Run-Off

The Chateauguay River has a drainage area of 920 square miles, most of which lies to the south and west of the area. However, similarities in topography, vegetation, and soil cover, together with the availability of stream-flow data make this basin suitable for study in connection with the Lachine–Saint-Jean area. The stream gauge is located at Ste-Martine. The monthly discharge record for the year 1953–54 is shown in Table III as a representative record from the 10-year period under study.

Table III

Monthly Discharge for the Chateauguay River at Ste-Martine, 1953-54

Discharge in cu. ft. per sec.					Run-off
Month	Maximum	Minimum	Mean	Per square mile	Depth in inches on drainage area
Oct.	674	170	339	0.37	0.43
Nov.	412	130	302	0.33	0.37
Dec.	2,120	296	566	0.62	0.71
Jan.	633	196	342	0.37	0.43
Feb.	7,470	308	1,610	1.75	1.82
Mar.	17,700	220	4,890	5.32	6.13
Apr.	12,500	1,350	5,130	5.58	6.23
May	7,780	747	2,240	2.43	2.80
June	4,280	478	1,270	1.38	1.54
July	992	300	492	0.53	0.61
Aug.	395	259	321	0.35	0.40
Sept.	2,500	373	1,170	1.27	1.42
Mean	4,788	402	1,550	1.68	
Total					22.89

The water flowing in a stream may have arrived there by one of three different routes:

1) Direct precipitation onto the surface of the stream (negligible).
2) Surface run-off; or precipitation that reaches the stream channel without infiltrating the soil.
3) Groundwater; or precipitation that percolates through the soil to the water-table and travels slowly toward the stream as groundwater.

It is possible to arrive at some idea of what percentage of a stream's discharge is the result of surface run-off and what percentage is groundwater inflow by calculating the base-flow of the stream. This is the quantity of water that remains in the stream throughout periods of no rainfall and is therefore assumed to be the amount of water supplied to the stream by groundwater. The mean minimum discharge gives a good approximation of the base-flow (Wundt, 1958). For the year 1953–54 it was 402 cubic feet per second (cfs) (Table III). The average mean minimum discharge for the 10-year period 1947–57 was 344 cfs (Table IV).

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Run-off
Depth in inches on drainage area
0.43
0.37
0.71
0.43
1.82
6.13
6.23
2.80
1.54
0.61
0.40
1.42
22.89

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Table IV

Mean Minimum Discharge

Year	Mean minimum discharge (cfs)	
1947–48	274	Measuring station: Chateauguay River at Ste-Martine
1948–49	357	
1949–50	300	
1950–51	479	
1951–52	282	Average mean minimum discharge is 344 cfs or 5.07 inches on the drainage area per year
1952–53	318	
1953–54	402	
1954–55	510	
1955–56	255	
1956–57	286	

'Cubic feet per second' may be converted into 'inches depth on the drainage area per year' by the following formula:

$$Di = \frac{(3.15 \times 10^7)(12)}{(5,280)^2} \quad \frac{Q}{A}$$

where

Di = depth in inches on the drainage area per year.
Q = discharge in cfs.
A = drainage area in sq. miles.
3.15×10^7 = number of seconds in a year.
5,280 = number of feet in a mile.
12 = number of inches in a foot.

By means of the above equation, the average mean minimum discharge during the period 1947–57 is calculated to be 5.07 inches on the drainage area per year. The total run-off can also be calculated in these units, and for the same 10-year period averaged 16.74 inches (*see* Table V).

Table V

Run-Off

Year	Run-off (inches depth on drainage area)	
1947–48	12.07	Measuring station: Chateauguay River at Ste-Martine
1948–49	13.63	
1949–50	14.48	
1950–51	21.88	
1951–52	16.26	Average run-off over 10-year period is 16.74 inches on drainage area per year
1952–53	18.34	
1953–54	22.89	
1954–55	25.25	
1955–56	13.16	
1956–57	9.39	

The run-off (16.74 inches) has now been divided into its two components: base-flow (5.07 inches) and surface run-off (11.67 inches). The base-flow is thus seen to be 30 per cent of the total run-off.

As the base-flow represents the amount of water that is discharged into the stream from groundwater storage (and assuming there is no change in groundwater storage), an amount of water equal to the base-flow must be recharged into the area each year. The recharge is therefore 5.07 inches a year over the drainage area. As the annual precipitation in the region is 37.42 inches, it can be stated that 13.5 per cent of the total precipitation becomes groundwater.

The recharge of 5.07 inches a year equals 200,000 gallons per day per square mile, or 140 gallons a minute per square mile (gpm/sq. mi.). This represents an approximation of the basin-wide safe yield, i.e., the amount of water that can be withdrawn without depleting the groundwater reservoir. This amount of water is ample to supply the rural, urban, and industrial needs of the area.

Although the Chateauguay River basin (upon which this study is based) is located in the west end of the area, the results are considered indicative of the whole region. The method used in the analysis is based on several assumptions and must be regarded as an approximation, but it has been found to be extremely accurate in humid climates such as this.

Evapotranspiration

If 16.74 inches of the annual precipitation of 37.42 inches becomes run-off, then from the basic hydrological equation evapotranspiration should equal 20.68 inches a year.

Knowing the mean monthly temperatures and precipitations, and the latitude of the measuring station, it is possible to calculate the 'potential evapotranspiration' and the 'water surplus' (which equals run-off) by using the Thornthwaite climatological equation (Thornthwaite, 1948). From Dorval data the potential evapotranspiration comes to 24.60 inches and the run-off to 15.07 inches. These figures are of the same order of magnitude as those obtained from the stream flow analysis.

GROUNDWATER

Basic Concepts

Aquifer. "A rock formation or material which will yield significant quantities of water has been defined as an aquifer." (Todd, 1959) An impermeable layer that will not yield water is called an aquiclude. A true aquiclude, however, probably does not exist, and all formations can be classified as excellent, good, fair, or poor aquifers. The classification depends on the supply-and-demand relationship of the groundwater, for a poor aquifer in Ontario may be considered excellent in Saskatchewan.

Seepage. "The movement of water between groundwater aquifers and surface sources is termed seepage. It is further classified as influent seepage, which is recharge from surface bodies of water, and effluent seepage, which is discharge to surface bodies of water. Thus surface streams are influent streams if the stream contributes water to the groundwater reservoir and effluent streams if water is received from the water table." (Ferris, 1949)

Artesian water. "Artesian water is groundwater that is under sufficient pressure to rise above the zone of saturation." (Meinzer, 1923)

Artesian system. Figure 1 illustrates the two principal types of artesian system.

The classic example (Fig. 1A) is that of an aquifer whose groundwater is confined under pressure by overlying, relatively impermeable strata. Water enters the aquifer in the recharge area, percolates downward into the formation, and flows laterally through it. The water in the aquifer thus has a head that defines the piezometric surface. The slope of the piezometric surface away from the recharge area is caused by frictional losses in the aquifer. If permeable material overlies the confining layer, water-table conditions will prevail in that zone.

An artesian system may also occur in an unconfined aquifer, i.e., where no confining aquiclude is present. In Figure 1B the water-table closely follows the configuration of the topography so that water entering the groundwater reservoir in the recharge area will tend to flow toward the valley and if the stream is effluent, discharge into the stream. This movement of water may be visualized in the form of flow lines, which follow a path at right angles to equipotential lines. Equipotentials are lines of equal pressure, which start and finish normal to the water-table. If at any point of equipotential a cased well is sunk into the aquifer, water will rise in the well to a level determined by the intersection of the equipotential line with the water-table.

If one accepts the theory that there is no such thing as a true aquiclude then the unconfined artesian system takes on more importance and may be considered to be the major cause of artesian conditions regardless of the geological setting. The effect of a poor aquifer overlying a good one will be on the *rate* of groundwater flow rather than on the head.

Piezometric surface. "The piezometric surface of a confined aquifer (Figure 1A) is an imaginary surface coinciding with the hydrostatic pressure level of the water in the aquifer. The water level in a well penetrating a confined aquifer defines the elevation of the piezometric surface at that point. Should the piezometric surface lie above ground surface, a flowing well results." (Todd, 1959)

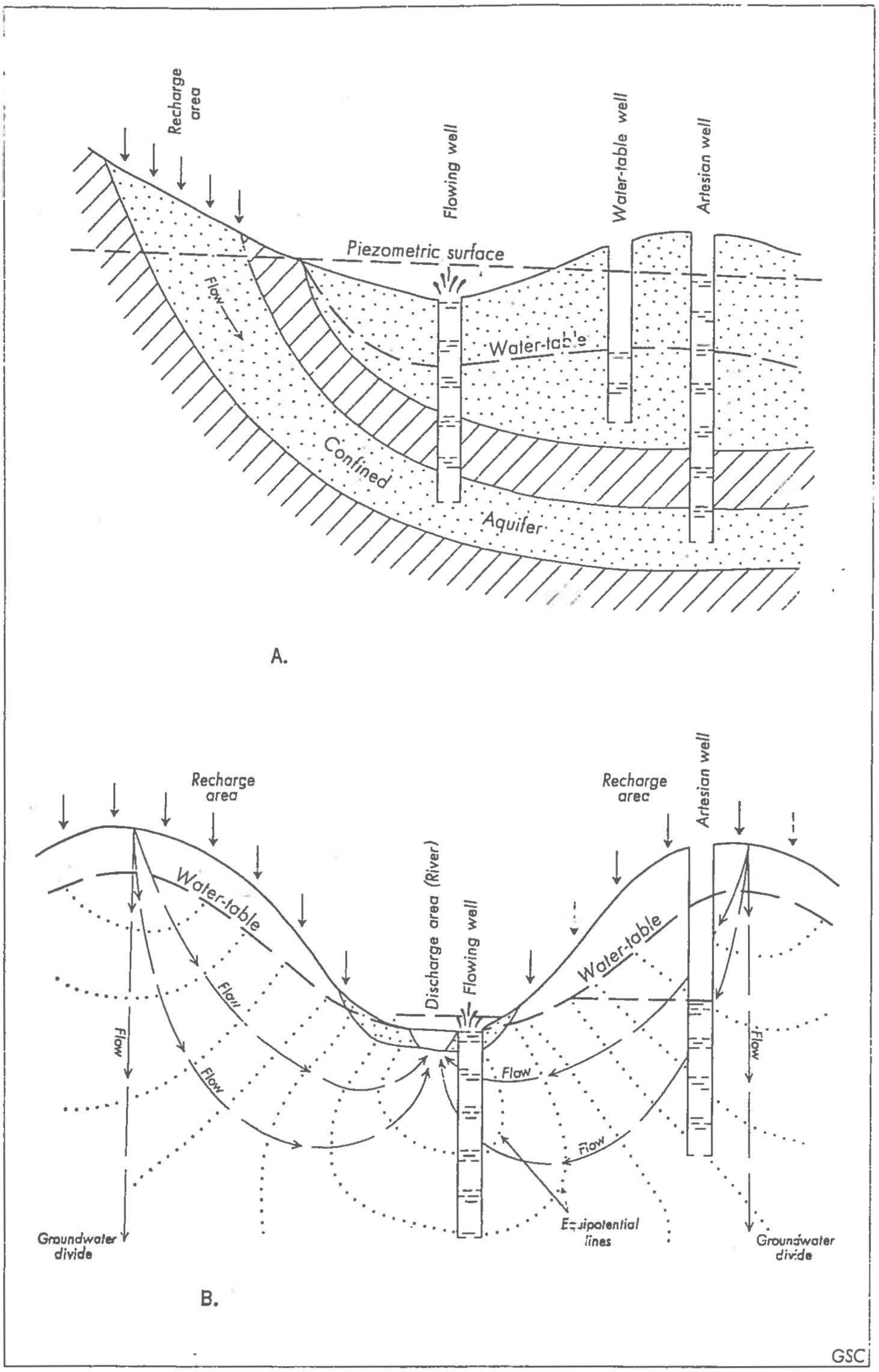
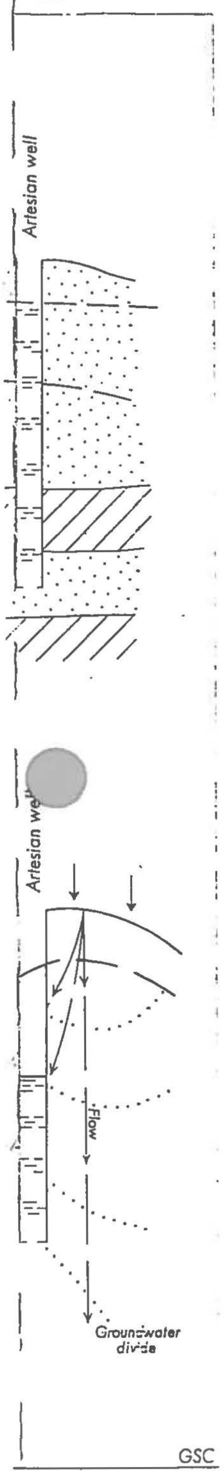


FIGURE 1. Artesian system. A. Confined aquifer (after Todd, 1959); B. Unconfined aquifer (after Krynine and Judd, 1957).



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7).

With the growing acceptance of the concept of an unconfined artesian flow system (Figure 1B), the concept of a piezometric surface is necessarily in a state of flux. The unconfined system concept holds that groundwater moves according to a three dimensional flow net controlled by equipotential lines (or in three dimensions, equipotential surfaces). Adjacent wells drilled to different depths will therefore exhibit different water levels, and as the piezometric surface is defined by the water level, it, too, will vary with depth. The piezometric surface map of the Lachine–Saint-Jean area (Fig. 2) is representative of an average well depth of 40 feet and has been constructed using only water levels from a limited range of well depths.

The unconfined system concept also holds that vertical groundwater movement is at least equally as important as lateral movement. The piezometric surface, however, reflects only the lateral component of flow and consequently cannot be used for any quantitative calculations.

In this report, the piezometric surface is retained because, if the limitations are realized, it still serves the very fundamental purpose of outlining the direction of groundwater flow. The highest elevations represent recharge areas, the lowest elevations represent discharge areas, and groundwater flow is from areas of recharge to areas of discharge.

Piezometric Surface of the Lachine—Saint-Jean Area

The groundwater of the Lachine–Saint-Jean area occurs under artesian pressure, but neither regional geology nor physiography indicates which of the two types of artesian system is responsible. On the one hand, a clay layer covers more than 95 per cent of the area and confines the water-bearing formations beneath it, leading one to believe that this is an example of the classic confined aquifer system. On the other hand, the whole region can be compared to one-half of Figure 1B in which the St. Lawrence River is the effluent stream and the upland recharge area occurs to the south. The following evidence leads one to the conclusion that the region basically acts as an *unconfined* artesian aquifer:

1) The elevation of the water level in deep wells is generally lower than that in adjacent shallower wells.
2) Wells in drift conform to the same piezometric surface as those in bedrock for the plotted well-depth range; i.e., there is no evidence of a confined aquifer exhibiting a unique piezometric surface.
3) The clay is not an aquiclude but actually supplies enough groundwater flow to sustain shallow low-capacity wells.
4) The piezometric surface closely follows the topography and does not appear to be affected by outcrop areas or changes in geology.

In Figure 2 contours of the piezometric surface, prepared from a well water-level inventory, outline the pattern of groundwater flow in the area.

Recharge occurs throughout the region, but is concentrated in the areas of higher elevation. The major recharge area is in the south-central part of the area near St-Remi. Other smaller piezometric highs such as those at St-Luc and St-Isidore conform to the topography.

Groundwater flow is toward and into the St. Lawrence River and its tributaries. For example, if a drop of water were to enter the groundwater reservoir at the town of St-Remi it would flow at right angles to the piezometric contours and enter the Chateauguay River near Ste-Martine. The streams therefore obtain part of their flow from groundwater and may be termed effluent. This is an important point, as the basic assumption in the hydrologic analysis of the Chateauguay River basin was the effluent character of the stream.

The spacing of the piezometric contours delineates the groundwater gradient and consequently the rate of flow. The rate of flow is, in turn, controlled by the permeability of the geological formations. Therefore the uniformity of spacing of the contours throughout the area indicates an aquifer homogeneity. This is, however, a large-scale homogeneity, which is the overall result of a mixture of component aquifers, any one of which may control the occurrence of water at any one place.

Aquifers

Surficial Deposits

Recent Alluvium

The alluvial sand and gravel deposits along the St. Lawrence River between Beauharnois and Chateauguay constitute an excellent aquifer. Small diameter shallow wells yield sufficient supplies for domestic use and the possibility of developing this aquifer for high-capacity industrial wells should be investigated. The major drawback to the aquifer is the high iron content of the water, but this problem is also present in the underlying bedrock. Another alluvial deposit near La Prairie does not attain sufficient thickness to be of major importance.

Glacio-fluvial Deposits

Glacio-fluvial sand and gravel deposits represent another excellent aquifer, which is virtually untapped by high-capacity wells. The aquifer has been utilized with great success for farm supplies and appears to underlie much of the region. The sand and gravel occurs in a 4- to 8-foot layer directly beneath the clay and overlying the till or bedrock. Its areal extent can best be approximated by encircling all the surface exposures outlined on Figure 2. These exposures represent underlying bedrock knobs that have been covered by glacio-fluvial material but not by Champlain Sea clay. Bedrock is therefore near the surface and the thin sand layer will generally be above the water-table. However, in the area between exposures where the sand is overlain by clay, it is at sufficient depth to be saturated and can thus be considered an aquifer. Aquifer tests (pumping tests) are still needed to determine if this formation can supply enough water to support larger demands. Unfortunately many wells have been drilled into bedrock at great expense and with mediocre results in lieu of fully investigating the water potential of the surficial deposits.

Glacial Till

The glacial till of the region is a relatively impermeable boulder clay containing a permeable network of sand and gravel lenses. Sufficient water for domestic or farm use is available from these lenses, but because of their random location and variable size the water supply is unsure and generally insufficient to meet the demands of high-capacity wells.

Champlain Sea Clay

The extensive mantle of clay that covers the region is the only deposit that must be termed a *poor* aquifer. Wells in clay generally produce inadequate supplies of water of a cloudy, salty, or sulphurous quality.

Buried Valleys

The possibility of having a well in drift is controlled in part by the depth to bedrock. The configuration of the bedrock surface in the area is shown on Figure 2, which also indicates the presence of two buried river valleys or pre-glacial channels. The locations of the two channels and their elevations (60 feet at Chateauguay, 10 feet at Chambly) suggest that they formed part of a single river system. Buried valleys are of great economic importance in terms of groundwater because they are usually filled with a considerable thickness of sand and gravel and therefore constitute sizeable aquifers.

The westernmost section of the buried valley has been outlined by seismic methods (Hobson and Collett, 1960) from Caughnawaga to Chateauguay and interpreted from well inventory data between Chateauguay and Beauharnois. More information is needed between these last named points, however, to confirm the continuation of the valley in that direction. Several wells along Chateauguay River provide water from the sand and gravel in the buried channel with great success. There is room for further development of the aquifer.

The eastern section of the pre-glacial channel is not really a buried valley, in that it lies under only a few feet of drift along a present topographic low. The presence of sand and gravel has not been reported so there is little possibility that this section of the channel represents an aquifer.

Bedrock

None of the rock formations underlying the area is porous enough to allow interstitial flow; groundwater therefore moves through the bedrock by fracture flow, i.e., through the open joints and along bedding planes. The controlling factor in the assessment of a formation as an aquifer is the degree of fracture of the rocks. An insight into the behaviour of the various formations is given by Peckover and Tustin (1958) who studied the soil and foundation problems during the construction of the St. Lawrence Seaway, and reported as follows:

> The chief source of water in all excavations was the sedimentary bedrock. Shale, found between Montreal Harbour and Cote Ste. Catherine was generally massive in structure and yielded little water. Limestone underlying the channel between Cote Ste. Catherine and Lake St. Louis was weathered in the top few feet and contained occasional faults. It gave little water in most areas, but produced as much as 15,000 g.p.m. in a particular 3,000-ft. length of channel.
>
> The sandstone, and particularly that underlying the Upper Beauharnois Lock site, produced the greatest quantity of seepage. This rock is weathered to a depth of a few feet and contains zones of shattered rock. In some locations the shattering has been extreme and has left a pulverized material that acts as a barrier to the water circulating through the general joint pattern. More commonly, however, the rock is broken to such a degree that it channels the water in large quantities.

It is clear then, that the bedrock may be divided into three aquifers which, in order of decreasing yield, are:

1) Sandstone aquifer—Potsdam Formation.
2) Carbonate aquifer—Beekmantown, Chazy, Black River, and Trenton Groups.
3) Shale aquifer—Utica and Lorraine Groups.

The chances of obtaining water from the bedrock depend on intercepting a suitably fractured zone. These zones are well developed near the bedrock surface, but decrease in abundance and size with depth. It is therefore unlikely that significant quantities of water will be encountered by indiscriminant deep drilling.

Quantitative Data

The specific capacity of a well is the discharge in gallons per minute, per foot of drawdown of the well. It is obtained by pumping a well at a fixed rate until the water level in the well becomes nearly stable. This figure has been arrived at for several industrial and municipal wells in the area. It can be used to obtain the order of magnitude of the coefficient of transmissibility of the formation from which the water is coming. "The coefficient of transmissibility is defined as the rate of flow of water in gallons per day through a vertical strip of the aquifer one foot wide and extending the full saturated height, under a hydraulic gradient of 100% at a temperature of 60°F." (Ferris, 1949)

The range of transmissibility for the bedrock aquifers, as calculated from the specific capacities, is as follows:

1) Sandstone aquifer	(6 test wells)—	1,000 to	20,000 gpd/foot.
2) Carbonate aquifer	(9 test wells)—	500 to	7,000 gpd/foot.
3) Shale aquifer	(2 test wells)—	300 to	400 gpd/foot.

The above figures show the wide range of possible values and indicate the impossibility of predicting the yield of a bedrock well. No figures are available from wells in the surficial deposits of the area, but a good sand and gravel aquifer will generally have transmissibility values in the range of 20,000 to 200,000 gpd/foot.

Quality of Groundwater

Groundwater quality must satisfy the requirements of domestic, agricultural, and industrial needs. Although some industries and agricultural processes require the presence or absence of a certain rare element, the quality of water can generally be expressed in terms of a *few* chemical properties. These include colour, odour, taste, hardness, total dissolved solids, and the nature of the major chemical constituents. The first three of these can be related to certain offensive constituents, that may be present in the water, namely iron (Fe), salt (NaCl), and hydrogen sulphide (H_2S). The second three can be directly correlated with the source aquifer.

Occurrence of Iron, Salt, and Hydrogen Sulphide

Iron

Figure 2 shows a few small regions in the area where excessive iron occurs in the water. It can be seen that iron does not constitute a major problem in any aquifer except the alluvial deposits along the St. Lawrence River. The upper limit for domestic use is listed by Hem (1959) as 0.3 parts per million (ppm) iron plus manganese.

Salt

Areas in which salt is present in the water in sufficient quantities to cause an offensive taste are also shown on Figure 2. They are assumed to represent connate zones where the movement of groundwater is extremely slow or non-existent. In some places freshwater may exist at lesser depths, and this possibility should be explored when salty water is encountered.

Hydrogen Sulphide

H_2S imparts an unpleasant odour to water. Its presence can be partly correlated with the bedrock aquifers, because most wells in shale are plagued with the problem, some wells in sandstone, and few wells in the carbonate aquifer.

The Piper Diagram

A trilinear diagram, first developed by Piper (1944), is used to show the chemical composition of the dissolved ions in the groundwater of the Lachine–Saint-Jean area (*see* Fig. 2). One hundred and twenty samples from wells in bedrock were analyzed in parts per million, converted to percentage equivalents per million (Hem, 1959) and plotted. No samples from surficial deposits were analyzed.

Each analysis is plotted on all three fields; first in terms of the cations Ca^{++}, Mg^{++}, and $Na^{+} + K^{+}$; then in terms of the anions $SO_4^{=}$, Cl^{-}, and $CO_3^{=} + HCO_3^{-}$; and finally in ion pairs $SO_4^{=} + Cl^{-}$, $Ca^{++} + Mg^{++}$, $CO_3^{=} + HCO_3^{-}$, and $Na^{+} + K^{+}$. The plot on the diamond-shaped field is arrived at as shown under 'use of diagram'. The diamond-shaped field can be divided into sections, each representing a different field of chemical composition. For example salty water (high in Na^{+} and Cl^{-}) would plot on the extreme right-hand corners of the two triangles and thus in zone C when projected onto the diamond-shaped field.

The analyses are plotted in terms of their source aquifer so that a correlation between water quality and aquifer is possible.

Correlation of Water Quality with Aquifer

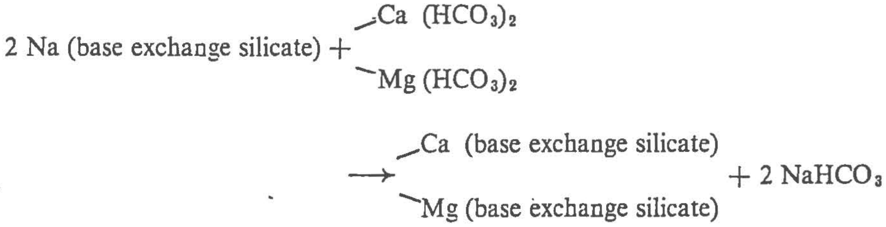
The nature of dissolved solids in groundwater is controlled by the soluble products of the rocks (or soils) with which the water has been in contact. The Piper diagram graphically illustrates the chemical similarities and differences in the water from the various bedrock aquifers.

Shale Aquifer

Almost all wells in shale produce soft sodium bicarbonate ($NaHCO_3$) water, which falls in zone D on the Piper diagram. Hardness varies from 10 to 150 ppm.

Shallow wells (less than 30 feet), however, present an entirely different water; one that is high in Ca^{++} and Mg^{++} with a hardness between 200 and 500 ppm (zone A). This change in the chemical character of groundwater with an increase in depth is brought about by base exchange.

Groundwater, originating as precipitation, derives a high concentration of dissolved Ca^{++} and Mg^{++} salts from the uppermost few feet of ground through which it percolates. Upon penetration of a shale formation, however, the Ca^{++} and Mg^{++} ions are removed in exchange for the Na^{+} ions present in the hydrated aluminum silicate minerals that make up the shale. These minerals are known as base exchange silicates; examples are feldspar, mica, kaolin, and certain other clay minerals. The hypothetical reaction is:



$$2\ \text{Na (base exchange silicate)} + \begin{array}{l} \nearrow \text{Ca}\ (HCO_3)_2 \\ \searrow \text{Mg}\ (HCO_3)_2 \end{array}$$

$$\longrightarrow \begin{array}{l} \nearrow \text{Ca (base exchange silicate)} \\ \searrow \text{Mg (base exchange silicate)} \end{array} + 2\ NaHCO_3$$

The result is a naturally softened water high in dissolved $NaHCO_3$. It is not suggested that the groundwater is softened by direct downward percolation, for most of the deeper soft water has moved laterally through many feet (or miles) of formation. "But . . . the conclusion seems justified that groundwater will have its calcium and magnesium essentially removed by percolating through relatively few feet of rock containing base exchange silicates." (Renick, 1924)

Most water from the shale aquifer in the area also contains a high concentration of H_2S. This is probably a byproduct of the sulphate reduction that often accompanies base exchange.

Carbonate Aquifer

The waters of the carbonate aquifer are highly mineralized for the total dissolved solids range from 300 to 1,000 ppm and the hardness ranges from 350 to 500 ppm. As expected, the water is high in Ca^{++} and Mg^{++} and therefore plots in zone A of Figure 3. A few samples plot in zones E and D, but without exception these are from wells located near the Delson fault, which is the limestone-shale boundary, where some mixing of the two types of water must be occurring.

Except for a few localized regions where salty water is encountered, the groundwater of the carbonate zone can be described as hard but good.

Sandstone Aquifer

Samples taken from wells in sandstone do not show a characteristic grouping on the Piper diagram. Hardness ranges from 100 to 600 ppm and total dissolved solids from 300 to 1,000 ppm. This variation can be attributed to the insolubility of pure quartz sandstone and to water deriving its chemical properties from the overlying deposits and from the mixing of waters from adjacent aquifers.

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Surficial Deposits

Although no samples from wells in drift have been analyzed, water from surficial deposits is subject to the same quality control as that from the parent materials. Thus, calcareous sands and tills are comparable to limestone, quartzose sands and tills to sandstone, and clay to shale.

PRACTICAL USE OF FIGURES

The suitability of prospective well sites can be established in terms of possible aquifers, depth to bedrock, expected quality of water, and type of pump needed, by a short study of the figures accompanying this report. The following procedure is suggested:

1) Find the position of the well site on Figure 2.
2) Note the type of surficial deposit exposed and consult the text to see if there is a possibility of an underlying surficial aquifer.
3) Note the formation and type of bedrock at the well site.
4) Check the bedrock topography map (Fig. 2). Obtain the depth to bedrock by subtracting the bedrock elevation as outlined by the heavy contours from the topographic elevation, which is contoured on this map.
5) The elevation of the piezometric surface (Fig. 2) may be subtracted from the topographic elevation to obtain the expected depth to water. This together with an estimate of the desired water supply will determine the type of pump needed.
6) Check the possibility of getting water with a high iron or salt content, as outlined on Figure 2. The chemical characteristics of the water can be predicted by referring to the chemical analysis diagram (Fig. 3) and to the text.

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