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A Study of Groundwater Flow in Russell County, Ontario

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Abstract

The average groundwater yield of the wells in Russell County is less than 10 gpm. Good potable groundwater is found in the county, but the quality in many areas leaves much to be desired because of a relatively high hydrogen sulphide or sodium chloride content.

The predominant modifying phenomenon is sulphate reduction. Although it produces hydrogen sulphide, it also increases the carbon dioxide content of the groundwater. The latter makes the groundwater chemically active throughout its entire flow. There is a relatively large increase in the chloride value of the groundwater outside the recharge areas.

By using topographic, geological and hydrogeochemical data, the directions of groundwater flow throughout Russell County have been indicated. These flows can be described as follows: a main eastward flow; flow into channels of the Champlain Sea; flow towards the Ottawa River; and flow from the west ending at Mer Bleue, with a high observed total dissolved solids value of 106,985 parts per million possibly owing to the effects of a shale aquiclude.

The bedrock topography controls groundwater flow. It separates fresh and saline groundwater. The bedrock channels seem to guide the main eastward groundwater flow towards Alfred Bog in Prescott County. Vertical zonation of the groundwater exists, as shown by the fresh water floating on salty water. Finally, the groundwater can be said to evolve from a bicarbonate type of water in the recharge areas through a base exchange and sulphate reduction stage to finally become a chloride-bicarbonate type of water.

Résumé

La production moyenne d'eau souterraine des puits du comté de Russell est inférieure à 10 gal/min. Ce comté jouit d'une bonne eau souterraine potable quoique sa qualité laisse à désirer dans beaucoup de régions, à cause de la teneur relativement forte en hydrogène sulfuré ou en chlorure de sodium.

Le principal phénomène de modification est la réduction des sulfates qui non seulement produit de l'hydrogène sulfuré mais aussi augmente la teneur en bioxyde de carbone. Ce dernier fournit à l'eau la force chimique dont elle aura besoin au cours de son écoulement. Il y a une augmentation assez grande de la valeur des chlorures des eaux souterraines à l'extérieur des bassins d'alimentation.

Les directions de débit des eaux souterraines indiquées pour tout le comté de Russell sont basées sur des données topographiques, géologiques et hydrogéochimiques. La description des débits comprend: un débit principal en direction de l'est; un débit dans les canaux de la mer de Champlain; un débit en direction de la rivière des Outaouais et un débit en provenance de l'ouest qui se termine à la Mer Bleue où la valeur maximale observée de la totalité des solides dissous est de 106,985 parties par million, ce qui est probablement attribuable aux effets d'un aquiclude de schiste.

La topographie de la roche solide contrôle le débit des eaux souterraines et sépare les eaux salées et douces. Les canaux de la roche solide semblent diriger le principal débit des eaux souterraines en direction de l'est vers la tourbière d'Alfred dans le comté de Prescott. La stratification verticale des eaux souterraines existe tel que le prouve l'eau douce qui flotte à la surface de l'eau salée. Les eaux souterraines se forment donc à partir d'un type d'eau bicarbonatée dans les bassins d'alimentation, passent par un échange de base et une phase de réduction des sulfates et deviennent en dernier lieu un type d'eau composée de chlorures et de bicarbonates.

Introduction

This report is concerned mainly with research into the direction of groundwater flow in the area between the Ottawa and St. Lawrence Rivers in Russell County, using the hydrogeochemical approach. The data were gathered in the form of a well inventory. This gave the author a wealth of groundwater information that would not have been available otherwise and which will be useful to provincial authorities, principally the Ontario Water Resources Commission, and municipal authorities who may some day be searching for a groundwater supply. These data are published in the hope that they will provide a better understanding of the hydrogeology of the county and, consequently, a better explanation of the direction of the groundwater flow. The Ontario Water Resources Commission, which has carried out groundwater studies in search of municipal supplies within Russell County, has been of great assistance by supplying all the well inventory information accumulated since 1947. These well data, plus the well inventory carried out by the author, are the basis for this report.

This study was carried out because a thorough investigation of the Ottawa River is being initiated, and the author believes that the knowledge of groundwater flow along the Ottawa River will prove helpful in answering some of the questions that are certain to arise in the course of the larger study.

PREVIOUS WORK

Two previous groundwater studies have been conducted by the Department of Energy, Mines and Resources near the area covered in this report, one by Owen (1953) and the second by Brandon (1960). Owen's study covered Gloucester Township in Carleton County, whereas Brandon's covered a much larger area commonly known as the Ottawa-Hull area. In both studies, the main interest seemed to be to determine the quantity of groundwater available.

LOCATION, PHYSIOGRAPHY AND CLIMATE

The western boundary of Russell County is situated approximately six miles east of Ottawa's city limits. The county forms a rectangle, with the northwest corner located at the Ottawa River near Orleans. From Orleans, the county extends eastward some 19 miles along Trans-Canada Highway 17 and southward for approximately 23 miles, encompassing an area of approximately 440 square miles.

The county is composed of four townships: Cumberland and Clarence to the north and Russell and Cambridge to the south. The townships are subdivided into concessions and lots. Because of the irregularities of the lots and concessions in each township, the Universal Transverse Mercator Grid system was used to locate wells, water samples, analyses, etc., on the maps.

In general, the area can be described as relatively flat, especially in Russell and Cambridge Townships. The highest elevation, 350 feet above mean sea level, is in the centre of Cumberland Township and the lowest, approximately 140 feet, is along the Ottawa River in the northeast corner of Clarence Township.

At present, the surface topography is affected by two main rivers, the Ottawa and the South Nation, that pass through Russell County. Consequently, a surface water divide runs east to west (Fig. 2a).

Even though the Ottawa River is the much larger of the two rivers, only one-quarter of the land area of Russell County drains to the Ottawa River; the remainder drains to the South Nation River. It is for this reason that the South Nation River becomes the more important of the two rivers in this groundwater study of Russell County.

Another interesting topographical feature of the county is the remnants of the old Champlain Sea Channels that are delineated in Figure 2a. There are three channels shown, the main one extending in a west-east direction from Mer Bleue Bog to join with two north-south channels in Clarence Township. Bear Brook, which partially drains Mer Bleue, follows the path of the main channel. The channels are clearly visible, as are the stranded beach lines, on the aerial photograph (Fig. 2b). Because they follow the lowest land areas in the county, the channels should be areas of discharge and should have some influence on the direction of groundwater flow.

The climate is continental, with a mean annual temperature of 42°F (5.6°C). The mean annual precipitation is 38 inches (965 mm), approximately three-quarters of this amount falling as rain. There is, therefore, ample precipitation for recharge of the aquifers. The summer of 1968, during which this study was carried out, was an average summer with respect to precipitation; 11.75 inches (298 mm) of rain was recorded by the author during the period May 29 – October 1, 1968.

DRAINAGE

The one-quarter of the county that drains to the Ottawa River has better drainage than the rest of the county. The latter is divided into two parts by Bear Brook, which flows easterly across the county. This stream drains into the South Nation River one mile outside the eastern limit of the county. The South Nation River divides Cambridge Township into two relatively equal areas. Numerous other streams cut up the area, as can be seen on Figure 1. However, even with all this natural drainage, the area is poorly drained, as witnessed by the fact that there are two huge bogs in the area. One, Mer Bleue Bog situated on the western limits of Cumberland Township, extends into Gloucester Township, and is drained partially by Bear Brook. The other, Moose Bog, is situated south of the town of Casselman in the extreme southeast corner of the map. There is also the flat land around Cobb Lake (or "le lac de Bourget" as it is generally known to the French-speaking inhabitants of the area) where the water table is one foot below, and the piezometric surface is three feet above, the surface of the ground. Even in the area known as Larose Forest Reserve, which has basically a sandy surface, the water table is only one or two feet below ground surface in many places.

Hydrogeologically speaking, the two main bogs described above, as well as Cobb Lake, are natural discharge areas for the groundwater of the area.

Geology

INFILTRATION MAP

The infiltration map (Fig. 1) is derived from an excellent agricultural soil map (Wicklund and Richards, 1962), which was modified by the author to help in understanding the hydrogeology of the area. The resulting infiltration map shows only four main types of surficial deposits – clay, till, sand (fine and coarse) and gravel. Where bedrock outcrops, it is shown, but not differentiated into the various types of bedrock.

For the purpose of showing infiltration, the three types of surficial deposits shown on Figure 1 can be described as impermeable (clay), semipermeable (till) and permeable (sand and gravel). Generally, clay areas are the lowest topographically, but this is not necessarily true in Russell County, since we are dealing with marine clays, which were deposited when the water level (sea level) was much higher than at present (Chapman and Putnam, 1966). The clay areas are generally flat. Three main areas are shown on Figure 1: one covers the northwestern and central part of Cumberland Township; another is located along the southern portion of the county through Russell and Cambridge Townships; the third is located in Clarence Township and follows the path of the old Champlain Sea Channel, from Rockland, southward to Cobb Lake. Where these clay plains are associated with topographical low points, many springs occur, especially at the contact of the clay plains and the sandy beach deposits. The maximum clay depth encountered in this area of Cumberland Township was 290 feet, however, the average clay thickness in the county is 30 feet (Fig. 3). More than half the county area is covered by clay. The last factor alone will definitely decrease the rate of infiltration.

The till (hardpan) is a ground moraine that underlies the clay in almost the entire area except where bedrock outcrops. Very little till is exposed at the surface. The largest area of till outcrop overlaps the northwest corner of Russell Township and the southwest corner of Cumberland Township. The maximum till thickness drilled was 98 feet. The average till thickness in Russell County, is 12 feet (Fig. 3), which is only two-fifths of the area's average clay thickness of 30 feet. Even though the till is considered semipermeable, the average thickness of the till deposits (when compared to the average thickness of the clay deposits) coupled with the relatively small outcrop area of the till, will reduce the amount of precipitation infiltrating the ground.

The till matrix and stones reflect the bedrock that underlies the till, and nowhere is this better illustrated than where the till outcrops in the northwest corner of Russell Township. There, the till takes on the reddish colour that is peculiar to the red shale of the Queenston Formation.

Finally, there are the permeable surficial deposits of sand and gravel. The infiltration map differentiates between the deposits of fine sand (mainly windblown), coarse sand (mainly beach deposits), and the much less extensive gravel deposits.

The fine sand deposits are fairly extensive in two areas. One area forms the greater part of Larose Forest Reserve and extends somewhat to the south and west of the Forest Reserve. The other area stretches from the northwest corner of Clarence Township southeastward almost to the town of Bourget. These large areas are believed to be recharge areas; however, their influence on infiltration is limited, as they are underlain mainly by clay deposits.

The beach deposits of coarse sand form better potential recharge areas because they are more permeable than the fine sand deposits, although they are less extensive. Their infiltration capacity will also be limited, since they are underlain in most areas by clay deposits.

The only true gravel deposits occur in Cumberland Township. They are narrow and elongated, and appear to be esker remnants. These permeable deposits, or what is left of them, are the only true direct recharge areas in the entire county. Much of the gravel has been removed, as is apparent from the series of abandoned gravel pits to be found in these areas, and the natural groundwater recharge phenomenon has definitely been altered.

The maximum depth of sand and gravel found in the county was 154 feet. However, the average thickness of these permeable deposits was found to be only seven feet, which is approximately one-quarter the average thickness of the clay deposits (30 feet) and a little more than half the average thickness of the till deposits in the area. All in all, the surficial deposits are not very conducive to infiltration or to recharge of the groundwater.

Figure 3 shows a hypothetical well in each township and gives the average thickness of the various surficial deposits, assuming that they always occur in the order shown. An examination of the figure reveals several important features. First, the average clay thickness is greater in the two northern townships, mainly because of a deep buried channel all along the present channel of the Ottawa River. Second, the thickness of till mantle is relatively consistent, averaging 12 feet over the entire area. Finally, it should be noted that the surficial windblown and beach sands are included in the sand and gravel average thickness; therefore, the layer of truly permeable material found between the till and bedrock contact is probably closer to one or two feet of the seven-foot average shown in Figure 3, with the rest being made up of the windblown or beach sand deposits. Figure 3 also readily shows the thickness ratio between the impermeable, semipermeable and permeable surficial deposits to be 4/2/1 (approx.). The average thickness of the various surficial deposits was derived from the data for over 800 wells, averaging slightly less than two wells per square mile.

To summarize, it has been shown that infiltration or recharge in this area depends mainly on two factors: the extent of permeable and semipermeable deposits and the thickness of these deposits. In both cases, Russell County is at a disadvantage. More than half of the area is covered by clay and the permeable deposits average only seven feet in thickness. This means either that infiltration and recharge take place outside the area or that most of the recharge will be the result of slow infiltration through semipermeable or almost impermeable deposits.

BEDROCK GEOLOGY

Precambrian rocks underlie the entire county and form the basement on which all subsequent sedimentary rock formations lie. Nowhere in the county do Precambrian rocks outcrop. In the northwest corner of Russell County, deep holes place the Precambrian rocks as deep as 2,800 feet below the ground surface (2,549 feet below mean sea level). Consequently, the Precambrian rocks will not be considered at all in this groundwater study.

The bedrock geology map (Fig. 4) was derived from the bedrock map of the Ottawa-Cornwall map area (Map 852A) by Wilson (1946). The only change that could be suggested is that one, or possibly all three, shale formations (Billings, Carlsbad, and Queenston and Russell) extend further to the east in the southern portion of Clarence Township. Some shale underlies the surficial deposits where a blank appears on the map. The logs of wells located in Concession III, Lots 11 and 16; Concession IV, Lot 23; Concession V, Lot 12; and Concession X, Lot 22 in Clarence Township; and Concession I, Lot 23 and Concession IV, Lot 28 in Cumberland Township, show that shale does exist beneath the surficial deposits (Fig. 4).

The sedimentary bedrock formations between the Precambrian rocks and the limestone bedrock of the Ottawa Formation are classified as aquicludes. None of these formations is presently being used because of the great depth and the high cost of drilling such a well.

Figure 4 shows that the surficial deposits over more than half of Russell County are underlain by limestone of the Ottawa Formation. Because of its large extent and its hydraulic characteristics, this bedrock formation has to be considered the best aquifer of all the bedrock formations drilled in Russell County. The shales of the Carlsbad, Billings, and Queenston and Russell Formations are regarded as a single aquifer in this report because it is believed that the hydraulic characteristics of these various aquiferous formations are very similar.

Figure 4 also shows that the area is criss-crossed by faults. The major fault, running in an east-west direction, is located in the northern part of Russell and Cambridge Townships. Some faults follow the same trend as that of the old Champlain Sea channels (Fig. 2) and this seems true of the two major faults extending in a northwest-southeast direction in Clarence Township. In all probability, the various types of rock formations and the faults do have some influence on the direction of groundwater flow, but this is not readily apparent from the data collected during the study. In fact, it had been anticipated by the author that the faults would have a greater influence on the direction of groundwater flow than they seem to have. However, it will be shown later in this report that the rolling topography of the bedrock surface definitely affects or controls the direction of groundwater flow. The bedrock outcrops are shown on Figure 1, and the bedrock configuration or topography on Figure 5. Figure 6 shows, in cross sections, the bedrock as it exists beneath the surficial deposits. The fact that many wells in Russell County obtain their groundwater supply at the contact of the bedrock with the surficial deposits (even though many wells penetrate deeper into the bedrock) indicates that the rolling bedrock topography does affect the direction of groundwater flow, as explained in the hydrogeochemical part of this report.

One interesting aspect is the relationship between the present bedrock configuration and the main Champlain Sea channel in Cumberland Township (Fig. 7). Figure 7 shows a cross section trending north to south through Concession VI of Cumberland and Russell Townships. In the centre of the section is shown what appears to be a 7.25-mile-wide valley of the Ordovician period. The origin of this wide valley may have been a graben. The valley is filled with approximately 400 feet of shale. Superimposed above the cross section of this valley is a plan of the Champlain Sea channel (Fig. 7). It is remarkable that this channel basically follows the same path as that displayed by the valley some 350 million years ago. However, the Champlain Sea channel, formed some 10,000 years ago (Pleistocene epoch), is only 1.6 miles wide at the point where the cross section was made, and the relief of the channel is only in the order of 110 feet as compared with 400 feet for the Ordovician valley. Today, 10,000 years later, all that remains of this Champlain Sea channel is Bear Brook, with a relief of 15 feet and a maximum width of 0.35 mile at flood stage.

Hydrogeology

DUG WELLS, SPRINGS AND DRILLED WELLS

During the course of this study in the summer of 1968, the well inventory consisted of data for 1,777 wells. The data for half this total were supplied by the Ontario Water Resources Commission. Another 877 wells were encountered for which no information was available except generalizations, such as the type of well and whether the water was potable. The records for each numbered well (Fig. 8) are kept by the Ontario Water Resources Commission, Toronto, Ontario, and are available upon request. The location of each well is shown on Figure 8. The wells were numbered by individual township. Since there are four townships in the county, we therefore have four wells numbered 1 (one in each township), four numbered 2, etc. However, each well can also be located by coordinates using the Universal Transverse Mercator Grid (UTMG) system, thereby eliminating any ambiguity between wells with the same number. The unnumbered wells are those for which no information was available. Where the number of wells was too large to be illustrated clearly on Figure 8, as occurs where small communities are located, separate detail maps (Figs. 9 to 17) have been drawn.

The majority of wells shown on Figure 8 are drilled wells, nevertheless, dug wells (water-table wells) can be found almost anywhere in the map-area. The Larose Forest Reserve area has the least well information available simply because it is uninhabited.

Many springs were mapped, the largest concentration occurring between the 225- and 250-foot contour lines in the south central part of Clarence Township (Fig. 8). The springs appear at the surface along or near the contact between beach sand and clay.

The deepest hole in the area was drilled to a depth of 2,700 feet (exploratory hole for gas storage in Concession II, Lot 18, Russell Township). The deepest water well, 623 feet deep, (No. 149, coordinates 776-143) was also drilled in Russell Township in Concession VII, Lot 10, 398 feet below mean sea level. The water in this well was salty. Furthermore, the water had risen to only within 102 feet of the surface or 123 feet above mean sea level, which is very poor when compared to the average static water level (piezometric level) of the area, which is 18 feet below the surface of the ground (Fig. 18). Also, the piezometric level of well No. 149 is lower than the lowest water level of any surface stream in the area, including the Ottawa River. If only this one deep well were considered, the data would indicate that the hydraulic gradient over the entire area is negative, signifying that groundwater movement is from river to well. This is improbable, nevertheless, if the regional hydraulic gradient of the groundwater in Russell County is comparable to that of the South Nation River, it will be very small indeed, because the South Nation River has a slope of only 0.002 mile/mile. However, the groundwater gradient can be fairly large locally.

The well map (Fig. 8) also illustrates that flowing wells exist in the area, although there are none above the 225-foot contour except in Cumberland Township. The topography of Cumberland Township indicates that the recharge area of these flowing wells is not far from the wells. The largest concentration of flowing wells is in Clarence Township around Bourget. Anywhere in that area, below the 175-foot contour, a well drilled through the clay and till to the bedrock contact will result in a flowing well. However, the small number of flowing wells in the county reflects a low hydraulic head or pressure and, consequently, a low hydraulic gradient.

If one could interpret the springs, which are all contact springs, as representing the excess water in unconfined aquifers (groundwater whose water level is associated with the water table) and the groundwater from flowing wells as being the excess water in confined aquifers (groundwater whose water level is associated with the piezometric surface), then the small yield of the springs and flowing wells in the area would be indicative of a poor groundwater supply (10 gpm or less).

GROUNDWATER OCCURRENCE

When drilling in Russell County, groundwater can be encountered at various depths and in various aquifers, depending on the well location. Where there are large surficial sandy areas (Fig. 1), groundwater is obtainable from shallow dug wells, 10 to 25 feet in depth, that intersect the water table. In the clayey areas, groundwater may also be available from dug wells, but in this case it is usually derived from a thin silty or fine sandy lens or layer in the clay. The gravelly outwash deposits (eskers) in Cumberland Township, Concessions III, IV, V and VI, will yield groundwater. Because this is a true recharge area (or was before the gravel was largely mined out), the static water level (water table) will be much lower than normal and, unless such a deposit is quite thick, it is not usually considered a good aquifer, although it has to be considered a very good infiltration or recharge area. Where such a deposit extends underneath the clay or till, a better well location may be found away from the recharge area (in this case, the gravel ridge) because the aquifer changes its character from unconfined to confined. Where the clay or till acts as a confining layer, the water, under pressure, yields a more constant flow that depends not only on precipitation, as it does on top of the gravel ridge, but also on storage.

In Russell County, most drilled wells are drilled into the bedrock. Because most of the area is underlain by limestone of the Ottawa Formation, it is assumed that this formation yields most of the groundwater. The shale formations of the area also yield some groundwater. In both instances, the groundwater is obtained from fractures in the solid bedrock. In many instances, although well owners believe that the groundwater yielded by their well comes from the deep solid bedrock formation of shale or limestone that underlies their property, the groundwater is actually obtained from the till-bedrock or gravel-bedrock contact zone, simply because of the well construction. If the casing is not driven solidly into the bedrock for three or four feet, especially when the bedrock at the till-bedrock contact is weathered or fractured, the groundwater will enter the casing at the till-bedrock contact. The possible combination of weathered bedrock and a gravelly layer existing along the contact zone can form an aquifer that will supply such a well. Even if the bedrock does supply some groundwater, the chances are that the water produced by pumping is a mixture of water from the two zones.

Groundwater Quantity

AVAILABILITY OF GROUNDWATER

Determination of groundwater availability is a provincial responsibility and, for Russell County, falls under the jurisdiction of the Ontario Water Resources Commission. Groundwater availability data gathered during this study were for the determination of hydrogeologic characteristics and groundwater flow directions. The generalized availability picture presented by these data should, nevertheless, be of some interest to local municipal authorities. It is outlined here for their guidance. More detailed information concerning local variations in availability should be obtained from the Ontario Water Resources Commission.

Generally speaking, although the groundwater supply in Russell County is sufficient to satisfy the present demand, it can only be rated as fair, since very large requirements could not be fulfilled by the existing groundwater in the county. The supply is sufficient for farm demands (excluding irrigation) and for the small municipalities that exist at present. The possibility of supplying groundwater to other small communities is good, but much research would be necessary to locate a supply of one-half million gallons per day or more.

The well map (Fig. 8) is in itself proof of the availability of groundwater. Three regions within the county have the potential for yielding larger than average amounts of potable groundwater. They are Lot 1, Concession IV, and Lot 30, Concession VII, in Cambridge Township; Lot 4, Concession X, in Russell Township; and Lots 1, 2, 3 and 4, Concessions VIII, IX, X and the east half of Concession XI, in Cumberland Township.

WELL YIELD

Dug Wells

The data accumulated on dug wells may be summarized as follows. Over the entire area of Russell County, the average depth of dug wells is 15 feet, while the average depth to the water table is 7 feet, leaving approximately 8 feet of water available in a dug well. This is shown diagrammatically in Figure 18. The average depth of a dug well in each of the four townships is also shown, as well as the average depth to the water table. The latter is the same in each township except Clarence Township, where it is only 6 feet below the ground surface owing mainly to the sandy deposits found above the 250- and 275-foot contours in the northeast and northwest corners of the township. A four-foot-square well will yield approximately one imperial gallon per minute.

Drilled Wells

A person interested in drilling a new well in Russell County can estimate the cost (depending on cost per foot) and anticipate the results by using the data shown in Figure 18. It is assumed in this figure that the surface topography is level over the entire area and therefore, the data could be described as hypothetical; however, the number of wells used to calculate the averages is large enough to reflect with some accuracy the conditions that exist in the county.

The average depth of a drilled well in Russell County is 91 feet. The piezometric surface averages 18 feet below the surface, leaving some 73 feet of available drawdown in the well. This places the average piezometric surface of the drilled wells some 11 feet below the average water table found in dug wells. Bedrock will be encountered at an average depth of 49 feet below the surface of the ground. Consequently, approximately 50 feet of casing will be required. The average yield of such a well will be 8 gallons per minute, with an average drawdown of 19 feet below the average piezometric level. Figure 18 illustrates the averages for each township. From them it can be assumed that a drilled well will cost the most in Clarence Township and produce less water than would be the case in the other three townships; in Cambridge Township, a drilled well will cost the least and produce the most water, as indicated by the transmissibility value (T = 1,000 gpd/ft).

The data shown in Figure 18 are also used to illustrate the general direction of groundwater flow by means of four cross sections. It is well known that the water table configuration tends to follow the local topography. This general observation is confirmed for Russell County by the water table data collected and summarized on Figure 18. Therefore the groundwater flow in unconfined aquifers is probably local. The fact that the water table lies at about the same depth in the four cross sections is indicative of a very low hydraulic gradient.

The piezometric surface level (Fig. 18) is more varied. In the south, the direction of groundwater flow in confined aquifers is from west to east. Another peculiarity of the southern section is that the average gradient of the piezometric surface is very much the same as that of the bedrock surface. In the western cross section, the flow is from south to north and, again, the bedrock and piezometric gradients are almost identical. In the eastern cross section, the flow is also from south to north, but the average bedrock slope is much steeper than the average slope of the piezometric surface. Finally, the northern section shows no groundwater flow because the flow is northward. This can be interpreted in two ways. It is either indicative of the northward flow of both the eastern and western sections, or it reflects the surface water divide (Fig. 2). Consequently, a northward groundwater flow from the divide towards the Ottawa River would be suggested by the neutral flow in the northern section. The Ottawa River flows west to east and if the piezometric gradient for the wells in Cumberland and Clarence Townships is determined to three decimal places, there is a slight slope from west to east in this northern groundwater flow. Therefore, the piezometric surface reflects, as did the water table, a very low hydraulic gradient throughout the county.

It has been mentioned previously in this report that the bedrock topography strongly influences the direction of groundwater flow. This is true particularly in the northwestern part of Russell Township, as illustrated by the western and southern cross sections (Fig. 18), where the bedrock and piezometric gradients are almost parallel. Another interesting point is that Figure 3 confirms in part the facts brought out in Figure 18. There are three common denominators for both figures: the ground level, the depth to bedrock and the depth of the well. The clay deposits (Fig. 3), which are considered in this report to be impermeable, have an average thickness that is significant. This is well illustrated by Clarence Township, which has the thickest clay deposits (47 feet) and the lowest average well yield and transmissibility value (7 gpm and 740 gpd/ft respectively) of any of the four townships. The thickness and extent of the clay must have some control over the infiltration rate, which in turn is reflected by the amount of groundwater available from the aquifers, whether unconsolidated or bedrock aquifers.

Springs

Some 146 springs were located and mapped (Fig. 8) during the study of Russell County. Over 50 percent of the total occur in Clarence Township; 31 percent of the 146 springs occur within the area bounded by Concessions III and VII and Lots 8 and 24, mostly between the 225- and 250-foot contour lines at the base of the sandy beach ridges at or near the clay-sand contact. The fact that more springs exist in Clarence Township than in the other townships may mean that less of the water infiltrates to the deeper confined aquifers, partly explaining why the deep wells yield less water than those in Russell and Cambridge Townships, where springs are not so numerous.

Although many springs are used for water supply purposes, there is not one spring in the entire county with a large yield. The largest yield – some 50 gpm – is obtained from a series of springs that discharge into Leonard Creek in the northwest corner of Cumberland Township.

From the point of view of groundwater flow, a spring will be regarded as the discharge area of a local groundwater flow in an unconfined aquifer.

Flowing Artesian Wells

A total of 75 flowing wells were mapped (Fig. 8). Of these, 16 are flowing only because they were drilled in the bank or near the stream bed. The six flowing wells in Cambridge Township are of this type. Whether a well flows or not depends mainly on the pressure or hydraulic head of the water at recharge, however, it is also possible to think of the natural flow of a flowing artesian well as being excess groundwater in the confined aquifer. Because no large flows occur in any of the flowing wells in Russell County, it can be assumed that there is not a large excess of groundwater in the confined aquifers of the area. In general, the flow of these flowing wells is more constant throughout the year than that of the springs. This indicates that the groundwater flow associated with the confined aquifers is not as local as that of the unconfined aquifers, a fact also confirmed by the salinity content of some of the flowing wells.

The flowing wells with the largest discharge rates (14 gpm) are located in Clarence Township (UTMG coordinates, 806-415 and 792-442). Both are in the Ottawa watershed, north of the surface water divide (Fig. 2a). Of the flowing wells, 50 percent are located in Clarence Township and most are found between the villages of Clarence Creek and Bourget, near the eastern boundary of the township. These wells yield only 1 to 3 gpm. At the southeastern extremity of Cobb Lake, the wells yield only saline water (8,300 ppm NaCl). The well with the highest total dissolved solids (T.D.S.), 106,985 ppm, is a flowing well situated at the eastern limit of Mer Bleue in Lot 9, Concession IX, Cumberland Township (UTMG coordinates 671-242).

In this report, springs are considered to be the discharge zones of unconfined aquifers; and flowing wells, the discharge areas of confined aquifers.

To summarize the groundwater quantity data for Russell County, there is a daily excess of groundwater, but the amount probably does not exceed 1.5 million Igpd. Some untouched aquifer zones probably exist that with proper development would yield approximately 100,000 Igpd.

Groundwater Quality

In general, the quality of the groundwater in Russell County can only be considered fair, since there are regions of saline water and groundwater of high hydrogen sulphide and iron content. Nevertheless, excellent potable groundwater does exist.

Table 1 lists the analytical data obtained from 74 groundwater samples that were collected for this study. Average values for most of the constituents analyzed are given at the end of the table for comparison with the recommended Health Standard of the Department of National Health and Welfare, Canada (1968). Fluoride, whose limits depend on average daily maximum air temperatures, is an exception. The fluoride standard shown in Table 1 approximates that recommended by the United States Public Health Service (1962). Note that these chemical analyses do not indicate whether the groundwater is bacteriologically safe.

Depth, Temperature and Colour

The average depth of the wells from which groundwater samples were obtained for chemical analyses was 110 feet, the deepest well being 287 feet and the shallowest, only 35 feet. The temperature of the groundwater from wells completed in confined aquifers averaged 49°F (9.4°C), while that for water from springs or wells in unconfined aquifers was 44°F (6.7°C). Because it was often impossible to obtain the sample directly at the well, these average temperatures are based on many temperature tests carried out during the study and not solely on the groundwater samples collected for chemical analysis.

The average colour value of 23 Hazen units is quite high, although acceptable. This relatively high average value is due to a few groundwater samples with very high values. It should be noted that more than 50 percent of the analyses have a reading of 5 Hazen units, which is considered excellent.

pH and Carbon Dioxide (CO_2)

The pH of the groundwater is basic, with an average value of 7.7. All samples except No. 45 (pH 6.1) have a pH value in the range from 7.0 to 8.6. The average laboratory CO_2 value for the area is 19 parts per million (ppm). This value is relatively high, considering that all the wells sampled supposedly obtained water from only confined aquifers. All the groundwater samples analyzed except No. 13 and No. 43 (Table 2) are saturated in $CaCO_3$. It is a known fact that once the groundwater has reached a confined layer, it cannot accumulate any more CO_2 from the air. At that point the total amount of CO_2 becomes constant. Subsequently, as the groundwater flows through the confined aquifer, the free CO_2 acts as a dissolving agent. A large amount of free CO_2 in the groundwater makes it chemically active, especially if the bedrock is calcareous.

One way the amount of CO_2 could increase would be by infiltration of groundwater from another source. Thus an increase in CO_2 could be interpreted as indicating that recharge of the aquifer occurs nearby. This may be the explanation that can be given for sample No. 20, where direct infiltration is the only source of recharge of this well, thus giving a CO_2 value of 60 ppm.

However, Figure 19 shows that the high CO_2 values are mainly located in the discharge areas where, theoretically, the CO_2 value should be at a minimum. Sulphate reduction is accompanied by the production of CO_2 (Back and Hanshaw, 1965) and evidence of sulphate reduction can readily be found in Russell County. This will be discussed later in this report under "Hydrogen Sulphide (H_2S)."

Specific Conductance, Total Dissolved Solids (TDS) and Sodium Chloride (NaCl)

For purposes of this report, specific conductance, sum of constituents and total dissolved solids (TDS) are considered to be one because of the relationship that exists between them, and the abbreviation TDS will be used in the discussion of values. The average TDS value of 1,459 ppm (which excludes sample No. 45) indicates that the quality of groundwater in Russell County can be classified chemically as only fair. The TDS value varies widely, from a minimum of 142 ppm to a maximum of 8,659 ppm (again excluding sample No. 45). Of the total of 73 samples considered, 19 (26 percent) have TDS values exceeding 1,500 ppm. Standards recommended in Table 1 show 1,000 ppm as the upper limit for the TDS value; however, 1,500

Table 1. Chemical Analyses of Groundwater in Russell County, Ontario (Analyzed by Water Quality Division, Department of Energy, Mines and Resources; now Water Quality Branch, Department of the Environment)

Sample Number	Location			Coordinates, U T M G System	Depth of Well (feet)	Aquifer	Colour (Hazen Unit)	pH	Carbon Dioxide (CO_2) ppm	Conductance (micromhos/cm at 25 °C)	Chemical Constituents in Parts Per Million																
	Township	Concession	Lot Number								Hardness* Non-carbonate	Hardness* Total	Total Alkalinity as $CaCO_3$	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Iron (Fe)	Bicarbonate (HCO_3)	Sulphate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Silica (SIO_4)	Sum of Constituents	% of Sodium	SAR
1	C1	OF	21	793-442	–	–	5	7.3	22	1741	0	180	228	43.3	17.5	300.0	17.5	0.09	278	7.4	420.0	0.44	3.40	17	963	75	9.70
2	C1	VI	1	807-416	–	LS	20	8.2	5	1029	0	75	389	14.8	9.3	208.0	12.2	4.60	474	14.2	98.0	1.30	1.40	17	610	83	10.00
3	C1	V	6	840-395	–	TI	60	8.1	14	2649	0	70	895	17.7	6.3	585.0	21.0	0.24	1091	1.6	362.0	1.80	0.01	16	1549	93	30.00
4	C1	II	A	856-438	228	BRX	180	8.0	10	931	0	64	510	13.8	7.2	208.0	11.1	3.00	622	3.2	7.6	1.20	1.40	17	576	85	11.00
5	C1	II	13	884-368	–	TI	30	7.7	39	7155	0	173	1017	12.6	34.0	1600.0	41.0	0.67	1240	1.0	56.4	1.60	18.00	14	4332	94	53.00
6	C1	V	10	849-373	90	BRX	20	7.9	7	539	0	232	298	42.7	30.5	30.0	8.4	0.61	363	2.6	2.5	0.43	0.60	24	320	21	0.90
7	C1	V	15	862-342	60	BRX	5	7.7	9	417	0	178	227	43.0	17.2	23.5	6.2	3.10	277	2.4	1.4	0.25	0.33	20	250	22	0.80
8	C1	IV	22	881-303	–	TI	10	7.4	45	15261	160	746	586	47.3	153.0	3060.0	75.0	3.20	714	1.0	4920.0	1.10	37.00	13	8659	89	49.00
9	C1	X	22	814-274	124	BRX	70	8.0	11	1541	0	28	548	8.3	1.8	354.0	10.0	0.95	668	1.5	184.0	1.80	1.40	14	905	95	29.00
10	Ca	VI	30	822-151	–	–	50	7.9	15	1755	0	53	621	15.8	3.3	400.0	13.8	5.30	757	22.0	195.0	1.90	5.00	12	1041	92	24.00
11	Ca	VII	30	829-134	35	–	5	7.6	24	1645	0	126	487	15.8	21.0	300.0	19.0	2.90	594	75.0	190.0	1.30	2.20	13	930	81	12.00
12	Ca	IX	27	862-095	117	BRX	5	7.6	11	532	0	188	232	38.6	22.3	40.0	10.0	0.59	283	38.2	9.3	0.64	0.51	10	309	30	1.30
13	Ca	X	19	9050-1085	62	GR	5	7.5	5	242	22	107	85	32.3	6.4	4.5	2.3	0.03	103	28.7	5.0	0.13	0.04	12	142	8	0.20
14	Ca	III	8	921-226	108	GR	30	8.3	3	628	0	44	338	9.1	5.2	135.0	10.0	0.85	412	1.3	5.0	1.10	1.70	15	386	84	8.80
15	C1	I	21	919-327	90	BRX	10	7.5	33	5475	0	190	545	18.9	34.7	1120.0	36.0	0.26	664	4.0	1500.0	1.80	5.70	10	3058	91	35.00
16	Ca	IV	1	958-236	100	BRX	20	8.1	6	722	0	94	380	16.7	12.6	135.0	12.0	0.24	463	0.9	17.0	0.72	0.19	19	442	73	6.10
17	Ca	V	6	947-199	65	CL	10	8.2	5	987	0	185	454	29.2	27.2	150.0	36.5	9.60	553	19.3	50.0	0.90	2.50	18	606	58	4.80
18	Ca	VIII	G	985-178	90	GR	5	8.0	5	1405	0	36	284	11.8	1.6	290.0	6.7	0.38	346	58.0	245.0	1.60	0.10	10	795	93	21.00
19	Ca	VIII	6	955-165	82	SA	5	7.6	8	706	0	95	158	18.7	11.8	112.0	7.8	0.97	193	41.6	98.0	1.30	0.07	20	406	70	5.00
20	Ca	IX	11	943-128	70	LS	10	7.1	60	954	59	452	393	162.0	11.5	17.5	26.5	0.33	479	51.8	39.0	0.04	23.50	10	578	7	0.40
21	Ca	VII	20	885-139	92	–	50	7.6	55	6485	0	275	1126	27.6	50.1	1380.0	41.7	0.35	1373	5.0	1535.0	1.40	27.00	17	3761	90	36.00
22	Ca	VII	13	917-159	70	BRX	5	7.7	13	1163	0	80	337	19.7	7.5	240.0	10.5	0.40	411	25.7	188.0	0.90	2.30	13	710	85	12.00
23	Ca	V	20	873-171	169	LS	20	7.6	40	6312	0	297	816	31.5	53.0	1250.0	40.5	0.85	995	8.0	1615.0	1.20	13.00	14	3516	89	31.00
24	Ca	IV	15	885-208	129	TI	60	7.9	26	4221	0	113	1072	11.8	20.3	970.0	25.1	0.19	1307	3.0	784.0	1.20	10.00	15	2483	94	40.00
25	Ca	IV	23	847-194	40	SA	20	7.6	23	2688	0	230	466	39.4	32.0	490.0	14.3	0.41	568	13.6	578.0	0.50	2.90	15	1465	81	14.00
26	Ca	V	25	850-163	95	BRX	10	7.3	62	5338	5	646	641	90.6	102.0	900.0	25.5	3.20	781	36.5	1410.0	0.50	3.80	15	2969	74	15.00
27	Ca	VI	23	863-148	–	–	40	7.8	25	8468	0	407	826	33.5	78.6	1700.0	41.7	0.17	1007	4.0	2250.0	1.10	0.11	15	4619	89	37.00
28	Ca	IV	30	818-169	65	CL	40	7.9	11	1025	0	21	472	5.9	1.5	235.0	11.0	0.18	575	7.3	56.0	1.50	1.50	14	617	94	22.00
29	Cu	I	23	784-259	69	LS	70	8.2	4	658	0	8	335	2.4	0.5	165.0	8.5	0.05	408	9.0	18.0	1.80	0.04	8	415	95	25.00
30	Cu	II	13	760-312	48	LS	5	8.0	5	540	28	284	256	89.0	15.0	1.0	1.7	0.21	312	23.7	4.0	0.04	13.50	4	305	1	0.03
31	C1	IX	15	809-324	176	LS	5	7.5	22	1681	0	175	352	17.7	31.8	510.0	24.5	0.29	429	6.1	690.0	1.10	11.50	18	1522	84	17.00
32	C1	X	8	781-358	165	LS	5	8.0	6	919	72	405	333	132.0	18.3	31.0	15.0	3.00	406	44.6	52.0	0.12	46.00	11	549	14	0.70
33	C1	VIII	6	802-381	147	SA&GR	120	8.5	4	1102	0	31	606	9.5	1.8	265.0	12.5	0.99	711	1.7	12.0	1.60	2.20	16	686	92	21.00
34	Cu	I	5	750-362	40	LS	5	7.7	6	371	0	83	163	19.7	8.1	50.0	6.6	0.05	199	19.3	7.7	0.60	0.00	17	226	54	2.40
35	C1	X	2	766-394	84	GR	5	8.0	4	383	0	121	196	25.2	14.1	33.5	8.5	0.15	239	3.9	3.9	0.41	0.70	15	223	36	1.30
36	C1	OF	33	754-419	145	GR	5	7.3	34	8421	552	904	352	118.0	148.0	1470.0	46.9	0.80	429	303.0	2410.0	0.17	31.00	24	4763	77	21.00
37	Cu	IX	3	647-340	43	GR	5	8.1	4	527	0	207	271	50.4	19.7	36.5	6.8	0.73	330	15.2	7.2	0.41	0.08	16	315	27	1.10
38	Cu	XI	8	6331-2968	86	SH	40	8.6	2	535	0	37	410	9.9	2.9	206.0	10.7	0.22	481	4.4	73.2	1.70	0.00	13	568	90	15.00
39	Cu	VIII	13	675-283	118	SH	5	7.8	8	553	0	95	252	18.9	11.6	90.2	11.0	0.15	307	25.6	16.2	0.45	1.90	15	342	64	4.00
40	Cu	V	10	708-311	209	LS	5	7.7	11	632	0	215	275	65.9	12.2	60.2	7.6	1.00	335	33.6	26.0	0.59	0.26	10	381	37	1.80
41	Cu	IV	11	7293-3172	82	LS	5	8.0	8	829	5	418	413	106.0	37.2	23.5	5.4	8.20	503	19.2	27.6	0.18	0.00	21	488	11	0.50
42	Cu	IV	15	733-288	80	GR	5	7.7	10	549	27	275	248	77.1	20.0	16.5	3.5	0.04	302	39.7	7.3	0.14	4.00	15	332	11	0.40
43	Cu	IV	28	757-214	88	SH	10	7.4	11	274	0	99	145	23.4	32.5	20.0	6.5	0.22	177	1.1	1.8	0.25	0.00	16	165	29	0.90
44	Cu	VIII	26	707-208	65	SH	80	7.9	7	836	0	92	284	9.7	2.7	155.0	14.0	3.20	346	80.4	45.0	0.56	9.50	8	518	75	7.00
45	Cu	IX	19	671-242	–	–	30	6.1	70	128919	43754	43800	46	12100.0	3299.0	23600.0	500.0	11.50	55	700.0	66750.0	5.30	0.10	3	106985	54	49.00
46	Cu	IX	19	671-242	–	–	50	7.6	37	8005	0	379	768	45.7	64.4	1750.0	44.5	0.17	936	61.5	2300.0	0.90	22.00	17	4767	90	39.00
47	Cu	X	28	678-185	75	BRX	10	7.7	16	1849	0	66	411	20.1	3.7	372.0	16.9	0.23	501	57.0	315.0	1.40	1.50	12	1046	90	20.00
48	R	I	21	675-156	130	SH	5	7.0	12	7321	1319	1380	61	398.0	93.8	1300.0	31.5	0.95	74	1950.0	1420.0	0.70	3.70	8	5242	67	15.00

Sample Number	Location: Township	Location: Concession	Location: Lot Number	Coordinates, U T M G System	Depth of Well (feet)	Aquifer	Colour (Hazen Unit)	pH	Carbon Dioxide (CO_2) ppm	Conductance (micromhos/cm at 25°C)	Hardness*: Non-carbonate	Hardness*: Total	Total Alkalinity as $CaCO_3$	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Iron (Fe)	Bicarbonate (HCO_3)	Sulphate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Silica (SiO_4)	Sum of Constituents	% of Sodium	SAR
											Chemical Constituents in Parts Per Million																
49	R	V	19	735-176	62	LS	5	8.2	5	863	0	10	395	3.7	0.06	206.0	8.2	0.29	482	0.9	54.0	1.50	1.60	8	521	96	29.00
50	R	V	13	748-145	105	SH	30	7.8	28	3690	0	99	913	21.3	11.2	800.0	18.0	0.44	1113	9.0	695.0	1.50	6.70	11	2121	93	35.00
51	R	III	18	706-153	68	SH	5	7.4	22	868	93	374	281	113.0	22.3	36.0	15.0	0.01	343	80.0	40.0	0.20	44.00	12	531	17	0.80
52	R	II	15	704-132	130	–	5	7.6	12	716	87	342	255	90.0	28.5	17.0	11.0	0.28	311	85.0	27.0	0.06	10.00	13	435	9	0.40
53	R	V	10	747-121	100	GR	30	7.7	37	6938	0	260	956	27.6	46.4	1440.0	37.2	0.41	1165	11.5	1800.0	1.00	21.00	12	3970	91	39.00
54	R	VIII	11	778-151	160	LS	30	7.7	37	12294	0	678	953	49.3	135.0	2450.0	71.1	0.70	1162	78.0	3720.0	0.80	53.00	14	7143	87	41.00
55	R	VIII	15	782-176	190	BRX	20	7.7	39	10149	0	438	1010	44.5	79.4	2200.0	88.0	0.75	1231	73.0	2800.0	0.70	0.14	14	5705	89	41.00
56	R	VIII	9	785-133	148	LS	20	7.4	54	7136	0	608	697	96.1	89.4	1270.0	98.0	0.93	850	75.5	1930.0	0.69	13.50	13	4004	79	22.00
57	R	VIII	5	792-117	93	LS	5	7.8	9	861	0	272	309	60.1	29.6	85.5	9.5	0.10	377	110.5	28.8	0.80	1.30	17	528	40	2.20
58	R	VII	2	797-097	40	SA	5	8.0	5	783	0	175	251	36.8	20.2	100.0	11.1	0.30	306	68.2	61.0	0.55	0.27	18	466	54	3.30
59	R	X	C	840-098	60	LS	5	7.0	51	600	44	308	264	104.0	11.7	7.7	3.4	3.00	322	42.3	13.7	0.17	0.00	9	350	5	0.20
60	R	VI	B	782-066	65	LS	5	7.2	31	1421	429	683	254	175.0	59.8	69.2	8.3	0.52	310	471.0	54.0	0.78	0.65	18	1009	18	1.10
61	R	V	5	761-099	69	LS	5	7.8	9	591	0	137	280	21.6	20.1	82.8	11.1	0.18	341	27.7	9.2	0.69	1.30	14	357	54	3.10
62	R	III	5	743-084	62	LS	5	7.5	23	1116	192	562	370	104.0	73.4	24.0	20.7	1.00	451	183.0	48.0	0.50	0.17	19	695	8	0.40
63	R	II	1	737-050	120	BRX	5	7.6	12	591	74	320	246	81.5	28.3	3.9	1.6	0.76	300	74.4	3.6	0.12	0.00	20	361	3	0.09
64	R	I	8	707-086	115	LS	5	7.8	7	1206	0	102	218	30.1	6.5	216.0	9.9	0.11	266	146.0	155.0	2.10	0.00	8	705	80	9.30
65	Cu	OF	WC	597-357	170	LS	30	7.7	17	1208	0	320	441	75.6	31.9	160.0	11.9	0.33	538	41.2	145.0	0.74	0.46	19	750	51	3.90
66	Cu	XI	A	6130-3398	160	GR	5	7.7	14	2069	0	111	371	31.5	7.9	382.0	17.6	0.17	452	117.0	.358.0	1.00	2.30	19	1158	86	16.00
67	Cu	VIII	C	649-373	129	LS	5	7.8	13	891	0	375	437	122.0	17.1	44.4	26.9	2.80	533	22.8	19.0	0.21	6.80	16	537	19	1.00
68	Cu	OF	30	623-375	135	LS	5	7.9	9	943	0	228	357	50.0	25.1	117.0	12.1	2.80	435	29.6	82.0	0.49	1.70	22	554	51	3.40
69	Cu	OF	25	638-396	260	LS	5	7.5	11	495	29	217	188	61.5	15.4	23.1	4.4	0.08	229	54.7	15.0	0.50	0.05	13	301	18	0.70
70	Cu	VI	3	676-350	55	GR	5	7.6	13	680	0	234	266	67.9	15.7	60.0	5.9	0.81	324	35.4	41.0	0.28	0.03	17	403	35	1.70
71	Cu	OF	8	724-365	125	–	5	7.8	13	794	0	413	426	94.6	42.9	26.7	4.4	2.90	519	27.2	6.0	0.33	0.07	15	473	12	0.60
72	Cu	OF	10	696-409	287	LS	5	7.4	26	3469	0	332	332	58.3	45.3	585.0	24.0	0.09	405	38.0	890.0	0.55	125.00	16	1868	78	14.00
73	Cu	OF	3	728-411	158	SA	5	7.3	29	1580	0	275	294	56.7	32.4	200.0	13.3	0.61	358	49.0	280.0	0.45	18.50	14	841	60	5.20
74	Cu	OF	18	664-400	218	SA	170	8.2	9	1427	0	27	773	8.3	1.5	334.0	13.8	0.57	942	17.6	5.3	1.40	8.40	15	869	94	28.00
AVERAGE					110		23	7.7	19	2485†	43†	254†	434	52.0†	30.6†	462.0†	19.6†	1.32	529	79.0	514.1†	0.83†	8.52	14	1459†	60	14.37
STANDARDS‡				PERMISSIBLE	–		15	6.5 to	–	–	–	120*	30	75.0	50.0	–	–	0.05	–	200.0	250.0	0.50	10.0	–	500	–	–
				EXCESSIVE	–		50	8.3	–	–	–	–	500	200.0	150.0	–	–	0.30	–	500.0	250.0	1.50	10.0	–	1000	60	18

NOTE: Sample Nos. 1-47 were collected on September 24-26, 1968; sample Nos. 48-74 on October 2-3, 1968.

NOTE:
- Cl – Clarence
- Ca – Cambridge
- Cu – Cumberland
- Ru – Russell
- OF – Ottawa Front
- G – Gore
- WC – Western Common

- BRX – Bedrock
- CL – Clay
- GR – Gravel
- LS – Limestone
- SA – Sand
- SH – Shale
- TI – Till

*Over 120 ppm is considered hard water.

†Values for sample No. 45 are not included in average.

‡Standards are those of the Department of National Health and Welfare, Canada, 1968. Fluoride is an exception. Permissible = good potable water. Excessive = water is not considered potable.

ppm is also acceptable if a better source of water is not available. At the same time, 25 samples (34%) having TDS values less than 500 can be considered excellent sources of groundwater. As would be expected, the areas yielding excellent water are located in or near recharge zones, whereas samples with high TDS values are located in or near discharge zones.

Figures 22 and 23 illustrate that the specific conductance or TDS value of a groundwater sample is related to its sodium chloride value. Both figures show high values along the Ottawa River and throughout the central part of Russell County.

Figure 20 shows the quality of groundwater that one can expect to encounter in Russell County. It shows also that of the four townships, Cumberland Township has the largest area of excellent potable water.

Calcium (Ca), Magnesium (Mg) and Total Hardness

The water in Russell County is generally hard. The zones of soft water are shown (Fig. 21), but a trend cannot be established. It is curious that almost half the groundwater samples with less than 100 ppm total hardness have a high colour count of 50 Hazen units or more. It was thought by the writer that the areas with high hydrogen sulphide (H_2S) occurrence would yield soft water, as had been found in previous studies in Manitoba, but such is not the case in Russell County. Groundwater samples with H_2S can yield either hard or soft groundwater.

Sulphate (SO_4)

The sulphate value is remarkably low throughout the county. Figure 24 shows that in the greater part of the eastern half of Russell County the groundwater has less than 10 ppm sulphate. The low value is attributed to sulphate reduction, and the occurrence of H_2S is proof of this. The bacteria that cause sulphate reduction originate in the two large bogs, Mer Bleue to the west and Moose Creek to the southeast, therefore the reduction takes place to the west and south of the area shown with a low sulphate value (Fig. 24), and one can predict in a general way the direction of groundwater flow in Russell County. It should be west to east in the northern part and from south to north in the southern part of the map sheet, as illustrated on Figure 24.

Fluoride (F)

Over half the 74 groundwater samples collected (Table 1) had a fluoride content between 0.5 and 1.5 ppm. The optimum level of 1.2 mg/l has been recommended by the Department of National Health and Welfare (1968) for the prevention of tooth decay, however, most of the samples came from locations in the southern portion of Russell County (Fig. 25), where the water from many wells is not potable because of a high sodium chloride content.

Iron (Fe) and Nitrate (NO_3)

Iron values of more than 1 ppm are not uncommon in the area. Since 1 ppm is the maximum at which a water softener will work efficiently, it explains why so many householders are dissatisfied with their water-softening equipment. Nitrate is present in the groundwater samples, even though the wells supposedly obtain water only from confined aquifers. The presence of nitrate is almost inevitable in a rural area. However, defining a high nitrate value as one with greater than 60 ppm nitrate, only sample No. 72 can be said to have a high nitrate value.

Percent Sodium and Sodium Absorption Ratio (SAR)

Approximately two-thirds of the groundwater samples have an SAR ratio of less than 18. Fewer than half the samples have a percent sodium value of less than 60 percent. However, the availability of groundwater in Russell County is not sufficient to support irrigation and, consequently, these values are of purely academic interest.

Hydrogen Sulphide (H_2S)

Of the dissolved constituents that are highly objectionable in a water supply, hydrogen sulphide ranks near the top. Although it is not injurious to persons in the concentrations encountered, H_2S has a disagreeable rotten-egg odour and is also corrosive to metals. For the householder the odour is the more offensive characteristic of the two. Methods for removal of H_2S from groundwater are discussed by Giffen (1969).

As shown on Figure 26, H_2S is found in almost all of the groundwaters in the map-area. It is known that this H_2S is a product of sulphate reduction.

All the H_2S analyses were done with a Hach Kit analyzer, which detects only the soluble sulphides. It seems that the soluble sulphides produced by sulphate reduction are responsible for the disagreeable odour.

Two zones (I and II on Fig. 26) were chosen for a detailed study of H_2S. The selection was based on many wells (42% of the wells in these areas contained H_2S) with a relatively high concentration of H_2S (0.5 to 5.0 ppm). Zone I is situated in Cambridge Township on the road to St. Albert, Concessions IX and X and Lots 25 to 30. Zone II is in Cumberland Township on the Navan Road, Concessions X and XI and Lots 6 to 9. It was hoped that the data gathered would indicate a trend in the H_2S value, either increasing or decreasing from east to west, but they did not. It should be mentioned that, in many cases, it was very difficult to obtain good groundwater samples because every household has a pressure system hooked up to the well pump and, to make matters worse, some had subsurface reservoirs to balance their water supplies.

The study of the two zones showed that in Zone I the groundwater was generally hard (more than 125 ppm total hardness), and in Zone II it was generally soft (less than 100 ppm total hardness). Geologically, Zone I is situated on a bedrock high covered with only a thin, 18-foot mantle of overburden; Zone II is also underlain by a bedrock high, but it is covered by a relatively thick (80 feet) cover of overburden. The bedrock in both instances is limestone of the Ottawa Formation.

The H_2S content in a groundwater supply may vary with time. Generally, the only way the householder can readily detect H_2S is by odour. On this basis, some wells in the study area yield H_2S part of the time, whereas others yield H_2S all the time, although the amount produced varies noticeably. Variations for Well A (Fig. 26; also shown on Figure 8 as Well No. 271, UTMG coordinates 690-275) seem to be associated with changes in atmospheric pressure. During a period of high barometric pressure the odour from this well was quite pronounced and an H_2S test yielded 5.0 ppm, whereas during a barometric low the odour completely disappeared and an H_2S test resulted in 0.0 ppm. A similar test at Well B (Fig. 26; shown on Figure 8 as Well No. 427, UTMG coordinates 747-348), carried out simultaneously under the same atmospheric conditions, yielded 5.0 ppm H_2S at all times.

Finally, the odour of an H_2S sample did not seem to be directly related to the H_2S value as indicated by the Hach Kit test, that is, a sample that seemed to have a very strong odour did not always give a high H_2S value and vice versa. Actually, odour was never measured and was always a matter of judgment on the part of the observer who was, however, always the same person.

Of the more than one hundred samples found to contain H_2S, only two had a sodium chloride content greater than 500 ppm. It seems that wells of high salinity are free of H_2S.

It is hoped that these observations on the behaviour of hydrogen sulphide will arouse the curiosity of someone to develop a cheap method for the removal of the H_2S, so that someday the households presently affected in Russell County and elsewhere may be free of the nauseous odour caused by it.

Hydrogeochemistry

SEMI-LOGARITHMIC DIAGRAMS

Semi-logarithmic diagrams of Schoeller (1962) are the basis for this hydrogeochemical approach to determine the direction of groundwater movement. However, each analysis, instead of being presented graphically using Schoeller's semi-logarithmic diagrams, will be shown as part of a group. Table 2 lists the numerical data. The data are based on the usual six ions, Ca^{++}, Mg^{++}, Na^{+}, Cl^{-}, $SO_4^{=}$ and HCO_3^{-}. The 74 analyses have been divided into six groups, and most of the groups have also been subdivided. Therefore Table 2 is more than just a table with data; it is a table that illustrates the order of the six groups, as well as the order of the analyses within each group. Although the semi-logarithmic diagram is the basis on which the groups are formed, Table 2 is also very helpful in sorting out the groups and sub-groups, especially where some ambiguity occurs between certain analyses. The entire grouping process was carried out without reference to the aquifer from which the groundwater was obtained, to the depth of the well or to its location.

Once the six groups were established (Table 2, Figs. 27 and 30), it became evident that the sixth group was quite different from the first five groups and belonged to another regional groundwater flow. For that reason, it has been excluded from this presentation. Figure 27 shows that there is a chemical relationship between each group. Furthermore, if each analysis had been plotted individually on semi-logarithmic paper, it could be seen that a chemical relationship also exists between the analyses within a group. This chemical relationship within and between groups is the main component in establishing the direction of groundwater flow in this report.

CHEMICAL TYPES OF GROUNDWATER

With the exception of group 1, the order of the groups was determined by the average TDS value of each group. Therefore group 2 represents a recharge area, and group 5 represents a discharge area. The most striking features of the five groups as they are illustrated on Figure 27 are: (1) the very low sulphate value (less than 1.0 equivalents per million (epm) in all the groups, except group 1); (2) the change in the Na/Mg ratio at recharge (in group 1, Na/Mg was less than 1.0 epm, while the corresponding change in group 2 was greater than 1.0); (3) the change in the Mg/Ca ratio at discharge (in groups 1, 2, 3 and 4, Mg/Ca was less than 1.0, while the corresponding change in group 5 was greater than 1.0); and (4) the change in the SO_4/Cl ratio towards discharge (in groups 1, 2 and 3, SO_4/Cl was greater than 1.0, while the corresponding change in groups 4 and 5 was less than 1.0). It should be noted, however, that the groups could have been divided into two sequences. One sequence would have had an SO_4/Cl ratio greater than 1.0 and would have consisted of groups 1, 2a and 3a (Table 2), while the other sequence would have had an SO_4/Cl ratio of less than 1.0 and would have comprised groups 2b, 3b, 4, 5a and 5b (Table 2). Because of the low chloride and sulphate values (less than 1.0 epm) in most of the analyses of groups 1, 2 and 3, a slight change either in the chloride or sulphate value could have produced an SO_4/Cl ratio of less than 1.0 throughout this entire flow sequence. Therefore, the forming of two sequences was abandoned.

GROUP 1

Of the five groups discussed here, group 1 is the most irregular. First, its average TDS (453 ppm) is greater than that of group 2, mainly because of two analyses (No. 60 and No. 62). These two analyses have a relatively high TDS value and it seems unlikely that they are representative of natural recharge areas. They should therefore have been placed in another group but, because they do not fit any other pattern or group, they were placed in group 1. Analysis No. 60 has the distinction of having the highest sulphate value of all the analyses in these five groups. It can be classified as a sulphate-bicarbonate type of water on the hydrogeochemical map (Fig. 31). Analysis No. 62 has an Mg/Ca ratio greater than 1.0. This alone should place it near or in a discharge area. Because sample No. 62 has been placed in group 1, which is considered to be at the recharge end of a groundwater flow, it follows that sample No. 62 should be found near the outer limits of that recharge zone.

The pattern displayed by group 1 (Fig. 27) is concave in shape, which is typical of groundwater encountered in a recharge area or in unconfined aquifers (shallow-dug wells), especially if the concave pattern is more of a U-shape than a

Table 2. Chemical Analyses of Groundwater for Hydrogeochemical Interpretation

Sample No.	Group	Chemical Constituents and Ratios in epm (equivalent per million): Calcium ($_rCa$)	Magnesium ($_rMg$)	Sodium + Potassium ($_rNa_rK$)	Chloride ($_rCl$)	Sulphate ($_rSO_4$)	Bicarbonate ($_rHCO_3$)	$_rMg$ / $_rCa$	$_rNa$ / $_rMg$	$_rSO_4$ / $_rCl$	$\frac{_rCl - _rNa}{_rCl}$ (b.e.i.)	$\sqrt{(_rCa)(_rSO_4)}$ (S)	$\sqrt[3]{(_rHCO_3)^2(_rCa)}$ (Kr eq)	$\sqrt{(_rCa)(_rHCO_3)}$ (pH eq)	Total Dissolved Solids of Six Ions used	Ionic Strength (μ)	$3.618\sqrt{\mu}$ (ΔpH)	Temp. @ Testing (°C)	Correction for Temperature (θ)	pH	$\theta + \Delta pH + pH$ eq (pH eq corrected)	pH eq corrected from scale
13	11	1.61	0.53	0.26	0.14	0.60	1.69	0.33	0.49	4.29	−0.86	0.98	1.66	1.65	4.83	0.004	0.23	23	+0.04	7.5	1.92	7.6
12	11	1.93	1.83	1.90	0.26	0.80	4.64	0.95	1.03	3.08	−6.31	1.24	3.46	2.99	11.36	0.010	0.37	23	+0.04	7.6	3.40	7.2
59	11	5.19	0.96	0.42	0.39	0.88	5.28	0.18	0.44	2.26	−0.08	2.14	5.25	5.23	13.12	0.010	0.37	22	+0.06	7.0	5.66	6.7
30	12	4.44	1.23	0.08	0.11	0.49	5.11	0.28	0.07	4.45	+0.27	1.47	4.88	4.76	11.46	0.009	0.35	23	+0.04	8.0	5.29	6.8
71	12	4.72	3.53	1.27	0.17	0.57	8.51	0.75	0.36	3.35	−6.47	1.64	6.99	6.34	18.77	0.016	0.47	22	+0.06	7.8	6.87	6.5
63	13	4.07	2.33	0.21	0.10	1.55	4.92	0.57	0.03	15.50	−0.70	2.51	4.62	4.47	13.03	0.010	0.37	22	+0.06	7.6	4.90	6.8
52	13	4.49	2.34	1.02	0.76	1.77	5.10	0.52	0.44	2.23	−0.34	2.82	4.89	4.79	15.48	0.012	0.40	22	+0.06	7.6	5.25	6.8
62	13	5.19	6.04	1.57	1.35	3.81	7.39	1.16	0.26	2.82	−0.16	4.45	6.57	6.19	25.35	0.020	0.52	22	+0.06	7.5	6.77	6.5
60	13	8.73	4.92	3.22	1.52	9.81	5.00	0.56	0.65	6.45	−1.12	9.25	6.09	6.66	33.28	0.023	0.55	22	+0.06	7.2	7.27	6.5
7	2a1	2.15	1.41	1.18	0.04	0.05	4.54	0.69	0.84	1.25	−28.50	0.32	3.54	3.12	9.37	0.008	0.33	23	+0.04	7.7	3.49	7.1
37	2a1	2.51	1.62	1.76	0.20	0.32	5.41	0.65	1.09	1.60	−7.80	0.90	4.19	3.68	11.82	0.010	0.37	23	+0.04	8.1	4.09	7.0
42	2a1	3.85	1.64	0.81	0.21	0.83	4.95	0.43	0.49	3.95	−2.86	1.79	4.55	4.37	12.29	0.010	0.37	22	+0.06	7.7	4.80	6.8
69	2a2	3.07	1.27	1.11	0.42	1.14	3.75	0.41	0.87	2.71	−1.64	1.87	3.49	3.39	10.76	0.008	0.33	22	+0.06	7.5	3.78	7.1
51	2a2	5.64	1.83	1.95	1.13	1.67	5.62	0.32	1.07	1.48	−0.73	3.07	5.63	5.63	17.84	0.014	0.44	22	+0.06	7.4	6.13	6.0
43	2b1	1.17	0.80	1.04	0.05	0.02	2.90	0.68	1.30	0.40	−19.80	0.15	2.14	1.84	5.98	0.005	0.26	22	+0.04	7.4	2.14	7.5
35	2b1	1.26	1.16	1.68	0.11	0.08	3.92	0.92	1.45	0.73	−14.27	0.32	2.69	2.22	8.21	0.007	0.31	23	+0.04	8.0	2.57	7.4
6	2b1	2.13	2.51	1.51	0.07	0.05	5.95	1.18	0.60	0.71	−20.57	0.33	4.22	3.56	12.22	0.011	0.39	23	+0.04	7.9	3.99	7.0
40	2b1	3.29	1.00	2.80	0.73	0.70	5.49	0.30	2.80	0.96	−2.84	1.52	4.63	4.25	14.01	0.013	0.42	23	+0.04	7.7	4.71	6.9
41	2b1	5.29	3.06	1.16	0.78	0.40	8.24	0.58	0.38	0.51	−0.49	1.45	7.11	6.60	18.93	0.016	0.47	22	+0.06	8.0	7.13	6.5
67	2b1	6.09	1.41	2.62	0.54	0.47	8.74	0.23	1.86	0.87	−3.85	1.69	7.75	7.30	19.87	0.016	0.47	22	+0.06	7.8	7.83	6.4
70	2b2	3.39	1.29	2.76	1.16	0.74	5.31	0.38	2.14	0.64	−1.38	1.58	4.57	4.24	14.65	0.012	0.40	22	+0.06	7.6	4.70	6.9
32	2b2	6.59	1.50	1.73	1.47	0.93	6.65	0.23	1.15	0.63	−0.18	2.48	6.63	6.62	18.87	0.015	0.45	23	+0.04	8.0	7.11	6.5
20	2b2	8.08	0.95	1.44	1.10	1.08	7.85	0.12	1.52	0.98	−0.31	2.95	7.92	7.96	20.50	0.015	0.45	23	+0.04	7.1	8.45	6.4
34	3a1	0.98	0.67	2.34	0.22	0.40	3.26	0.68	3.49	1.82	−9.64	0.63	2.18	1.79	7.87	0.007	0.31	23	+0.04	7.7	2.14	7.6
39	3a1	0.94	0.95	4.20	0.46	0.53	5.03	1.01	4.42	1.15	−8.13	0.71	2.88	2.17	12.11	0.011	0.39	23	+0.04	8.6	2.60	7.4
74	3a1	0.41	0.12	14.87	0.15	0.37	15.44	0.29	123.91	2.47	−9.81	0.39	4.61	2.52	31.36	0.031	0.20	23	+0.04	8.2	2.76	7.4
44	3a2	1.62	0.22	7.10	1.27	1.67	5.67	0.14	32.27	1.31	−4.59	1.64	3.73	3.03	17.55	0.016	0.47	23	+0.04	7.9	3.54	7.1
57	3a2	3.00	2.43	3.96	0.81	2.30	6.18	0.81	1.63	2.84	−3.89	2.63	4.86	4.31	18.68	0.016	0.47	22	+0.06	7.8	4.84	6.9
29	3b1	0.12	0.04	7.39	0.51	0.19	6.69	0.33	184.75	0.37	−13.49	0.15	1.75	0.90	14.94	0.015	0.45	23	+0.04	8.2	1.39	7.9
33	3b1	0.47	0.15	11.84	0.34	0.04	11.65	0.36	78.93	0.12	−33.82	0.14	4.00	2.34	24.49	0.024	0.57	23	+0.04	8.5	2.95	7.3

Table 2 (Cont.)

Sample No.	Group	Chemical Constituents and Ratios in epm (equivalent per million): Calcium ($_rCa$)	Magnesium ($_rMg$)	Sodium + Potassium ($_rNa_rK$)	Chloride ($_rCl$)	Sulphate ($_rSO_4$)	Bicarbonate ($_rHCO_3$)	$_rMg / _rCa$	$_rNa / _rMg$	$_rSO_4 / _rCl$	$\frac{_rCl - _rNa}{_rCl}$ (b.e.i.)	$\sqrt{(_rCa)(_rSO_4)}$ (S)	$\sqrt[3]{(_rHCO_3)^2(_rCa)}$ (Kr eq)	$\sqrt{(_rCa)(_rHCO_3)}$ (pH eq)	Total Dissolved Solids of Six Ions used	Ionic Strength (μ)	$3.168\sqrt{\mu}$ (ΔpH)	Temp. @ Testing (°C)	Correction for Temperature (θ)	pH	$\theta + \Delta pH + pH\ eq$ (pH eq corrected)	pH eq corrected from scale
14	3b2	0.45	0.43	6.13	0.14	0.03	6.75	0.96	14.26	0.21	−42.79	0.12	2.74	1.74	13.93	0.014	0.44	23	+0.04	8.3	2.22	7.5
4	3b2	0.69	0.59	9.32	0.21	0.07	10.19	0.86	15.80	0.32	−43.38	0.22	4.15	2.65	21.07	0.021	0.53	23	+0.04	8.0	3.22	7.2
58	41	1.84	1.66	4.73	1.72	1.42	5.02	0.90	2.85	0.83	−1.75	1.83	3.59	3.04	16.39	0.014	0.44	22	+0.06	8.0	3.54	7.1
68	41	2.50	2.06	5.40	2.31	0.62	7.13	0.82	2.62	0.27	−1.34	1.24	5.03	4.22	20.02	0.017	0.48	22	+0.06	7.9	4.76	6.8
65	41	3.77	2.62	7.26	4.09	0.86	8.82	0.69	2.77	0.21	−0.78	1.80	6.64	5.77	27.42	0.023	0.56	22	+0.06	7.7	6.39	6.6
38	42	0.49	0.24	9.23	2.06	0.09	7.88	0.49	38.46	0.04	−3.48	0.66	3.12	1.96	19.99	0.019	0.51	23	+0.04	8.6	2.51	7.4
9	42	0.41	0.15	15.65	5.19	0.03	10.94	0.37	104.34	0.06	−2.02	0.35	3.66	2.12	32.37	0.030	0.63	23	+0.04	8.0	2.67	7.4
49	43	0.18	0.05	9.17	1.52	0.02	7.90	0.28	183.40	0.01	−5.03	0.06	2.24	1.19	18.84	0.018	0.49	22	+0.06	8.2	1.74	7.7
28	43	0.29	0.12	10.50	1.58	0.15	9.42	0.41	87.50	0.09	−5.65	0.21	2.95	1.65	22.06	0.021	0.53	23	+0.04	7.9	2.22	7.5
22	43	0.98	0.62	10.70	5.30	0.54	6.74	0.63	17.25	0.10	−1.02	0.73	3.54	2.57	24.88	0.021	0.53	23	+0.04	7.7	3.14	7.2
10	43	0.79	0.27	17.74	5.50	0.46	12.41	0.34	65.70	0.08	−2.23	0.60	4.96	3.13	37.17	0.034	0.65	23	+0.04	7.9	3.82	7.1
3	43	0.88	0.52	25.98	10.21	0.03	17.88	0.59	49.96	0.003	−1.54	0.23	6.55	3.97	55.50	0.050	0.81	23	+0.04	7.3	4.82	6.8
18	44	0.59	0.13	12.77	6.91	1.21	5.67	0.22	98.23	0.18	−0.85	0.84	2.67	1.83	27.28	0.023	0.56	23	+0.04	8.0	2.43	7.5
73	44	2.83	2.66	9.04	7.90	1.02	5.87	0.94	3.40	0.13	−0.14	1.70	4.60	4.08	27.32	0.023	0.56	22	+0.06	7.3	4.70	6.9
64	45	1.50	0.53	9.64	4.37	3.04	4.36	0.35	18.19	0.70	−1.21	2.14	3.05	2.56	23.44	0.019	0.51	22	+0.06	7.8	3.13	7.2
47	45	1.00	0.30	16.60	8.88	1.19	8.21	0.30	55.33	0.13	−0.87	1.09	4.07	2.87	36.18	0.031	0.64	22	+0.06	7.7	3.47	7.1
66	45	1.57	0.65	17.06	10.10	2.44	7.41	0.41	26.24	0.24	−0.69	1.96	4.42	3.41	39.23	0.034	0.65	22	+0.06	7.7	4.12	7.0
1	46	2.16	1.44	13.49	11.84	0.15	4.56	0.67	9.37	0.01	−0.14	0.18	3.55	3.14	33.64	0.027	0.59	23	+0.04	7.3	3.77	7.1
50	46	1.06	0.92	35.24	19.60	0.19	18.24	0.87	3.83	0.01	−0.80	0.45	7.06	4.40	75.25	0.065	0.90	22	+0.06	7.8	5.36	6.8
19	5a1	0.93	0.97	5.07	2.76	0.87	3.16	1.04	5.23	0.32	−0.84	0.90	2.14	1.71	13.76	0.011	0.39	23	+0.04	7.6	2.14	7.5
16	5a1	0.83	1.04	6.18	0.48	0.02	7.59	1.25	5.94	0.04	−11.88	0.13	3.63	2.54	16.14	0.015	0.45	23	+0.04	8.1	3.03	7.3
17	5a1	1.46	2.24	7.45	1.41	0.04	9.06	1.53	3.33	0.03	−4.28	0.24	4.93	3.64	21.66	0.020	0.52	23	+0.04	8.2	3.20	7.2
61	5a2	1.08	1.65	3.88	2.59	0.58	5.59	1.53	2.35	0.22	−0.50	0.79	3.23	2.46	15.37	0.013	0.42	22	+0.06	7.8	2.94	7.3
2	5a2	0.74	0.76	9.35	2.76	0.30	7.77	1.03	12.30	0.11	−2.39	0.15	3.55	2.40	21.68	0.019	0.51	23	+0.04	8.2	2.95	7.3
11	5a2	0.79	1.73	13.53	5.36	1.56	9.74	2.19	7.82	0.29	−1.52	1.11	4.22	2.77	32.11	0.029	0.62	23	+0.04	7.6	3.43	7.2
31	5b1	0.88	2.61	22.80	19.46	0.13	7.03	2.97	8.74	0.01	−0.17	0.34	3.52	2.49	52.91	0.043	0.75	23	+0.04	7.5	3.28	7.2
72	5b1	2.91	3.73	26.05	25.10	0.79	6.64	1.28	6.98	0.03	−0.04	1.51	5.04	4.40	65.22	0.051	0.82	22	+0.06	7.4	5.28	6.8
24	5b2	0.59	1.67	42.82	22.11	0.06	21.42	2.83	25.64	0.003	−0.94	0.19	6.47	3.55	88.67	0.077	1.00	23	+0.04	7.9	4.59	6.9
26	5b2	4.52	8.39	39.78	39.76	0.76	12.80	1.86	4.74	0.02	−0.001	1.85	9.05	7.61	106.01	0.083	1.04	23	+0.04	7.3	8.69	6.4
56	5b2	4.80	7.35	57.73	54.43	1.57	13.93	1.53	7.85	0.03	−0.06	2.75	9.77	8.18	139.81	0.109	1.19	22	+0.06	7.4	9.43	6.3

Sample No.	Group	Chemical Constituents and Ratios in epm (equivalent per million): Calcium ($_rCa$)	Magnesium ($_rMg$)	Sodium + Potassium ($_rNa_rK$)	Chloride ($_rCl$)	Sulphate ($_rSO_4$)	Bicarbonate ($_rHCO_3$)	$_rMg / _rCa$	$_rNa / _rMg$	$_rSO_4 / _rCl$	$\frac{_rCl - _rNa}{_rCl}$ (b.e.i.)	$\sqrt{(_rCa)(_rSO_4)}$ (S)	$\sqrt[3]{(_rHCO_3)^2(_rCa)}$ (K_r eq)	$\sqrt{(_rCa)(_rHCO_3)}$ (pH eq)	Total Dissolved Solids of Six Ions used	Ionic Strength (μ)	$3.168\sqrt{\mu}$ (ΔpH)	Temp. @ Testing (°C)	Correction for Temperature(θ)	pH	$\theta + \Delta pH + pH$ eq (pH eq corrected)	pH eq corrected from scale
25	5b3	1.97	2.63	21.66	16.30	0.28	9.31	1.34	8.24	0.02	−0.33	0.74	5.55	4.28	52.15	0.043	0.75	23	+0.04	7.6	5.07	6.8
23	5b3	1.57	4.36	55.38	45.54	0.17	16.31	2.78	12.70	0.004	−0.22	0.52	7.47	5.06	123.33	0.100	1.14	23	+0.04	7.6	6.24	6.8
27	5b3	1.67	6.46	74.99	63.45	0.08	16.50	3.87	11.61	0.001	−0.18	0.37	7.68	5.25	163.15	0.131	1.31	23	+0.04	7.8	6.60	6.7
21	5b4	1.38	4.12	61.07	43.29	0.10	22.50	2.99	14.82	0.002	−0.51	0.37	8.88	5.57	132.42	0.110	1.20	23	+0.04	7.6	6.84	6.5
46	5b4	2.28	5.30	77.23	64.86	1.28	15.34	2.32	14.57	0.02	−0.19	1.71	8.13	5.91	166.29	0.132	1.31	22	+0.06	7.6	7.28	6.5
15	5b5	0.94	2.85	49.62	42.30	0.08	10.88	3.03	17.41	0.002	−0.17	0.27	4.81	3.20	106.67	0.085	1.05	23	+0.04	7.5	4.29	7.0
5	5b5	0.63	2.80	72.62	56.40	0.02	20.32	4.44	25.94	0.0004	−0.29	0.11	4.98	3.58	152.79	0.124	1.27	23	+0.04	7.7	4.89	6.8
8	5b5	2.36	12.58	134.97	138.74	0.02	11.70	5.33	27.80	0.0001	+0.75	0.22	6.86	5.25	300.37	0.130	1.30	23	+0.04	7.4	6.59	6.6
53	5b6	1.38	3.82	63.56	50.76	0.24	19.09	2.77	16.63	0.005	−0.25	0.58	7.95	5.13	138.85	0.113	1.22	22	+0.04	7.7	6.39	6.6
36	5b6	5.89	12.17	65.12	67.96	6.31	7.03	2.07	5.35	0.09	+0.04	6.10	6.63	6.43	164.48	0.124	1.27	23	+0.04	7.3	7.74	6.5
55	5b6	2.22	6.53	89.21	78.96	1.52	20.18	2.94	13.66	0.02	−0.13	1.84	9.67	6.69	198.62	0.157	1.43	22	+0.06	7.7	8.18	6.4
54	5b6	2.46	11.10	108.35	104.90	1.62	19.05	4.51	9.76	0.02	−0.03	2.00	9.63	6.85	247.48	0.193	1.59	22	+0.06	7.7	8.50	6.4
48	6	19.86	7.71	57.33	40.04	40.60	1.21	0.39	7.44	1.01	−0.43	28.50	3.07	4.90	177.68	0.117	1.24	22	+0.06	7.0	6.20	6.6
45	6	603.79	271.31	1,038.92	1,882.35	14.57	0.91	0.45	3.83	0.008	+0.45	93.79	7.94	23.44	3,811.85	2.561	5.79	23	+0.04	6.1	29.27	5.3

V-shape (Charron, 1970). Analysis No. 59 is the best example in this group of a U-shaped pattern. This concave pattern is carried into group 2 with a slight modification, that is,with a slight increase in the sodium value.

GROUP 2

The slight increase in the sodium value of group 2 is accompanied by a similar increase in the chloride. At the same time, a lowering of the sulphate value is accompanied by a decrease in the calcium and magnesium values. The groundwater of this group is of the bicarbonate type, which identifies it with a recharge area.

GROUP 3

This group is a good illustration of base ion exchange, as shown by the relatively large increase in sodium, accompanied by a relatively large decrease in the calcium and magnesium, and a somewhat smaller decrease in the chloride value. The groundwater represented by these analyses is therefore very soft, so soft that in some instances the water has a flat taste. In three samples of this group (No. 4, No. 33 and No. 74) the colour of the water has a very high value (greater than 119 Hazen units, Table 1). Since the three analyses are unrelated with respect to location, it is rather remarkable that a physical characteristic should be reflected in this chemical grouping. The cause of the colour is not known. The lower sulphate value of this group is attributed to a continuation of the sulphate reduction process. This in turn produces carbon dioxide, which accounts for the increase in the bicarbonate value. The groundwaters are therefore of the bicarbonate type and represent, as did group 2, a recharge area. However, because of their higher average TDS values, the analyses forming group 3 should be located further down the groundwater flow than those of group 2.

GROUP 4

With group 4, the groundwater flow moves out of the true bicarbonate zone to a bicarbonate-chloride zone (Fig. 27). The group represents a transition zone between the recharge and discharge areas. The value of the chloride ion has remained relatively low and constant in the first three groups, but in group 4, it suddenly increased to catch up with the sodium value. The sulphate value still remains low because of the sulphate reduction phenomenon, nevertheless, the slight increase in the sulphate value is accompanied by a similar increase in the calcium and magnesium. This slight increase in the sulphate value, if it is due to a decrease in the sulphate reduction process, means that there is a decrease in the production of carbon dioxide, which in turn is reflected in group 4 (Fig. 27) by a decrease in the bicarbonate value.

GROUP 5

The three main characteristics of group 5 are: (1) the average TDS value (3,128 ppm) is greater than the combined value of the four groups preceding it; (2) the sodium and chloride values are generally above 10.0 epm; and (3) the change in the Mg/Ca ratio is now greater than 1.0. These three factors clearly separate this group from the other four groups. Also, two analyses (No. 8 and No. 36) have a positive base exchange index (b.e.i.), that is, the chloride value is greater than the sodium value (Table 2). For the other analyses in the group, it is negative. A positive b.e.i. is usually indicative of groundwater in a discharge zone. It should be noted that analysis No. 30 of group 1 also has a positive b.e.i. (Table 2). However, with low sodium chloride values, the positive b.e.i. does not have the same significance (Charron, 1970). The low sulphate value of group 5 proves that the sulphate reduction phenomenon is still effective. In fact, sulphate reduction accounts for the change in the Mg/Ca ratio between group 4 and group 5. Throughout the five groups the continuously low sulphate value has kept the calcium value from increasing, but in group 5, the higher solubility of magnesium (Toth, 1966) has increased the magnesium value enough to produce a reversal in the Mg/Ca ratio. The chemical relationship between the calcium and sulphate ions is well illustrated on Figure 29. In general, most of the analyses forming group 5 are located in the southern half of the map sheet (Fig. 28). The analyses that are located in northern half are found in the old Champlain Sea channels (Fig. 2). These channels are areas of groundwater discharge and, even though we come to the main discharge zone at the eastern boundary of Russell County, the principal eastward groundwater flow does not stop there. For, in a true discharge zone, the chloride value is much more predominant than it is in group 5. The water represented by group 5 is a chloride-bicarbonate type. The groundwater in Russell County does not have a higher TDS value because of the sulphate reduction phenomenon that has persisted throughout the groundwater flow.

At this point one can start to visualize the direction of groundwater flow in a general way. However, to examine it in detail is somewhat more difficult because of the many factors, other than chemistry, involved. For instance, one cannot point to two analyses and say that the flow is from sample point No. 7 to sample point No. 37 (Fig. 28) simply because both analyses form part of group 2 and the TDS value of No. 7 is less than that of No. 37. All other factors being equal, it would be possible to assume that such a flow (from No. 7 to No. 37) occurs, but, as it is, one has only to look at the topography of the land (Fig. 1) to realize that such a flow cannot occur. Instead, one should look at the general sequence formed by the five groups. Groups 1 and 2 can be combined to represent a recharge area. Group 5 then represents a discharge area, and groups 3 and 4 become a transition zone between recharge and discharge. This is well shown diagrammatically on Figure 28. The flow can be seen as originating mainly in the northwest and southern parts of Russell County, and flowing mainly eastward and northward. Figure 28 also shows that the south central part of the map is a large discharge area. There are other smaller discharge areas along the Ottawa River, as well as along the western margin of the county. The western discharge area coincides with the eastern tip of Mer Bleue Bog. As for the discharge areas located along the Ottawa River, they represent the end of the northward groundwater flow that began at the surface water divide (Fig. 31). This groundwater flow discharges into the Ottawa River. From recharge to discharge this flow path, as indicated by the chloride-bicarbonate type of water of the discharge zones, is a short one. Apart from this chemical explanation, there are two other reasons why the Ottawa River is believed to be the ultimate end of this northward groundwater flow. One is that the deep bedrock valley, over which the Ottawa River flows, is filled with clay (Fig. 7), thus preventing the northward groundwater flow from continuing under the Ottawa River. The other is the fact that Precambrian rock outcrops across the Ottawa River. The outcrop would definitely stop the northward path of this groundwater flow if the clay-filled valley did not. To complete Figure 28, a few arrows have been drawn from the recharge zones towards the discharge zones and, already, a fair indication of the direction of groundwater flow is provided for Russell County.

GROUP 6

The two exceptional analyses (No. 45 and No. 48) that form this group are situated on the western margin of Russell County (Fig. 31). They are grouped separately because their patterns (Fig. 30) have little in common with those displayed by any of the other five groups, mainly because of the high sulphate value displayed by these two analyses. At this point some explanation is required to describe the well arrangement where sample No. 45 was collected. It is two wells in one, with a smaller diameter casing inside a larger diameter casing. The true depth of these wells is not known nor is a log available for them. Both wells are flowing artesian wells, which would suggest that there might be two sources of water. For this reason, a second sample was collected at the same site – No. 46, group 5b (Table 2). Sample No. 45, taken from the inner casing, has a very high TDS value of 106,985 ppm and is very salty. Sample No. 46, on the other hand, has a TDS value of only 4,767 ppm. The large difference in the TDS value of these two wells is explained this way. First, it is believed that the casings of both wells are full of holes because of the salt content of No. 45 and because both casings are very old. The groundwater represented by sample No. 45 is believed to come from a fairly deep confined aquifer (>300 feet), while that represented by No. 46, because of the holes in the casings, would be a mixture of No. 45 with water from an upper zone or aquifer (about 100 feet). That is, sample No. 46 might be a diluted version of No. 45. This explanation seems valid, but does not account for the difference in the Mg/Ca ratios.

Group 6 forms part of a groundwater flow originating to the west and southwest of Russell County and ending in Mer Bleue Bog. Sample No. 48 is representative of a sulphate-chloride type of water, whereas No. 45 represents a chloride-sulphate type of water. Because sample No. 45 has a high TDS value (106,985 ppm), a positive b.e.i. (+0.45 epm) and a low bicarbonate value (0.91 epm), it is considered to be more representative of a true discharge area than any of the other 73 analyses described in this report. It is therefore believed that the bog known as "Mer Bleue" represents the end of a groundwater flow.

IONIC CHANGES

The changes in concentration of the six ions plotted in the semi-logarithmic diagrams are further illustrated in Figures 27 and 29. In Figure 27, the average concentration values of the six ions in each two successive groups of Table 2 are plotted on semi-logarithmic paper so that the shaded areas emphasize the changes in the ion values between the groups. The four individual graphs form a sequence that reveals the changes in the relative ion concentrations from recharge to discharge. Figure 29 is also based on the average values of the six ions in each group. It not only represents the ion change as a whole from recharge to discharge, but also neatly illustrates the relationship that exists between certain ions, for example, Ca^{++} and Mg^{++} or Na^{+} and Cl^{-}.

Calcium and Magnesium (Ca^{++}, Mg^{++})

These two ions are grouped together because their variations are quite similar (Fig. 29). There are decreases in the Ca and Mg values from the first to the second group, accompanied by a decrease in the SO_4 value. The decrease in value of the Ca and Mg continues from the second to the third group, but to a larger degree than between the first two groups. Again these decreases are accompanied by a decrease in the SO_4 value. Between the third and fourth groups there are slight increases in the Ca and Mg values, accompanied by a somewhat similar increase in the SO_4 value. Finally, between the fourth and fifth groups, the increase in the Mg value is much more prominent than the increase in the Ca value. This time, however, the increases in the Ca and Mg values are accompanied by a decrease in the SO_4 value. This is strongly indicative of sulphate reduction.

In all 74 analyses except two (No. 13 and No. 43), the groundwater was found to be supersaturated in $CaCO_3$ as shown by the pH (laboratory) value, which is greater than the pH-of-equilibrium corrected from scale (Table 2). Nevertheless, the groundwater still has free CO_2 available, as indicated by the pH-of-equilibrium and the Kr-of-equilibrium lines on the semi-logarithmic diagrams. The pH-of-equilibrium is equivalent to the CO_2-of-equilibrium in the water, and the Kr-of-equilibrium represents the free CO_2 in the water (Schoeller, 1962; Charron, 1970). If the water is saturated in $CaCO_3$ and if the Kr-of-equilibrium value is greater than that of the pH-of-equilibrium, as it is in each group (Fig. 27 and Table 2), there is still free CO_2 available and the groundwater remains chemically active even though it is saturated. This excess of free CO_2 means that, in Russell County, groundwater is chemically active throughout its entire flow. Consequently, it will dissolve the rocks it comes in contact with, especially carbonate rocks. To summarize, the Ca and Mg values in the recharge area decrease, and in the discharge area, they increase slightly. Nevertheless, the Ca and Mg values are lower at discharge than they were originally at recharge (Fig. 27).

Sodium and Chloride (Na^+, Cl^-)

These two ions appear to be compatible (Fig. 29). The sodium ion is the most variable of all the ions. From group 1 to group 2 there is an increase in the Na value, accompanied by a similar increase in the Cl value. Between the second and third groups there is a much larger increase in the Na value, but the Cl value decreases. However, the large increase in the Na value is accompanied by a comparable large decrease in the Ca value as a result of the base exchange of calcium ions for sodium ions. The Na value continues to increase between groups 3 and 4, but this time the Cl value increases considerably and they become compatible once more. It is at this point that one can say that the groundwater has left the recharge zone. The increase in both ion concentrations is continued between group 4 and group 5. In the groundwater flow described by these groups, the sodium ion is therefore the only ion that increases continuously in concentration, from recharge to discharge. The Cl value remains fairly constant in the recharge zone and its value increases only near the discharge area.

Sulphate ($SO_4^=$)

In the various groundwater flows that exist within Russell County, the sulphate concentration is the most stable of the six. This stability is usually reserved for the bicarbonate ion. The average SO_4 value is less than 1.0 epm in all the groups except group 1. In fact, in 25 percent of the analyses, the value is 0.1 epm or less. This low sulphate value is attributed to the modifying phenomenon known as sulphate reduction, which is assumed to be caused by anaerobic bacteria. Three large bogs surround Russell County: Mer Bleue to the west, Moose Bog to the south and Alfred Bog to the east in Prescott County. There are also numerous small sloughs and swamps in many places within the map-area. All of these are believed to be sources for the sulphate-reducing bacteria. In the field, the best indicator of sulphate reduction is the odour of H_2S emanating from a well. The widespread occurrence of H_2S in the county, accompanied by the relatively constant low SO_4 values in the water, is proof that sulphate reduction is widespread over the entire map-area. Therefore the groundwater in Russell County, which is saturated in $CaCO_3$, is less saturated in sulphate at discharge than it was at recharge. This is well illustrated by the S-line on the semi-logarithmic diagrams (Figs. 27 and 29).

Bicarbonate ($HCO_3^=$)

As mentioned before, the bicarbonate ion is usually the most stable ion in groundwater flow. In Russell County the HCO_3 value generally increases from recharge to discharge (Figs. 27 and 29) because of the excess production of CO_2 due to sulphate reduction. To summarize, the groundwater flow represented by the five groups illustrated in this hydrogeochemical interpretation begins at recharge as a bicarbonate type of water that goes through a base exchange process that naturally softens the groundwater. At the same time, sulphate reduction sets in and becomes the dominant modifying phenomenon that produces the nauseating H_2S in so many wells. Finally, the groundwater reaches a point where it becomes a chloride-bicarbonate type of water. Further studies will probably show that the main east-west groundwater flow does not end in Russell County, but continues in a generally easterly direction into Prescott County.

HYDROGEOCHEMICAL MAP

This map (Fig. 31) illustrates the direction of groundwater flow in Russell County. Horizontal chemical zonation is the criterion used to develop this map. At the beginning of a groundwater flow system, the recharge area is represented by a bicarbonate type of water. The groundwater then evolves into a bicarbonate-chloride type of water and so on, following the sequences established by Chebotarev (1955) and Charron (1970).

At the beginning of this study, it appeared that the Champlain Sea channels (Fig. 2), because of their extent, might be an important factor controlling groundwater flow. Analysis of the data, however, shows the importance of the channels to be more local than regional. For example, the occurrence of springs along the banks of the channels is due to the presence of the channels themselves. Naturally, the beach part of a channel is a recharge area, while the flat clayey part (bottom of channel) is a discharge area. The two north-south channels in Clarence Township (Fig. 2) seem to exert some influence on the direction of groundwater movement at greater depths because the two channels and the region where they join the main channel from the west reflect the chemical zones outlined on the hydrogeochemical map (Fig. 31).

Bedrock topography is the main factor controlling groundwater flow in Russell County. Figure 5 is the author's diagrammatic representation of the bedrock topography in the county, based mainly on the outcrop configuration. As seen by the author, the bedrock surface represents an impermeable layer whether it is exposed at the surface or covered by surficial deposits, therefore, it would be equivalent to the impermeable basement required by Freeze (1969) in the formation of a groundwater basin model. The impermeable basement in Russell County is undulating. As mentioned before, much of the groundwater yielded by the wells in Russell County is believed to be obtained at the contact between the surficial deposits and the bedrock. Therefore, the surface configuration of the bedrock probably has a great influence on the direction of groundwater flow. Nowhere in Russell County is this more evident than in Russell Township. Figure 31 points out that a groundwater flow emerging in the northwest corner of the township flows southeastward. Where this flow reaches Concession VIII, between Lots 8 and 15, the TDS value of the groundwater is approximately 5,000 ppm (analyses Nos. 54, 55 and 56). In Lot 7, just to the south of this zone, a bedrock ridge outcrops. It trends in a southwest-northeast direction and can be easily located (Figs. 5 and 31). South of this bedrock ridge, the groundwater TDS value is less than 600 ppm (Fig. 31, analysis No. 57). It is assumed, therefore, that the flow of salt water encountered on the north side of this ridge does not cross it, but veers to the northeast (Fig. 31). At Embrun, the Castor River flows almost parallel to this bedrock ridge, and the residents of the town have known for a long time that there is good potable water on the south side of the river, but only salty water on the north side. They attribute this to the presence of the river, whereas actually it is due to the bedrock topography.

Another example of bedrock control of the groundwater flow can be seen in the most easterly of the Champlain Sea channels, situated in Clarence Township. At first glance the groundwater flow (Fig. 31) is interpreted as coming from the topographic highs (beaches) on either side of the channel. Once in the channel, the groundwater should flow in a southeasterly direction following the channel, but in Lot 8, Concessions III and V, another bedrock ridge outcrops. This ridge stretches in an east-west direction across the channel floor and acts as a barrier or dam. From this point the groundwater flows either in a northwesterly or southeasterly direction. Another remarkable aspect of these bedrock ridges is the pattern formed by their linear arrangement (Fig. 5). They form lines pointing toward an area to the east of the Russell County map sheet. This area coincides with Alfred Bog in Prescott County. Therefore, it can be assumed that the groundwater in Russell County flows along the contact between the surficial deposits and bedrock, following the troughs (Fig. 5) eastward to Alfred Bog.

Figure 31 illustrates that there are three main recharge areas in the northern part of Russell County. They correspond closely to the topographic highs delineated by the beaches that define the Champlain Sea channels. From these recharge areas, the groundwater flows in all directions. Another recharge area occurs in the southern part of the map-area, but the groundwater from that area flows northward. Figure 31 shows that there is no bicarbonate zone or recharge area in the southwestern part of Russell County. If there is one, it would be to the southwest, outside of the map sheet. The groundwater flow that begins in the southwest corner of the map sheet as a bicarbonate-sulphate type of water seems to move in a northeasterly direction. It should be noted that this is the only time in this report that the author uses a geological fault to delineate a chemical zone (Figs. 4 and 31). Many faults exist in the area (Fig. 4) and many of them coincide with the Champlain Sea channels (Fig. 2), but none appear to have any bearing on the direction of groundwater flow.

To conclude, the groundwater flows from the southern and northern recharge areas appear to converge towards the eastern margin of Russell County, as shown by the chloride-bicarbonate zone (Fig. 31). Similar chloride-bicarbonate discharge zones exist along the Ottawa River, but this northerly flow is not as important, for it only begins at the water divide and is relatively limited in extent.

In one area on the map sheet the groundwater flow does not seem to fit the plan of Figure 31. It is the area that forms the east end of Mer Bleue in Cumberland Township. Chemically it is represented in Figure 31 by sample No. 45. It is assumed that a groundwater flow originating west of the map sheet ends in Mer Bleue. Figure 7 is used to explain why it is thought that this groundwater flow, from the west, ends in Mer Bleue.

The cross section (Fig. 7) shows that the shale formation, with its low permeability, possibly acts as a plug or dam that prevents this western flow from continuing eastward, forcing the piezometric level of the groundwater to rise and appear at the surface. This would explain the presence of Mer Bleue Bog. Finally, an equilibrium point would be reached where the piezometric level would not rise anymore because the overflow would be used up in surface runoff and evaporation. Another possibility is that the shale formation does not act as a plug or dam, but more as a membrane. Therefore, the process known as reverse osmosis could occur here. If so, the water on one side of the membrane would be less salty because the salt would be accumulated on the other side, thus explaining why sample No. 45 has a TDS value of 106,985 ppm, while that of No. 47 is only 1,046 ppm. It is also possible that the two interpretations given occur simultaneously; however, with the data available, it is likely that the first interpretation is the more valid one.

Figure 31 illustrates what is called horizontal zonation. It should be possible to illustrate vertical zonation in a similar way, however, the data available are insufficient to demonstrate it on a large scale. One well 728 feet deep was sampled at three depths, and the results of Hach Kit analyses on the samples are shown in Table 3. The well, which is situated in Lot 18, Concession II, Russell Township (UTMG coordinates 702-150, Figure 8), is more than 45 years old. Water is obtained from it daily, but the data in the table indicate that most, if not all, of the water comes from very shallow depths.

Table 3. Analyses of Water from Different Depths in Same Well

Depth (ft)	Hardness (ppm)	Iron (ppm)	pH (ppm)	Sodium (ppm)	Specific Conductance (micromhos/cm at 25° C)
20	85	0.3	8.0	775	—
100	633	4.5	8.0	2900	5,000
375	2137	3.0	8.2	8350	approx. 12,000

A change in the chemical composition of the groundwater with depth is clearly indicated by Table 3. Because no log of the well is available, it is assumed that the groundwater used daily enters the well mainly from a shallow zone directly below the casing. It is probable that, in the course of drilling this well, bedrock fractures that yielded groundwater were encountered at various depths. In all probability, the deeper the fracture, the more salty was the groundwater. If this is so, the groundwater with high salt content (higher density) may have collected at the bottom of the well, and over the years would have produced a gradation such as we have in the three samples in Table 3. From this example, it is believed that vertical zonation of groundwater does exist over the entire Russell area.

Conclusions

This report has shown that the average groundwater yield of the wells in Russell County is less than 10 gpm. Although many of these wells yield good potable groundwater, there are also widespread areas where the quality of the groundwater leaves much to be desired because it has a disagreeable H_2S odour (0.5–5.0 ppm) or a salt content (NaCl) exceeding 1,500 ppm.

Furthermore, using data on surface topography, surficial geology, bedrock geology, hydrogeology and hydrogeochemistry, an attempt has been made to determine the direction of groundwater flow throughout Russell County. It has been shown that the bicarbonate type of water at recharge goes through a base exchange process while, at the same time, sulphate reduction sets in and becomes the dominant modifying phenomenon, producing H_2S. Finally, the groundwater becomes a chloride-bicarbonate type. It is believed that the main easterly groundwater flow does not end at the eastern boundary of Russell County, but continues on in a general easterly direction into Prescott County.

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