INLAND WATERS BRANCH

Hydrogeology of the Moncton Map-Area, New Brunswick

P. A. CARR

SCIENTIFIC SERIES NO. 1

DEPARTMENT OF ENERGY, MINES AND RESOURCES

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ABSTRACT

Throughout most of the Moncton map-area, the development of large amounts of potable groundwater is not possible. The glacial till is thin and not very permeable; therefore, it yields barely enough groundwater for domestic use. Most of the bedrock is a poor aquifer which yields less than 20 gallons per minute of groundwater. The groundwater contains mainly calcium and sodium bicarbonate, and generally has a total dissolved solids content of less than 400 parts per million.

The presence or absence of fractures has produced a wide range of permeability values, which are related to the bedrock formations. A region of relatively high permeability occurs in the well-fractured sandstone of the Richibucto Formation, situated in the northeastern part of the area. The high permeability has permitted the development of a deep fresh-water flow system within this formation; therefore, this is the most favourable part of the map-area for developing high yielding wells.

HYDROGEOLOGY OF THE MONCTON MAP-AREA, NEW BRUNSWICK

INTRODUCTION

This report evaluates the results of the groundwater investigation started in 1960 in the Moncton map-area. A preliminary report and map was published (Carr, 1961, 1962) concerning the qualitative aspects of the groundwater. In the present report, the previous qualitative results are used and expanded, and the quantitative aspects of groundwater availability are reported. These results are integrated to permit the description of the groundwater flow system.

Acknowledgments

The writer was assisted by R.K. Jull, M. Hone and K. Daughtry in the summer of 1961 and by D.E. Lawson, A.S. Pederson and D. Gamache in 1962.

Location of Area and Physical Features

Moncton map-area lies between latitudes 46°00′ and 46°15′ north and longitudes 64°30′ and 65°00′ west. It contains about 400 square miles of parts of Albert and Westmorland counties, New Brunswick. The map-area is well wooded and easily accessible by paved and secondary roads. Approximately two thirds of the map-area forms an undulating plain having elevations between sea level and 250 feet above sea level. This plain is covered with a thin veneer of glacial drift which is underlain by nearly flat-lying Pennsylvanian rocks.

A series of ridges northwest of Moncton forms the main height of land in the area; the maximum elevation is about 675 feet. These ridges are part of the Kingston uplift and are composed of steeply inclined pre-Carboniferous and Mississippian rocks.

In the southeast corner of the map-area, pre-Carboniferous and Mississippian rocks are exposed in the Memramcook valley, which has over 250 feet of relief.

The two main rivers draining the map-area are the Petitcodiac and the Memramcook. Both rivers have tidal bores which carry salt water and mud inland from the Bay of Fundy. Their banks are formed of reddish brown mud deposited by these tides.

GENERAL GEOLOGY

The amount and the chemistry of groundwater in the area are controlled largely by the geology through which the groundwater moves; thus, a brief description of the geology is warranted. A more detailed geological description of the map-area including the log of the boreholes has been prepared in another report (Carr, in press). The distribution of the rock units is shown in Figure 1,* and their dominant lithology and ability to transmit groundwater are listed in Table 1.

Bedrock Geology

The Basement Complex (map-unit 1, Figure 1) of pre-Carboniferous age is the lowermost rock unit and occurs in the Kingston uplift and Memramcook valley. The rocks are well fractured and are predominantly granites and greenstones. Overlying the Basement Complex is the Memramcook Formation (map-units 2a and 2) of Devonian and Mississippian age comprising pebble conglomerate, poorly sorted green and grey sandstone, and red shale. This is overlain by the Albert Formation (map-unit 3) which consists of grey shale and siltstone; interbedded with this formation is a well sheared greyish red boulder conglomerate (map-unit 5). Overlying these rocks (map-units 3 and 5) is the Moncton Group (map-unit 4), a succession of grey and red siltstone, sandstone and conglomerate. All the above rocks are exposed only in the Kingston uplift or the Memramcook valley. They were tilted and indurated by an orogeny in Mississippian or early Pennsylvanian time; however, this disturbance does not appear to have developed large interconnected fracture zones associated with good aquifers.

An angular unconformity occurs between these sediments and the nearly flatlying Hopewell (age uncertain) and Petitcodiac Groups (Pennsylvanian age). The Hopewell Group (map-unit 6) consists of relatively impermeable red shale and granite, pebble conglomerate and breccia. The overlying Petitcodiac Group (map-unit 10) is the most extensive rock group in the map-area and forms most of the undulating plain. South of the Kingston uplift, this Group has been separated into the yellowish orange sandstone, and rounded pebble conglomerate of the Boss Point Formation (map-unit 7), the red claystone and siltstone of the Salisbury Formation (map-unit 8), and the yellowish orange to grey sandstone of the Richibucto Formation (map-unit 9).

These Pennsylvanian sediments have not been indurated by orogeny and have only a small amount of calcite cement. In the weathered outcrops, the calcite cement has been removed, and they are friable and porous; hence, these rocks are better aquifers than the Mississippian rocks.

*In pocket of inside cover

Surficial Deposits

Glacial drift, mainly till, covers nearly the entire map-area. The till is sandy and brown to red. The drift has an average thickness of 18 feet (Hobson and Carr, 1967) and in several areas near the Petitcodiac River valley has thickness greater than 100 feet. Numerous wells have been dug into the till but they yield barely enough groundwater for domestic use.

The remainder of the surficial deposits includes some Pleistocene sand, recent tidal muds and sand beaches. All these deposits are thin, limited in areal extent and are thus of no importance for groundwater supplies.

HYDROGEOLOGY

General

Groundwater occurs in the bedrock, which is predominantly sandstone and claystone, and in the glacial drift, which is mainly sandy till. Most of the groundwater is produced from wells drilled into the more permeable bedrock. Large diameter wells are dug into the till, and characteristically have lower yields than wells drilled into the bedrock.

Groundwater movement within the bedrock occurs through the fractures and the interconnected pore spaces between the individual grains. As the fractures have a much higher permeability than the pore spaces, most of the groundwater moves through the fractures. Large losses of drilling fluid during well-construction and the existence of high transmissibilities in sandstone that do not show pronounced permeability in hand specimens, suggest fracture permeability. Unfortunately, the fractures cannot be readily assessed regionally as few exposures are large enough to reveal a fracture pattern.

The permeability of the sandstone in the map-area is estimated to be similar to the permeability of the sandstone in Prince Edward Island. There, Brandon (1966) has estimated the coefficients of permeability from pump test data to range from 25 to 70 gallons per day per square foot. The horizontal and vertical intergranular permeabilities of four samples of arkosic sandstone were determined in the laboratory. The maximum permeability was 41 gallons per day per square foot (horizontal) and the minimum permeability was 0.05 gallon per day per square foot (vertical). From this, it is concluded that higher coefficients of permeability determined from the pump test data are due to the combined effect of fracture and intergranular permeability.

The rock units of Table I were grouped into aquifers and aquitards, water bearers or water restrictors respectively. These terms are relative; a unit that is an aquifer within the map-area may be an aquitard outside the area.

The Basement Complex is an aquitard and no wells are known in these rocks. Very small flows (up to 10 barrels per day) of salty water were reported in this unit in borehole number 12 at depths of 625 and 1,045 feet and in borehole number 13 at depths of 393 and 656 feet.

The Memramcook and Albert Formations, the Moncton Group, and the boulder conglomerate unit are poor aquifers. Groundwater movement occurs mainly through fractures. In the area of the Kingston uplift, numerous domestic wells have been drilled into these formations, generally yielding between 3 and 10 gallons per minute.

The boulder conglomerate unit forms a ridge with a maximum elevation of about 650 feet. On the south side of this ridge, a spring line occurs at an elevation of about 410 feet (Figure 8).

The Hopewell Group is an aquitard. The basal conglomerate is poorly sorted and contains a considerable amount of shale and claystone matrix between the granite pebbles. The upper part of this group is mainly claystone which transmits very little groundwater. No wells are known to exist within this group.

Throughout the Moncton basin, the Petitcodiac Group varies from a poor to a good aquifer. Very little information is available concerning the area north of the Kingston uplift. South of the Kingston uplift the Boss Point Formation varies from a good to a poor aquifer. It is the best aquifer within the Moncton basin but not the best aquifer in the map-area. The base of this formation is a source of springs. As groundwater permeating this sandstone reaches the claystone of the underlying Hopewell Group it flows laterally on top of the claystone until it comes to the surface in a river valley. This was first noted by Wright (1922, p. 26) on the banks of the Petitcodiac River and can also be seen on the Trans-Canada Highway west of the village of Memramcook.

The Boss Point conglomerates are generally poor aquifers for a considerable amount of sand-size particles occurs between the pebbles reducing the intergranular permeability. Outside the map-area, McAlary (1960) reported a flow of 1.2×10^6 gallons per day (gpd) of fresh water in Imperial Oil's Pollett River number 1, coming from 40 feet below the top of the formation. Also, he reported a flow of 1×10^5 gpd of fresh water in New Brunswick Oilfield's Turtle Creek number 1, from 19 feet below the top of the formation.

Within the map-area, borehole number 10 just east of Moncton intersected the Boss Point Formation at 535 feet and yielded 20,000 gpd of salty water. Thus, the Boss Point Formation near Moncton is a poor aquifer and does not contain potable water.

The Salisbury Formation varies from a good to a poor aquifer throughout the Moncton basin but is a poor aquifer within the map-area. Many domestic wells have been drilled into this formation and the yield is generally about 10 gpm (gallons per minute).

In borehole number 14, a small amount of groundwater was found in the first 100 feet of drilling but no more water was found until a depth of 1,100 feet. At site 1, at a depth of 190 feet within this unit, the water contained over 450 parts per million (ppm) sodium chloride. However, outside the map-area, the well at the Jordan Sanitorium yields up to 48 gpm and a well near Dunsinane yields up to 34 gpm of potable water.

The Richibucto Formation varies from a good to a

TABLE I

Table of Formations*

PERIOD OF EPOCH	ROCK-STRATIGRAPHIC UNIT		LITHOLOGY	Maximum thickness (in feet)	Water transmitting ability
RECENT			Tidal muds, beach sands	36+	
Pleistocene			Sandy till	160	Poor aquifer
			UNCONFORMITY		
PENNSYLVANIAN	Petitcodiac Group (10)	Richibucto Formation (9)	Yellowish orange to grey sandstone	400	Good to poor aquifer
PENNSYLVANIAN	Petitcodiac Group (10)	Salisbury Formation (8)	Red claystone and siltstone	1100+	Poor aquifer
PENNSYLVANIAN	Petitcodiac Group (10)	?	DISCONFORMITY	?	
PENNSYLVANIAN ?	Petitcodiac Group (10)	Boss Point Formation (7)	Yellowish orange to grey sandstone, rounded pebble conglomerate	200±	Poor aquifer
?	Hopewell Group (6)		Red shale and red granite pebble conglomerate and breccia	550±	Aquitard
			UNCONFORMITY		
MISSISSIPPIAN	? Boulder conglomerate unit (5)	Moncton Group (4)	Red and green siltstone, sandstone and conglomerate	3200±	Poor aquifer
MISSISSIPPIAN	Boulder conglomerate unit (5)	Albert Formation (3)	Grey shale and siltstone	5700±	Poor aquifer
MISSISSIPPIAN / Devonian	Boulder conglomerate unit (5) ?	Memramcook Formation (2)	Red shale, siltstone, sandstone and pebble conglomerate	3000±	Poor aquifer
			UNCONFORMITY		
Pre-Carboniferous		Basement Complex (1)	Granite and greenstone	?	Aquitard

* Numbers in parentheses refer to map units in Figure 1

poor aquifer and is the best aquifer within the map-area. In this formation, fresh water is found at greater depths (up to 450 feet) than in any other rock unit within the map-area.

Generally, wells yielding at least 20 gpm can be drilled into the formation. The highest capacity well in the area is in the town of Shediac for which no accurate figures are known. However, the driller reported a yield of more than 1 x 10^6 gpd during the pump test. The two other town wells of Shediac produce 50 to 150 gpm. All these wells are situated in a discharge area in the general flow system near the Scoudouc River from which some induced infiltration may take place.

The sandy till is a poor aquifer. The wells dug into the till yield only enough water for domestic use.

Quantity

The main hydraulic properties of an aquifer are the coefficients of transmissibility "T" and storage "S" (Theis, 1935). These coefficients were determined for some of the boreholes by pump tests in which one well was pumped at a constant rate while the drawdown in a nearby observation well was measured at regular intervals. The results of the pump tests were analyzed mainly by the Theis nonequilibrium method (equations 1 and 2, Graph 1A, Appendix A).

The method is based on the following assumptions:

(1) that the water-bearing rock is homogeneous and is isotropic;

(2) that the water-bearing rock has an infinite areal extent;

(3) that the discharge well penetrates the entire saturated thickness of the aquifer;

(4) that the coefficient of transmissibility is constant at all places and all times;

(5) that the discharging well has an infinitesimal diameter;

(6) that water taken from storage by the decline in water levels is discharging instantaneously with the decline in head (Wenzel, 1942).

Assumptions (1), (2) and (4) are never satisfied in the geological environment. Assumption (3) may not be satisfied, because the aquifer thickness is rarely known. However, useful approximations of "T" and "S" can still be obtained. These are average values, which apply to the aquifer within the area affected by the cone of depression. The depth of the cone of depression is limited by the depth at which the pump is placed and the radial extent of the cone is dependent on the duration of the pump test.

Equations 1 and 2 (Graph 1A, Appendix A) are solved by superimposing the drawdown-versus-time graph on the "W(u)" versus "u" type curve. After the two curves are properly matched, an arbitrary match point is selected; for example, W(u) = 1 and u = 1; the corresponding values of drawdown "s" and time "t" are determined from the graph and are substituted into equations 1 and 2. Then these equations are solved for "T" and "S". Some of the pump test analyses were determined by the distance drawdown method or the leaky artesian method. For a complete description of the theory of these techniques see Walton (1962).

The calculations for each pump test are recorded in Appendix A. The results are tabulated in Table II and illustrated in Figure 1.

The field coefficient of permeability[1], or hydraulic conductivity, P, in gallons per day per square foot (gpd/ft^2) was determined from equation 3 and tabulated in Table II.

$$P = \frac{T}{m} \qquad (3)$$

where "m" equals the saturated thickness of the aquifer in feet, which in each case was taken to be the difference between the static water level and the bottom of the hole.

[1] as defined by Wenzel, 1942, p. 7

Boreholes 5 and 14 were bailed dry within a few minutes of testing. Thus, pump tests were not run at these sites; it is certain, however, that the values of transmissibility at these boreholes are low.

Theoretical Specific Capacity Determination

The theoretical specific capacity "Q/s" of a well is the ratio of discharge to drawdown. For a uniformly discharging well that fully penetrates a homogeneous, isotropic, nonleaky aquifer of infinite areal extent, the theoretical specific capacity is given by equation 4 (Ferris, 1951)

$$\frac{Q}{s} = \frac{T}{264 \log \dfrac{T t'}{2246 rw^2 S} - 65.5} \qquad (4)$$

where Q/s = specific capacity in gallons per minute per foot of drawdown (gpm/ft of drawdown).

rw = radius of the well in feet.

t' = duration of pump test in minutes.

Specific capacity varies with the radius of the well and the length of the pumping period.

The value calculated by equation 4 is probably a maximum theoretical value, for in practice the actual specific capacity would decrease, owing to clogging of the well or the presence of barrier boundaries. For each pump test the specific capacity was calculated (Appendix A) and is shown in Figure 1.

The city of Moncton owns 4 wells (A, B, C and D, Figure 1) ranging in depth from 117 to 453 feet, which were tested before this study was started. The pumping rate and the initial and final water levels in the pumped wells have been recorded. From these data the specific capacity has been calculated (Figure 1).

Virtual Radius Determination

The virtual radius, "re", is defined as the distance from the pumped well at which the drawdown is equal to 0.01 foot. This is considered the areal extent of the cone of depression. Using the average value of "T" and taking "s" = 0.01 foot equation 1 is solved for "W(u)". Wenzel (1942, face p. 89) determined a range of values "W(u)" versus "u", from which the specific value of "u" can be obtained. This value of "u" and the average value of "S" are substituted in equation 2, which is then solved for "re^2". The square root of this value is the virtual radius.

A circle having this radius was drawn with the pumped well at the centre for each site (Figure 1). In the case of fracture flow, a circular cone of depression is not likely; however, this method does give an approximation of the size of the cone. The virtual radius for each of the remaining pump tests was also calculated (Appendix A).

Sites 6 and 8, which have the highest values of transmissibility, also show the largest cones of depression. At these sites, the fractures were sufficiently large and interconnected to transmit groundwater from a considerable area toward the well being pumped. Sites 2 and 4, which have the smallest values of transmissibility, show the smallest cones of depression. These small cones with steep sides are characteristic of poorly permeable rock.

Summary

Where more than one type of analysis was made at a site, the results agreed closely. This agreement indicates that the Theis nonequilibrium formula or a modification of it can be used for fracture flow in these Pennsylvanian aquifers.

During a pump test, the size of the cone of depression developed is large enough that the effect of an individual fracture or joint conducting groundwater is microscopic when compared to the combined effect of all the fractures and joints. This macroscopic aspect permits the aquifer to be considered as homogeneous and isotropic; thus, assumption (1) of equations 1 and 2 is satisfied.

Although no areas of high transmissibility values were found, the range of hydraulic properties of these rocks is large. The transmissibility ranges from 372 to 34,400 gpd/ft, the permeability ranges from 2.2 to 229 gpd/ft^2 and the specific capacity from 0.6 to 19 gpm/ft of drawdown. The large range in the hydraulic properties of the rocks indicates the variability of the Salisbury and Richibucto Formations as aquifers. This variability is caused mainly by the presence or absence of fractures in the bedrock. The larger, more extensive fractures occur in the sandstone, whereas fractures in the claystone do not tend to remain open at depth.

The range of storage coefficients determined from the pump tests is small 4.0×10^{-3} to 6.3×10^{-4}. These values are low and indicate that large pressure changes over extensive areas are required to produce significant yields of groundwater. This is substantiated by the calculated values of virtual radius of the cones of depression.

There appears to be a zone of low transmissibility crossing both formations, extending northeastward from sites 1 and 2 to sites 4 and 5, which can be seen on the permeability map (Figure 2). This zone is mainly underlain by claystone and siltstone on the Salisbury Formation. Higher capacity wells occur to the north of this zone in the more fractured sandstone of the Richibucto Formation.

Quality

Fifty-eight samples of groundwater from the Moncton map-area were analyzed by the Mines Branch in Ottawa. The location of each sample is shown on Figure 3 and the chemical composition of each is recorded in Appendix B. Also, numerous groundwater samples were analyzed for total hardness with a Hach kit in the field. These wells are nearly all less than 200 feet deep and are cased off from the surficial till; thus, the groundwater sampled is a mixture of groundwater coming from several fractures in the bedrock.

The groundwater contains mainly calcium and sodium bicarbonate and generally has a total dissolved solids (tds) (sum of constituents, Appendix B) content of less than 400 parts per million (ppm).

The values for tds of the groundwater are shown in Figure 3; they range from 47 to 2823 ppm. Only 4 samples indicate more than 1000 ppm of tds. Sample number 3, from a well just north of Irishtown, has a tds value of 2009 ppm. It contains mainly calcium and sulphate ions and is believed to be in contact with gypsum of the Windsor Group adjacent to the Lutes Mountain fault. Although no outcrops of the Windsor Group occur in the map-area, a conformable sequence of Mississippian strata including 650 feet of gypsum of the Windsor Group occurs on strike with this fault in the adjacent Petitcodiac map-area to the southwest (Stewart, 1941; Gussow, 1953). Thus it is believed that gypsum may occur at depth near Irishtown.

There are 3 large areas containing groundwater with a tds content greater than 200 ppm: the Kingston uplift, the south central part, and the southeastern part of the map-area. The presence of groundwater there is attributed to the low permeability of the pre-Pennsylvanian rocks and the Salisbury Formation, which allows the groundwater more time to react with the bedrock and increase the dissolved solids content.

The total hardness in ppm is shown in Figure 4. In most of the map-area the groundwater has a hardness of less than 100 ppm. The largest area with groundwater having a hardness of more than 100 ppm is in the area of the Kingston uplift. There the Mississippian rocks contain little claystone and shale, which could soften the groundwater by base exchange.

The hardness of the groundwater from the Pennsylvanian rocks changes abruptly over short distances. Soft groundwater, having a hardness less than 60 ppm occurs irregularly throughout the area underlain by Pennsylvanian rocks. This suggests the existence of small-scale vertical and horizontal facies changes between claystone and sandstone.

Types of Groundwater

The cations calcium, magnesium and sodium, and the anions bicarbonate, sulphate and chloride of each analysis were converted from parts per million to equivalents per million (epm). These values were plotted on a trilinear diagram (Figure 5)* as percentages (Piper, 1953). A single point was plotted in each of the triangular fields according to conventional trilinear co-ordinates. A third point was plotted in the diamond-shaped field by the intersection of lines projected from the points in the 2 triangular fields. These points represent relative concentrations of dissolved solids.

Bicarbonate is the predominant anion and calcium and sodium are the predominant cations; thus, the groundwater samples can be grouped into areas of calcium bicarbonate water and sodium bicarbonate water on the diamond shaped field. The few samples that are not grouped into these areas are either calcium sulphate or sodium chloride waters or mixtures of these.

Seven samples from the Salisbury Formation have been selected at progressively greater depths and the pattern of their chemical analyses has been plotted on Figure 6. Two

*In pocket of inside cover

TABLE II – Hydraulic Coefficients of the Pump Tests

Borehole	Formation	Method of Analysis	Saturated thickness of the aquifer, m, in feet	Coefficient of transmissibility, T, in gpd/ft	Field coefficient of permeability, P, gpd/ft^2	Coefficient of storage S
1	Salisbury	Time drawdown		1315		$4.3(0) \times 10^{-4}$
		Recovery		1390		$3.6(7) \times 10^{-4}$
		Average	244	1350*	5.5	4.0×10^{-4}*
2	Salisbury	Time drawdown	376	860	2.3*	2.2×10^{-3}*
4	Richibucto	Leaky artesian	173	372	2.2*	6.3×10^{-4}
6	Richibucto	Distance drawdown		7000		$2.8(5) \times 10^{-4}$
		Recovery		7200		$0.6(4) \times 10^{-4}$
		Average	262	7100	27	1.8×10^{-4}*
8	Richibucto	Distance drawdown		34,000		$0.2(7) \times 10^{-2}$
		Recovery		34,800		$0.5(1) \times 10^{-2}$
		Average	150	34,400	229	0.4×10^{-2}*

* rounded.

distinct groups are visible; the samples above 110 feet are calcium bicarbonate waters and those below are sodium bicarbonate waters. This indicates a softening of the groundwater which is due to an exchange of calcium ions from the groundwater for sodium ions from the mineral lattices of clay minerals. Although Figure 6 indicates that softening of groundwater increases with depth, there is no correlation for all 58 samples between depth and softening. This is due in part to variation in permeability of the rocks and in part to the fact that areas of upward, lateral and downward flow would have to be differentiated and only samples within one type of flow area should be compared.

The indicated softening of bicarbonate water is the first step in the metamorphism of groundwater. The second step is the mixing of sodium bicarbonate and sodium chloride. Samples 51 and 57 (Figure 5*) are examples of this. The general absence of the third step in this sequence, the appearance of sulphate waters, is due to the lack of sulphate in the bedrock and drift. The final result, salt water, is evident from samples 49 and 50 and has been reported in a few domestic wells.

Flow System

Groundwater flow comprises an upper fresh-water flow and an underlying saline water flow (Carswell and Bennett, 1963). The upper surface of the fresh-water flow system in the map-area is the water table and the base of the fresh-water flow system is ascertained by the depth to salt water. The contact between the 2 systems is usually gradational.

Base of Fresh-Water Flow System

The base of the fresh-water flow system is illustrated in Figure 7 which shows the depths at which salt water was encountered in wells and the depths of deeper wells having a very low yield of groundwater.

Borehole number 10, situated just east of Moncton, intersected a small flow of salty water between the depths of 550 and 670 feet. Borehole number 12 intersected small flows of salty water at depths of 635, 1,045 and 1,700 feet, and borehole number 13 intersected salty water between the depths of 393 and 656 feet. Two domestic wells in the southeast quarter of the map-area also yield salt water. Boreholes numbers 5 and 14 both yielded less than 10 gpm of fresh groundwater.

The southern half of the map-area (Figure 7) has salty water at fairly shallow depths or very low yields of fresh groundwater. This area is underlain mainly by the Salisbury Formation, comprising siltstone and claystone, which is shown in Figure 2 to be relatively impermeable. Here salty groundwater can be expected beyond a depth of 350 feet. Underlying this formation are the rocks of the Boss Point Formation and of the Basement Complex, both of which contain salty water.

North of this area and south of the Kingston uplift, deep wells yield larger quantities of fresh groundwater. The water wells, A, B, C and D (Figure 7) of the city of Moncton were drilled to depths of 453 feet and encountered yields generally between 100 and 200 gpm of fresh water. Boreholes numbers 6 and 8 yielded 38 and 48 gpm respectively of fresh groundwater, and the town well of Shediac, borehole number 7, can produce 700 gpm of fresh water. Thus, fresh water can be obtained in large quantities from wells at least 450 feet deep. This zone corresponds roughly to the area underlain by the Richibucto Formation, which, because it contains sandstone, is relatively permeable (Figure 2). This sandstone is well fractured and will hold fractures open at greater depths than the claystone or siltstone of the Salisbury Formation.

Approximate Water-Table Surface

The upper surface of the fresh-water flow system is the water table. The elevations of water levels in wells drilled in bedrock were measured and plotted on Figure 8.* These data were supplemented by measuring the elevations of springs flowing out of the bedrock.

The wells used for measurement were drilled to different depths within the bedrock and were cased only to the top of the bedrock. Therefore, in the saturated zone the wells may receive water from their entire uncased length. In recharge areas, the fluid potential decreases with depth and the water-level measurements represent the average potential of all the strata intersected, so the potential measured will be less than the potential at the water table. In discharge areas where the potential increases with depth, the water level measurements also represent an average potential, which may or may not be higher than the potential at the water table. These deviations cannot be readily avoided or corrected and Figure 8 is accordingly named "approximate water-table surface". The approximate water-table surface has a close resemblance to the topographic surface of the area, and the groundwater divides are reasonably congruous with the topographic divides. Thus the overlying and very sandy till, which has an average thickness of only 18 feet, is not an effective confining layer. Because of this and because bedrock outcrops are rare, most of the recharge must occur through the till.

Flowing Wells

The most readily available evidence for differentiating between discharge and recharge areas is the presence of flowing wells. These are proof of upward flow and hence of discharge areas either on a local or a regional scale. There are sixty-two flowing wells in the map-area (Figure 8), 44 of which are situated in valley flats, or valley sides, or in the topographically low coastal areas. These wells indicate areas of upward flow and are considered discharge areas of the regional flow system. The remaining 18 flowing wells occur in topographically high areas. The existence of discharge areas here is attributed to locally confined flow produced by lenticular layers of siltstone or claystone interbedded in sandstone, or to highly fractured zones within poorly fractured zones. These kinds of inhomogeneities in the geology produce local modifications in the regional flow system by creating small discharge areas superimposed on regional recharge areas.

On a regional scale the discharge areas include valley flats, valley sides and the coastal area; and recharge areas contain the remainder of the map-area. Although the movement of groundwater is controlled by bedrock fractures and jointing, it is believed to be similar in its gross behaviour to the theoretical movement of groundwater flow through porous media as developed by M.K. Hubbert (1940).

CONCLUSIONS

Recharge occurs through the till to bedrock aquifers where groundwater movement is controlled by fractures. The bedrock consists mainly of poor aquifers yielding less than 20 gpm. The groundwater contains predominantly calcium and sodium bicarbonate ions and generally has less than 400 ppm of tds.

Pump tests were analyzed by the Theis nonequilibrium method even though it was not derived for fracture flow. When two different types of analyses were used, the agreement of hydraulic coefficients was good. This indicates that when a large enough cone of depression is developed during a pump test, the effects of individual fractures are averaged, and a macroscopic view of uniform flow within a zone of homogeneous and isotropic rock is obtained. Either the zone is well fractured and has a high permeability, or it is poorly fractured and has a low permeability.

Throughout the map-area the presence or absence of fractures within the tested zones has produced a wide range of permeability values, which is related to the bedrock formations. A region of high permeability occurs in the sandstone of the Richibucto Formation and a region of low permeability occurs in the siltstone and claystone of the Salisbury Formation. This distribution of permeability also has caused the development of a deeper fresh-water flow system within the Richibucto Formation than in the Salisbury Formation.

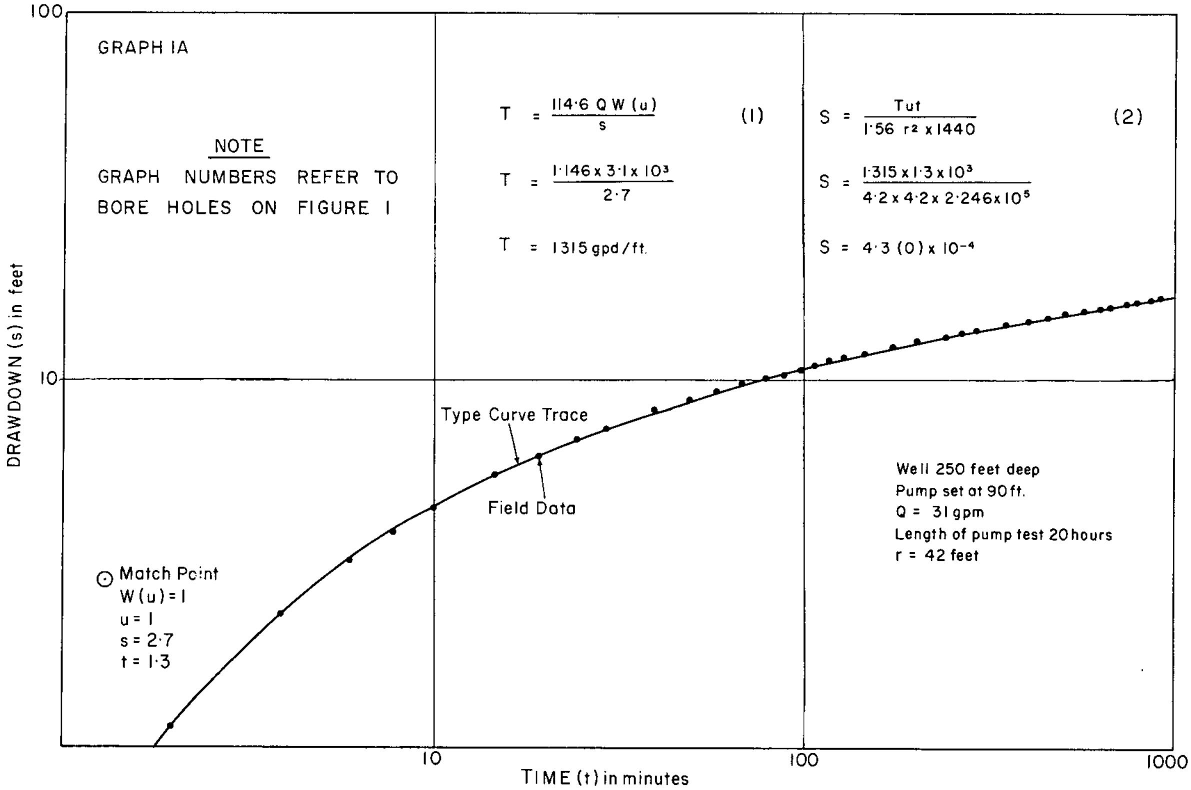
Flowing wells indicate that the regional discharge areas are confined to valley flats, valley sides and coastal areas. High capacity wells can be constructed in the Richibucto sandstone where it is well fractured and is situated in a discharge area of the regional flow system.

*In pocket of inside cover

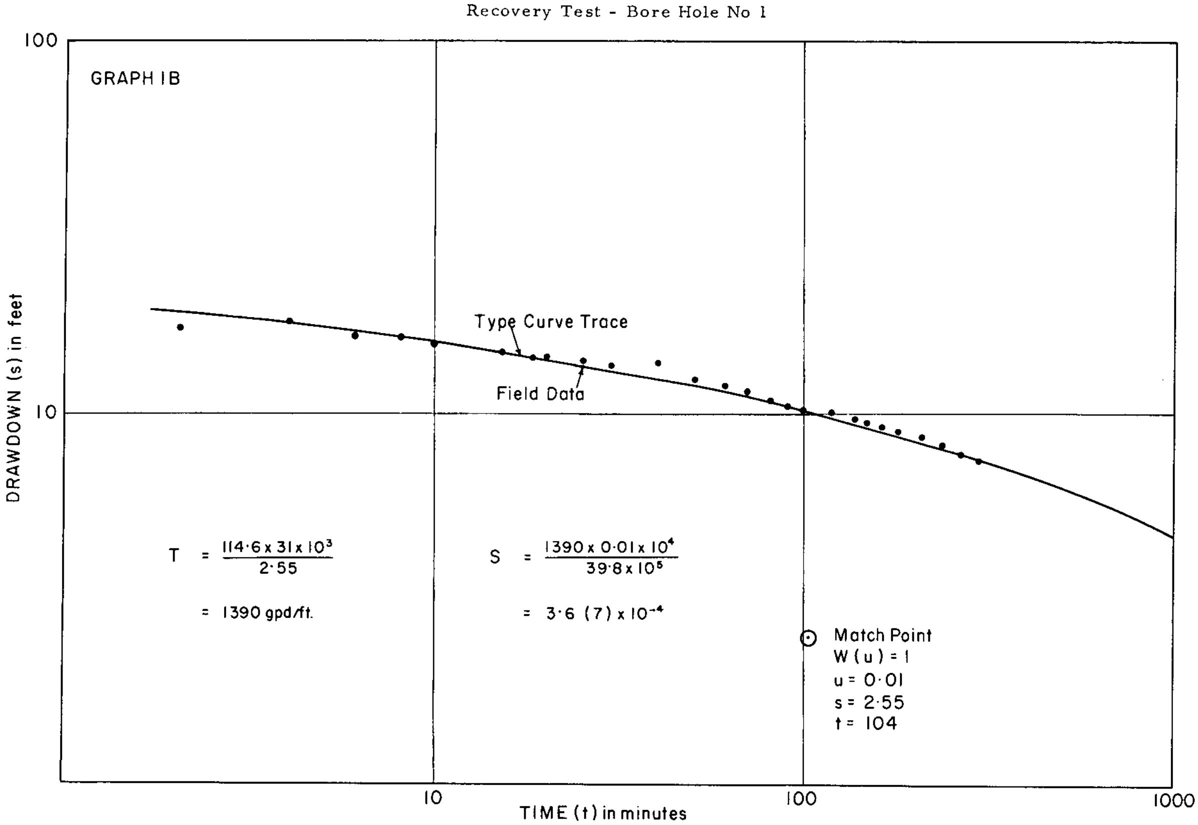
APPENDIX A

(See Figure 1, inside pocket at back of book, for location of bore holes and sites.)

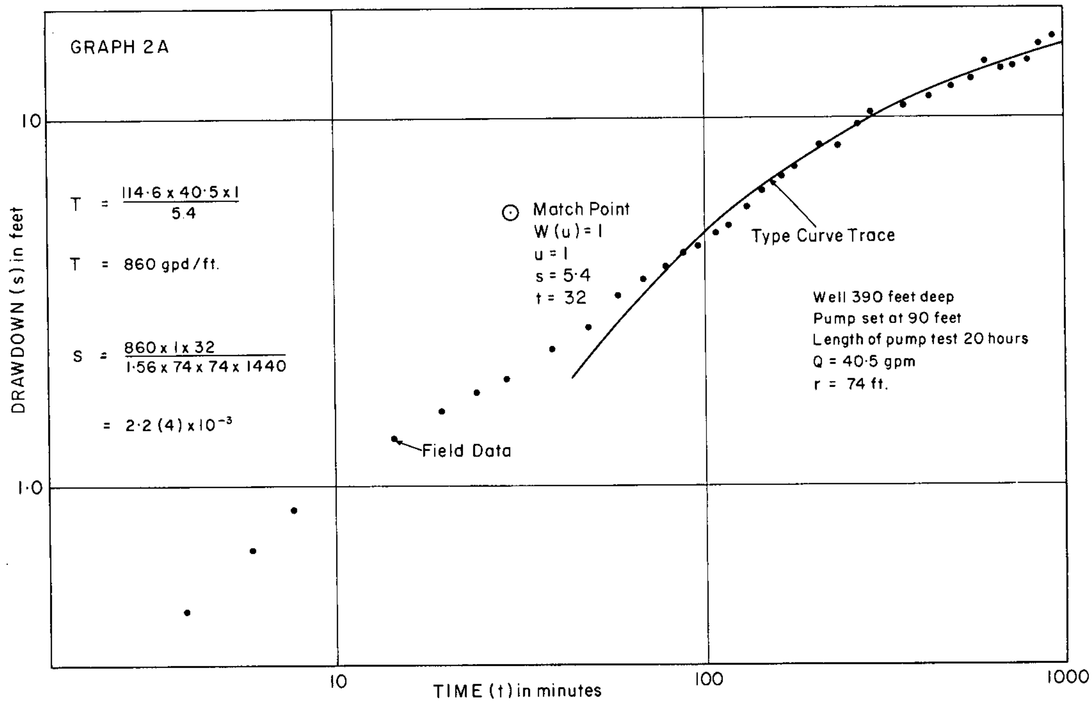
Pump Test - Bore Hole No 1 (See Figure 1 for location)



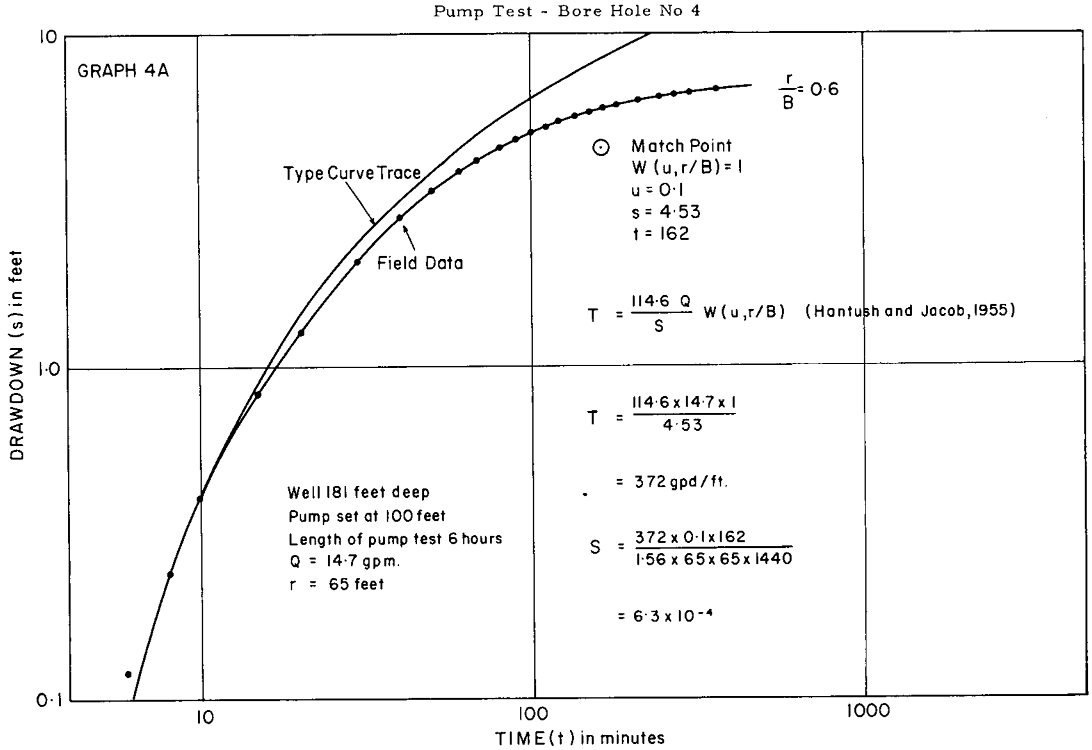
Recovery Test - Bore Hole No 1



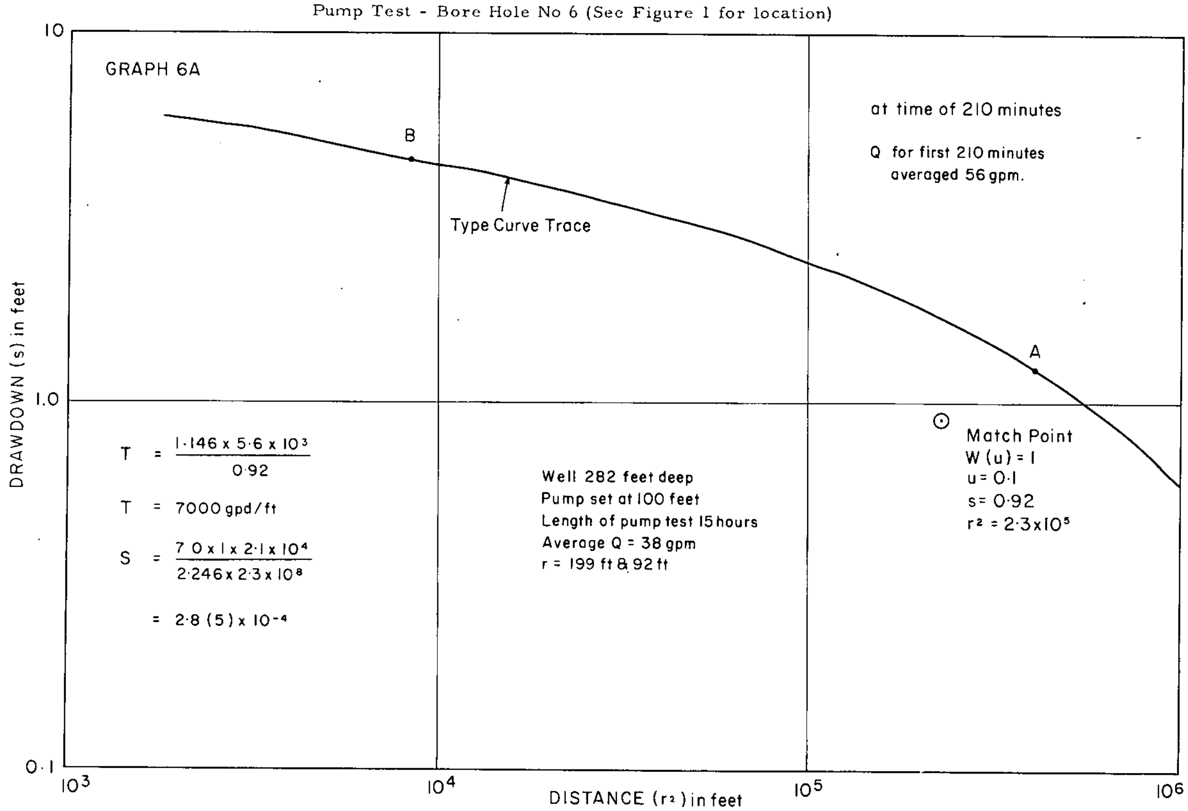
Pump Test - Bore Hole No 2 (See Figure 1 for location)



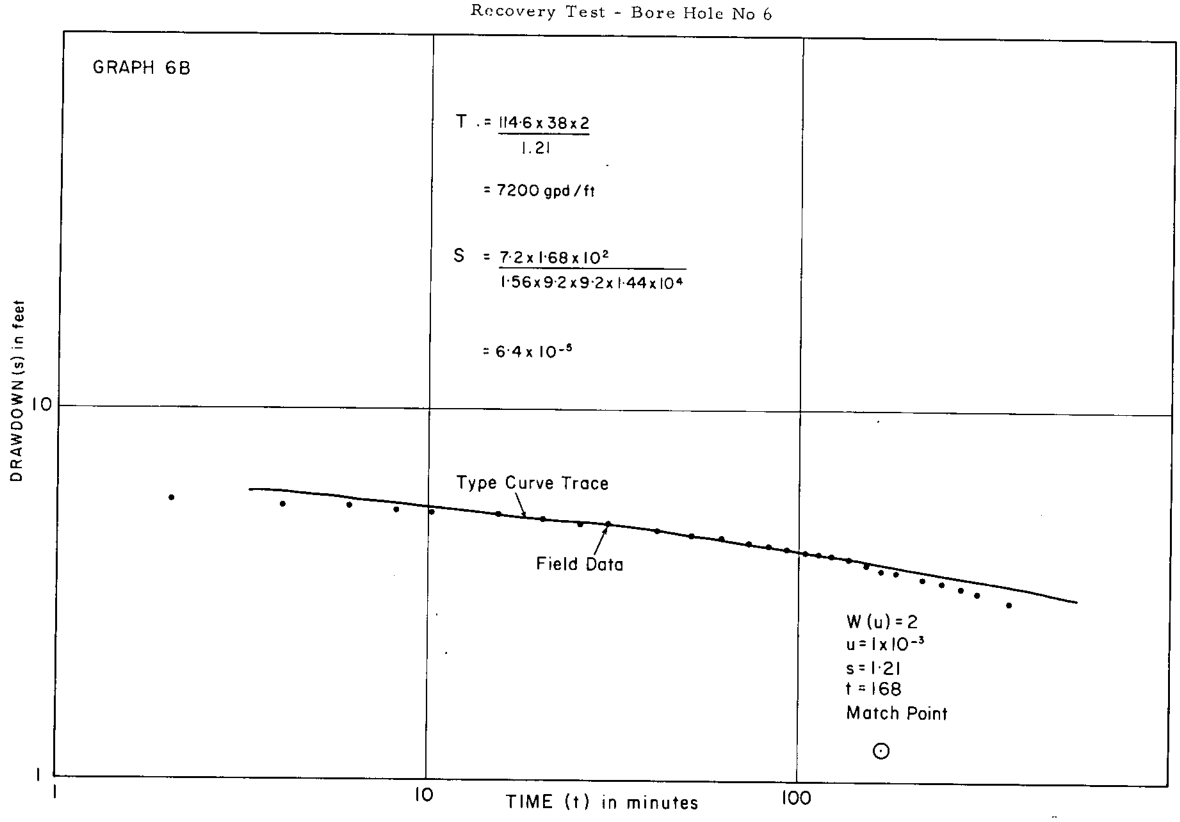
Pump Test - Bore Hole No 4



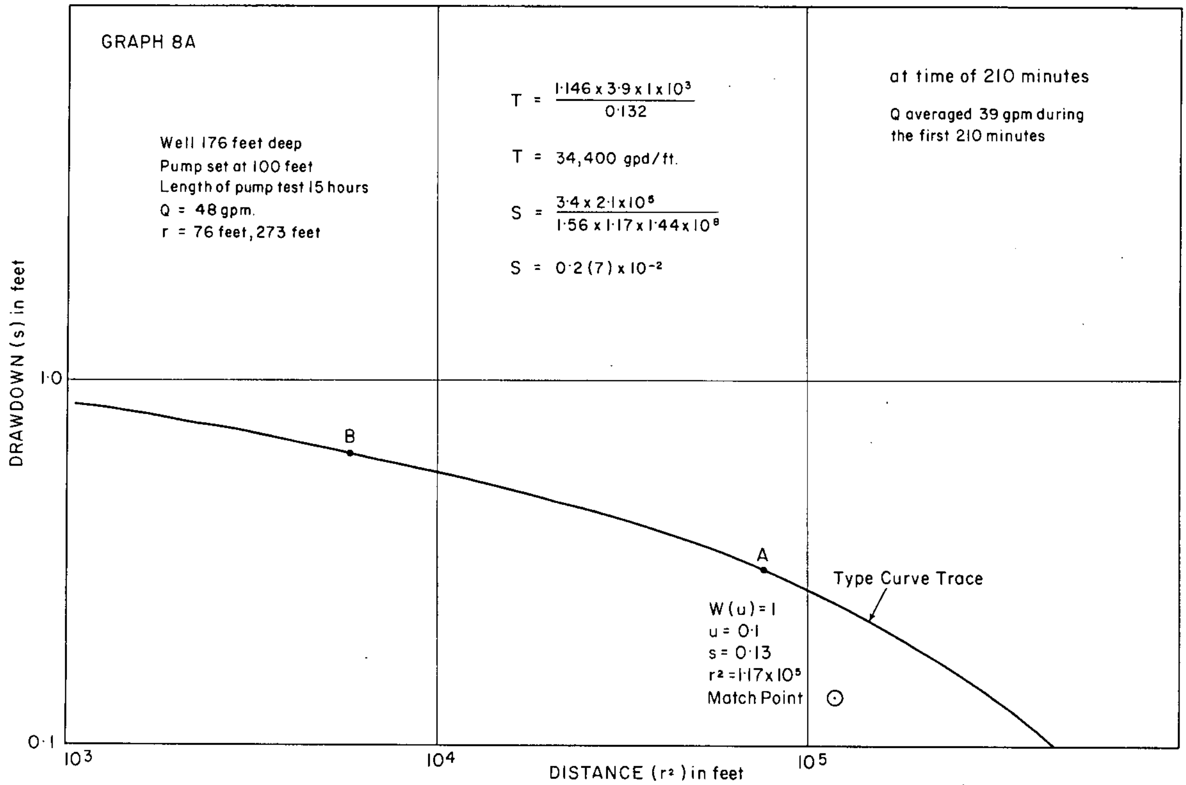
Pump Test - Bore Hole No 6 (See Figure 1 for location)



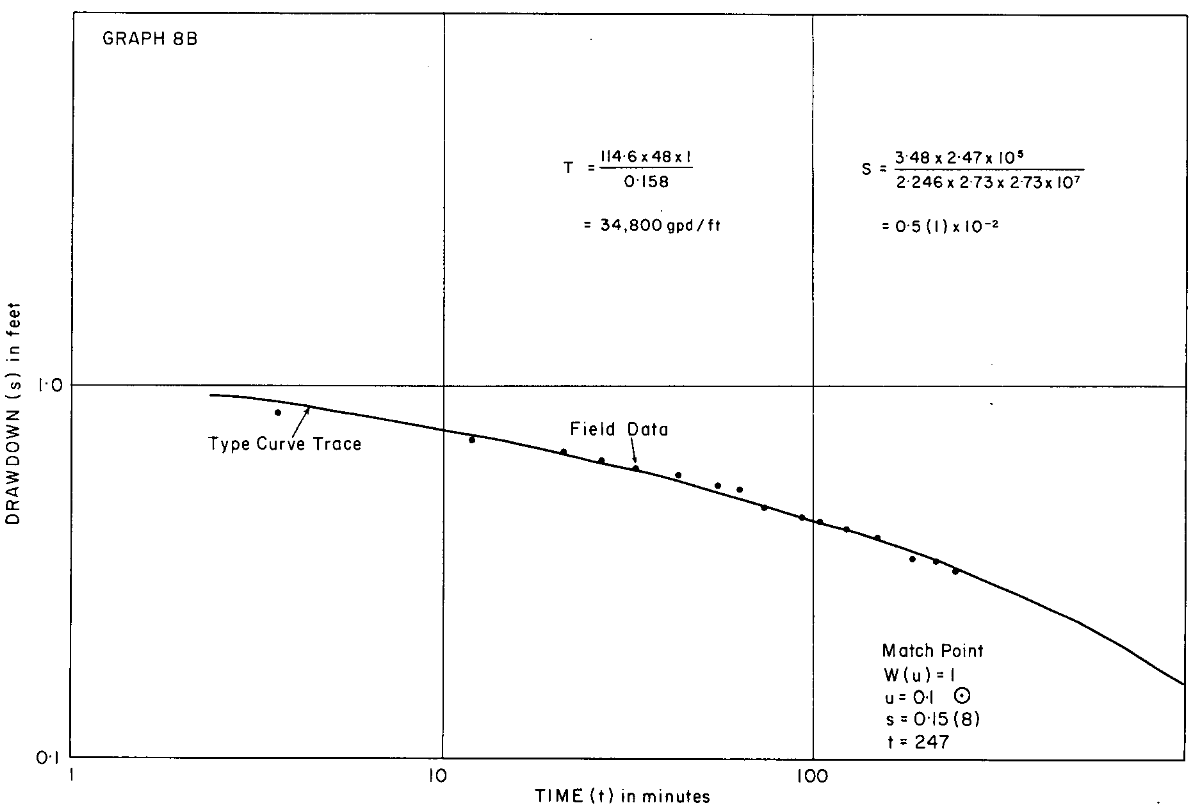
Recovery Test - Bore Hole No 6



Pump Test - Bore Hole No 8 (See Figure 1 for location)



Recovery Test - Bore Hole No 8



Specific Capacity Determination

Site 1 $rw^2 = 0.221$ feet $t' = 1200$ minutes

$$\frac{Q}{s} = \frac{1.35 \times 10^3}{264 \log \dfrac{1.35 \times 10^3 \times 1.2 \times 10^3}{2.246 \times 10^3 \times 0.22 \times 4.10 \times 10^{-4}} - 65.5}$$

$\frac{Q}{s} = 0.8$ gpm/ft of drawdown.

Site 2

$$\frac{Q}{s} = \frac{860}{264 \log \dfrac{8.6 \times 1.2 \times 10^5}{2.246 \times 0.221 \times 2.2} - 65.5}$$

$\frac{Q}{s} = 0.6$ gpm/ft of drawdown.

Site 4

A specific capacity value cannot be determined for leaky aquifer conditions.

Site 6

$$\frac{Q}{s} = \frac{7100}{264 \log \dfrac{7.1 \times 9.0 \times 10^5}{2.246 \times 0.22 \times 1.8 \times 10^{-1}} - 65.5}$$

$\frac{Q}{s} = 3.5$ gpm/ft of drawdown.

Site 8

$$\frac{Q}{s} = \frac{34{,}400}{264 \log \dfrac{3.44 \times 9.0 \times 10^6}{2.246 \times 2.2 \times 0.41} - 65.5}$$

$\frac{Q}{s} = 19$ gpm/ft of drawdown.

Virtual Radius Determination

Site 1

$$W(u) = \frac{sT}{114.6\,Q} = \frac{0.01 \times 1350}{114.6 \times 31} = 3.81 \times 10^{-3}$$

From Wenzel's table "u" = 4.0

$$re^2 = \frac{TuT}{2246\,S} = \frac{4.0 \times 1350 \times 1200}{2246 \times 4.0 \times 10^{-4}} = 7.21 \times 10^6$$

re = 2685 feet

Site 2

$$W(u) = \frac{0.01 \times 860}{114.6 \times 40.5} = 1.85 \times 10^{-3}$$

From Wenzel's table "u" = 4.6

$$re^2 = \frac{860 \times 4.6 \times 1200}{2246 \times 2.2 \times 10^{-3}} = 9.43 \times 10^5 \text{ feet squared.}$$

re = 980 feet.

Site 4

$$W(u) = \frac{0.01 \times 372}{114.6 \times 14.7} = 0.0022$$

From the table of "u" versus "W(u,r/B)" (Walton, 1962, p. 75) "u" = 4.6

$$re^2 = \frac{372 \times 4.6 \times 360}{2246 \times 6.3 \times 10^{-4}} = 4.35 \times 10^5$$

re = 660 feet.

Site 6

$$W(u) = \frac{0.01 \times 7100}{114.6 \times 38} = 1.63 \times 10^{-2}$$

From Wenzel's table "u" = 2.8

$$re^2 = \frac{7100 \times 2.8 \times 900}{2246 \times 1.80 \times 10^{-4}} = 44.2 \times 10^6$$

re = 6650 feet.

Site 8

$$W(u) = \frac{0.01 \times 34{,}400}{114.6 \times 48} = 6.3 \times 10^{-2}$$

From Wenzel's table "u" = 1.8

$$re^2 = \frac{34{,}400 \times 1.8 \times 900}{2246 \times 0.40 \times 10^{-2}} = 6.24 \times 10^5$$

re = 2497 feet.

APPENDIX B

APPENDIX B

CHEMICAL CONSTITUENTS IN PARTS PER MILLION

Rock Unit	Sample No.	pH	Conductance (micromhos at 25°C)	Hardness		Alkalinity		Ca	Mg	Na	K	Total Fe	Total Mn	CO_3	HCO_3	SO_4	Cl	F	NO_3	SiO_2	Sum of Constituents
				Total	Non Carb.	Phenol.	Total														
Till	1	8	279.8	158	5.2	0.0	153	50.3	8.0	7.8	0.8	0.03	Tr.*	0.0	187	14.6	4.5	0.0	1.2	10	189
Richibucto	5	7.1	115.2	45.0	9.2	0.0	35.8	14.9	2.0	4.1	0.8	0.05	0.01	0.0	43.6	8.1	5.6	0.0	2.4	8.3	67.9
	11	8.0	264.0	115	0.0	0.0	122	33.0	8.0	10.8	1.3	0.04	0.02	0.0	149	9.1	3.6	0.0	1.0	10	151
	12	8.0	277.5	92.1	0.0	0.0	138	27.7	5.6	24.5	1.6	0.08	0.07	0.0	168	4.6	3.5	0.32	0.0	12	163
	14	8.1	273.7	129	7.1	0.0	122	34.1	10.7	5.8	1.2	0.19	Tr.*	0.0	149	15.5	3.3	0.0	1.2	7.2	152
	15	7.3	155	60.6	10.2	0.0	50.4	20.1	2.5	6.1	0.6	0.02	0.01	0.0	61.4	4.8	8.8	0.05	5.4	8.5	87.1
	16	8.2	288.5	73.3	0.0	0.0	134	22.6	4.2	33.2	1.5	0.0	Tr.	0.0	163	13.2	3.0	0.0	0.6	11	170
	18	7.7	261.8	83.1	0.0	0.0	109	28.5	2.9	25.2	1.2	0.0	0.0	0.0	132	9.6	9.3	-	8.0	8.2	158
	33	7.5	245.0	17.0	0.0	0.0	111	4.6	1.3	50.0	0.8	0.0	0.04	0.0	135	11.9	3.9	0.10	0.5	8.9	149
	34	5.7	82.9	19.0	14.9	0.0	4.1	3.6	2.4	5.4	0.9	0.06	0.02	0.0	5.0	11.2	6.9	0.09	5.9	8.3	47.2
	35	7.9	161.6	67.3	0.0	0.0	67.6	20.1	4.2	5.0	2.2	0.0	0.0	0.0	82.4	3.7	4.6	0.15	2.0	11	93.1
	37	7.0	266.6	102	21.0	0.0	77.9	29.8	6.6	11.4	0.8	3.6	1.9	0.0	95.0	6.6	31.5	0.14	0.4	18.3	152
	38	7.5	169.2	73.5	0.5	0.0	73.0	25.6	2.3	4.4	1.0	0.34	0.04	0.0	89.0	2.1	6.7	0.11	0.4	12	97.9
	39	8.0	225.1	101	0.0	0.0	102	32.5	4.7	6.6	0.8	0.71	0.03	0.0	124	5.1	6.0	0.13	1.2	7.2	125
	40	7.4	172.8	73.8	0.0	0.0	75.2	17.4	7.4	5.9	0.5	0.37	1.1	0.0	91.7	4.9	6.0	0.17	0.5	9.7	97.6
	42	7.7	483	218	63.5	0.0	154	46.1	25.0	12.1	0.7	2.7	3.0	0.0	188	49.7	28.6	0.14	0.5	13	269
	48	8.1	210	87.3	3.5	0.0	83.8	28.5	3.9	7.4	0.7	0.15	0.01	0.0	102	7.8	8.6	0.08	0.1	6.5	114
Salisbury	6	7.5	145.9	69.5	0.0	0.0	78.8	20.3	4.6	7.5	0.8	0.0	0.01	0.0	96.1	4.2	2.8	0.0	1.0	13	102
	17	9.1	285.3	5.4	0.0	21	160	1.2	0.6	78.0	0.5	0.02	0.0	25	143	9.8	2.4	0.4	0.4	7.4	197
	19	8.0	4,214	355	288	0.0	127	128	9.0	770	2.1	0.61	0.4	0.0	155	49.9	1,320	-	0.5	7.0	2,364

APPENDIX B (Cont'd)

CHEMICAL CONSTITUENTS IN PARTS PER MILLION

Rock Unit	Sample No.	pH	Conductance (micromhos at 25°C)	Hardness		Alkalinity		Ca	Mg	Na	K	Total Fe	Total Mn	CO_3	HCO_3	SO_4	Cl	F	NO_3	SiO_2	Sum of Constituents
				Total	Non Carb.	Phenol.	Total														
	20	8.4	357.8	17.4	0.0	7.1	169	5.3	1.0	74.4	0.8	0.06	0.01	8.5	188	8.2	4.6	-	0.4	8.7	205
	21	8.5	300.1	9.2	0.0	2.8	142	3.2	0.3	68.0	0.9	0.45	0.01	3.4	167	11.6	2.1	-	0.4	7.4	180
	22	7.0	162.0	52.9	10.5	0.0	42.4	17.4	2.5	8.3	2.3	0.12	0.02	0.0	51.7	9.2	6.1	-	16	12	98.8
	23	8.2	1,790	29.7	0.0	0.0	121	10.9	0.6	354	1.1	0.27	0.01	0.0	148	202	340	-	0.3	7.0	989
	24	8.6	422.6	4.7	0.0	6.1	194	1.6	0.2	102	0.5	4.5	0.02	7.3	222	31.6	2.7	-	0.4	7.4	263
	25	8.5	318.6	3.7	0.0	2.0	156	1.3	0.1	77.6	0.4	0.04	0.0	2.4	185	11.8	4.0	0.8	0.2	7.8	186
	26	7.8	315.4	100	0.0	0.0	168	35.2	3.0	33.5	1.4	0.31	0.2	0.0	205	7.8	2.0	0.4	0.0	11	196
	27	7.5	336.6	144	48.3	0.0	96.0	51.4	3.9	8.8	0.5	0.07	0.0	0.0	117	12.2	20.6	0.0	34	14	203
Salisbury	28	7.2	287.6	111	29.3	0.0	81.6	35.4	5.4	12.9	2.8	0.18	0.01	0.0	99.5	20.2	19.0	0.0	16	13	173
	29	6.7	360.4	115	62.5	0.0	52.1	36.3	5.8	19.0	1.1	0.24	0.04	0.0	63.5	22.5	56.3	0.0	6.0	13	191
	30	8.7	508.3	3.5	0.0	11	241	1.1	0.2	121	0.7	0.08	0.0	13	268	10.1	11.8	1.5	0.0	6.3	298
	32	8.3	329.8	150	0.0	0.0	165	50.5	5.7	11.9	2.2	0.04	0.01	0.0	201	4.1	5.5	0.0	4.0	10	193
	36	7.5	309	134	54.4	0.0	95.6	48.6	3.1	6.3	1.0	1.3	0.03	0.0	117	15.6	7.1	0.09	24	7.6	171
	46	8.7	565	8.7	0.0	7.6	259	1.6	1.1	134	0.8	0.03	0.04	9.1	298	14.0	9.4	5.7	0.3	5.8	329
	47	7.7	202.5	69.0	0.0	0.0	79.0	22.5	3.1	13.0	1.4	0.22	0.0	0.0	96.3	9.6	7.1	0.10	1.2	8.4	114
	49	8.1	2,364	53.4	0.0	0.0	84.7	16.4	3.0	461	1.2	0.10	0.07	0.0	103	65.0	632	4.4	0.0	5.8	1,251
	55	8.6	247	18.3	0.0	3.0	93.1	5.1	1.4	48.3	1.1	0.47	0.0	3.6	106	14.7	8.2	2.3	0.7	6.2	144
	56	8.2	449	38.3	0.0	0.0	209	11.0	2.6	90.8	0.9	0.29	0.0	0.0	255	1.4	18.8	1.6	0.9	8.0	261
	57	8.2	1,328	56.8	0.0	0.0	272	15.4	4.5	268	1.2	11.0	0.19	0.0	331	3.2	250	5.1	0.7	5.9	717
	58	8.8	350.8	4.4	0.0	6.0	178	1.0	0.5	853	0.5	0.03	0.01	7.2	202	5.3	3.2	0.32	0.0	7.3	210

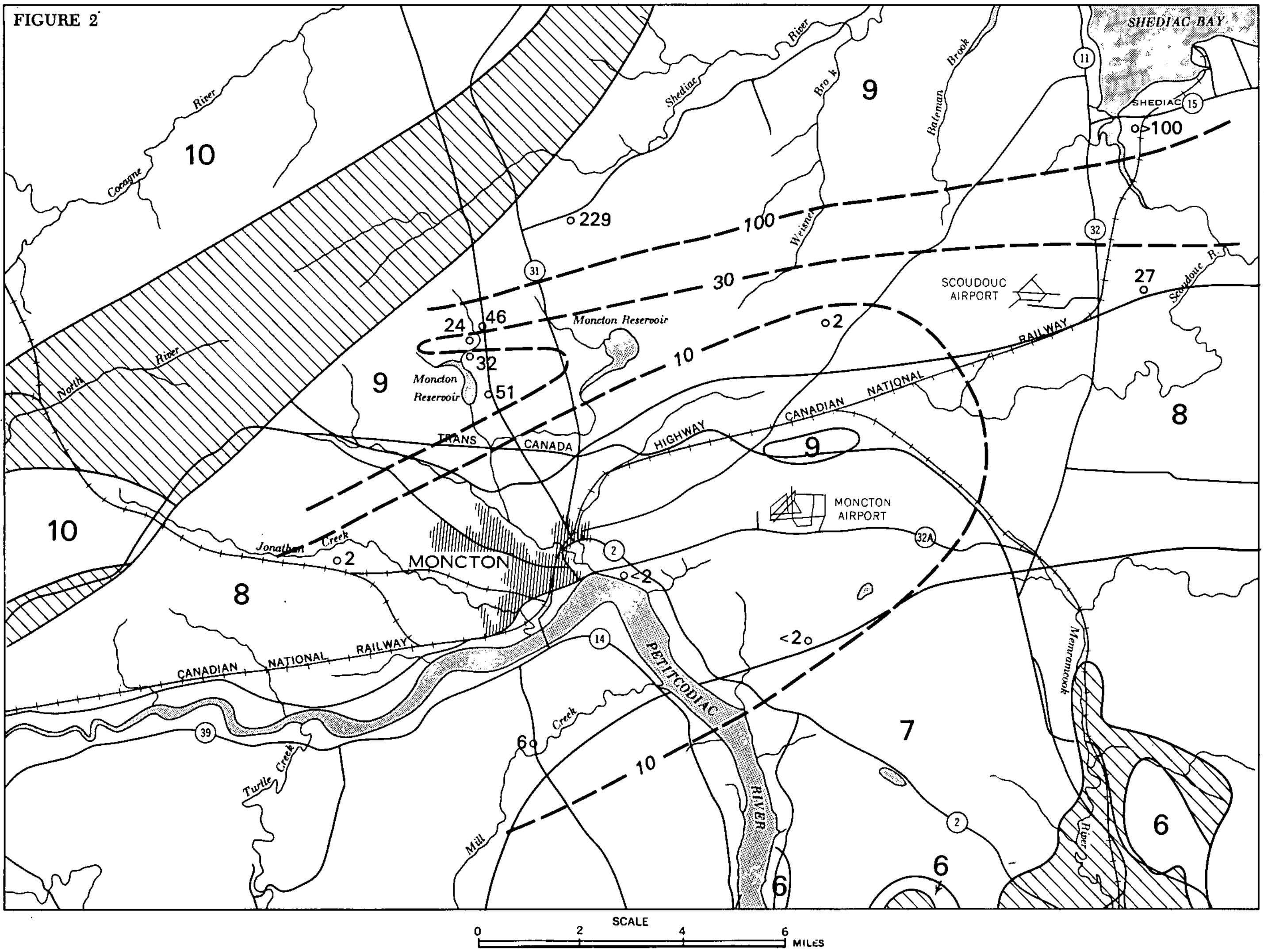
APPENDIX B (Concl.)

CHEMICAL CONSTITUENTS IN PARTS PER MILLION

Rock Unit	Sample No.	pH	Conductance (micromhos at 25°C)	Hardness		Alkalinity		Ca	Mg	Na	K	Total Fe	Total Mn	CO_3	HCO_3	SO_4	Cl	F	NO_3	SiO_2	Sum of Constituents
				Total	Non Carb.	Phenol	Total														
Boss Point	31	8.2	231.9	51.2	0.0	0.0	112	18.3	1.3	33.5	0.7	0.20	0.16	0.0	136	4.2	4.4	0.7	0.0	7.3	138
	41	7.0	215	32.7	0.0	0.0	95.8	9.3	2.3	35.3	0.8	0.06	0.03	0.0	117	7.5	4.2	0.42	1.5	4.8	124
	43	7.3	419	178	47.0	0.0	131	52.5	11.5	11.3	1.3	0.54	0.0	0.0	160	20.9	21.9	0.16	24	4.8	227
	53	6.7	221	65.2	39.2	0.0	26.0	20.0	3.7	11.4	4.3	0.06	0.0	0.0	31.7	14.8	15.7	0.05	38	9.8	144
	54	8.5	648	8.8	0.0	4.0	261	1.3	1.3	153	0.5	0.02	0.0	4.8	309	17.5	38.0	2.7	1.1	6.4	379
Hopewell	51	9.0	631	5.5	0.0	15.5	208	1.4	0.5	144	0.5	0.19	0.0	18.6	216	27.8	47.6	5.0	0.1	6.6	359
	52	6.9	209	74.6	43.8	0.0	30.8	24.2	3.4	6.7	0.7	0.18	0.01	0.0	37.5	5.7	16.6	0.08	38	13	127
Boulder Conglomerate	7	6.9	162.7	65.7	33.9	0.0	31.8	16.0	6.3	6.6	1.5	0.04	0.01	0.0	38.8	9.6	20.3	0.0	10	12	101
	9	7.5	247.7	114	13.7	0.0	100	40.0	3.3	4.7	0.6	0.0	0.2	0.0	122	7.7	6.8	0.0	5.0	9.1	137
	10	7.7	422.2	223	28.5	0.0	195	66.3	14.1	5.2	0.6	0.18	0.7	0.0	238	10.8	17.2	0.0	1.2	16	239
	13	8.1	283.1	127	48.6	0.0	78.3	41.6	5.8	5.7	0.4	0.02	0.0	0.0	95.4	56.3	3.2	0.0	1.2	9.6	171
Moncton	2	8.0	506.0	127	0.0	0.0	186	36.8	8.4	69.6	2.4	1.1	0.16	0.0	227	56.8	25.2	0.0	0.2	9.2	321
	3	7.7	2,208	1,390	1,266	0.0	124	478	47.9	46.2	2.6	0.14	0.8	0.0	151	1,315	18.5	0.4	2.0	13	2,009
Albert	4	7.8	461.1	212	79.3	0.0	132	49.2	21.6	12.8	0.6	0.04	0.03	0.0	161	47.6	18.0	0.0	35	15	279
	8	8.3	361.8	194	14.6	0.0	179	46.1	19.1	8.0	0.6	0.05	0.02	0.0	218	24.6	3.6	1.0	1.6	13	225
Memramcook	44	7.5	483	197	83.4	0.0	113	62.9	9.6	12.2	0.8	0.39	0.03	0.0	138	14.6	61.8	0.16	9.2	8.0	247
	45	6.5	126	44.3	18.7	0.0	25.6	14.4	2.0	4.1	1.4	1.2	0.03	0.0	31.2	16.2	5.2	0.04	4.8	8.4	71.9
	50	8.3	5,157	208	0.0	0.0	209	67.9	9.4	1,020	4.0	0.32	0.05	0.0	255	6.0	1,579	4.8	0.2	6.2	2,823

* Tr. = Trace.

ILLUSTRATIONS



PERMEABILITY VALUES IN THE SALISBURY AND RICHIBUCTO FORMATIONS

Coefficient of field permeability....................gallons/day/ square foot o 24

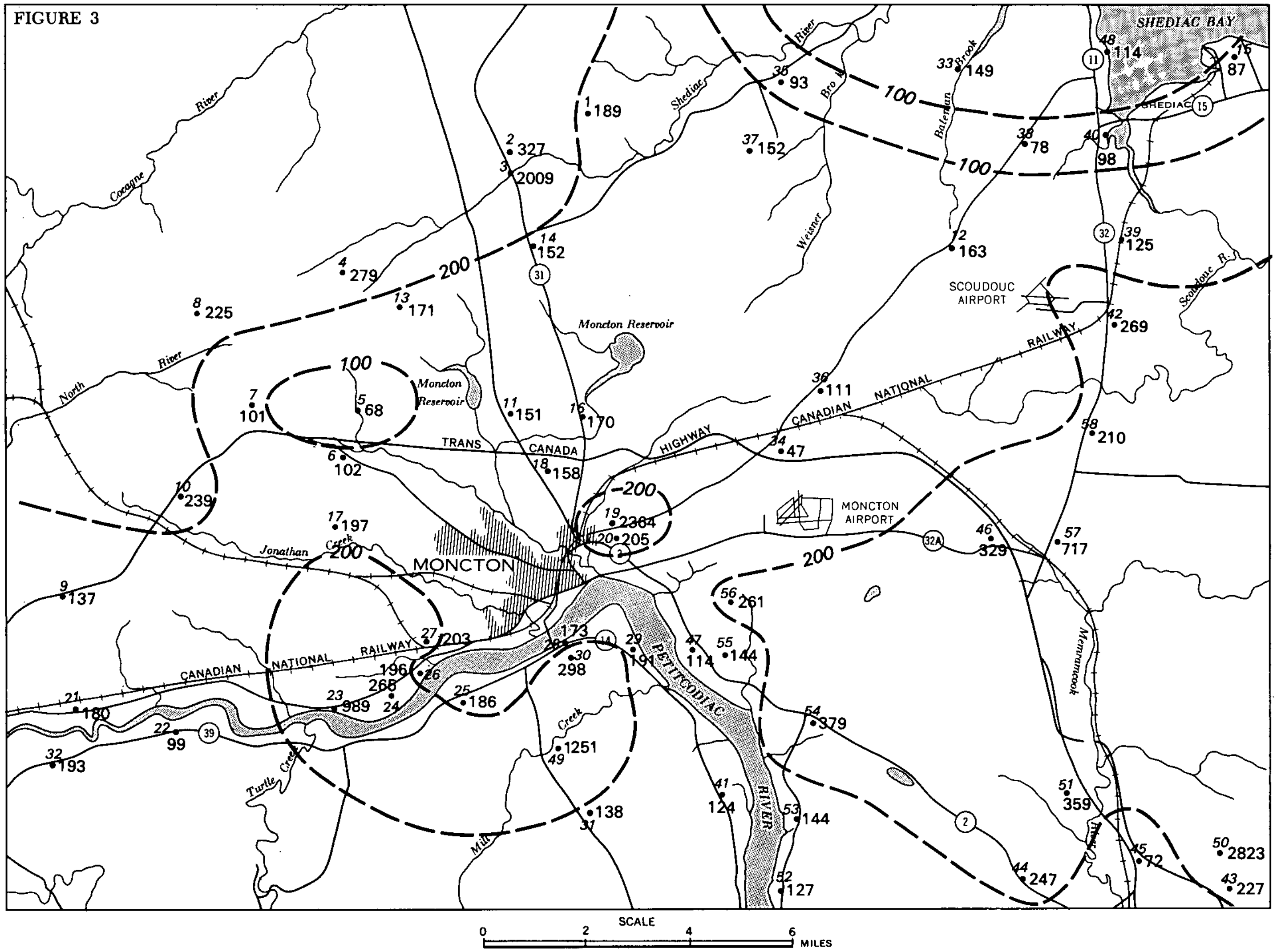
Permeability contour.. —30—

Rock unit.. 9

Geological boundary..

Area of pre-Hopewell rocks..

FIGURE 3



TOTAL DISSOLVED SOLIDS OF THE GROUNDWATER

Contour of sum of constituents of the groundwater in parts per million...... —*200*—

Sample location and number.. • *51*

Value of total dissolved solids in p.p.m.................................. 359

FIGURE 6

CHEMICAL PATTERNS OF GROUNDWATER FROM THE SALISBURY FORMATION

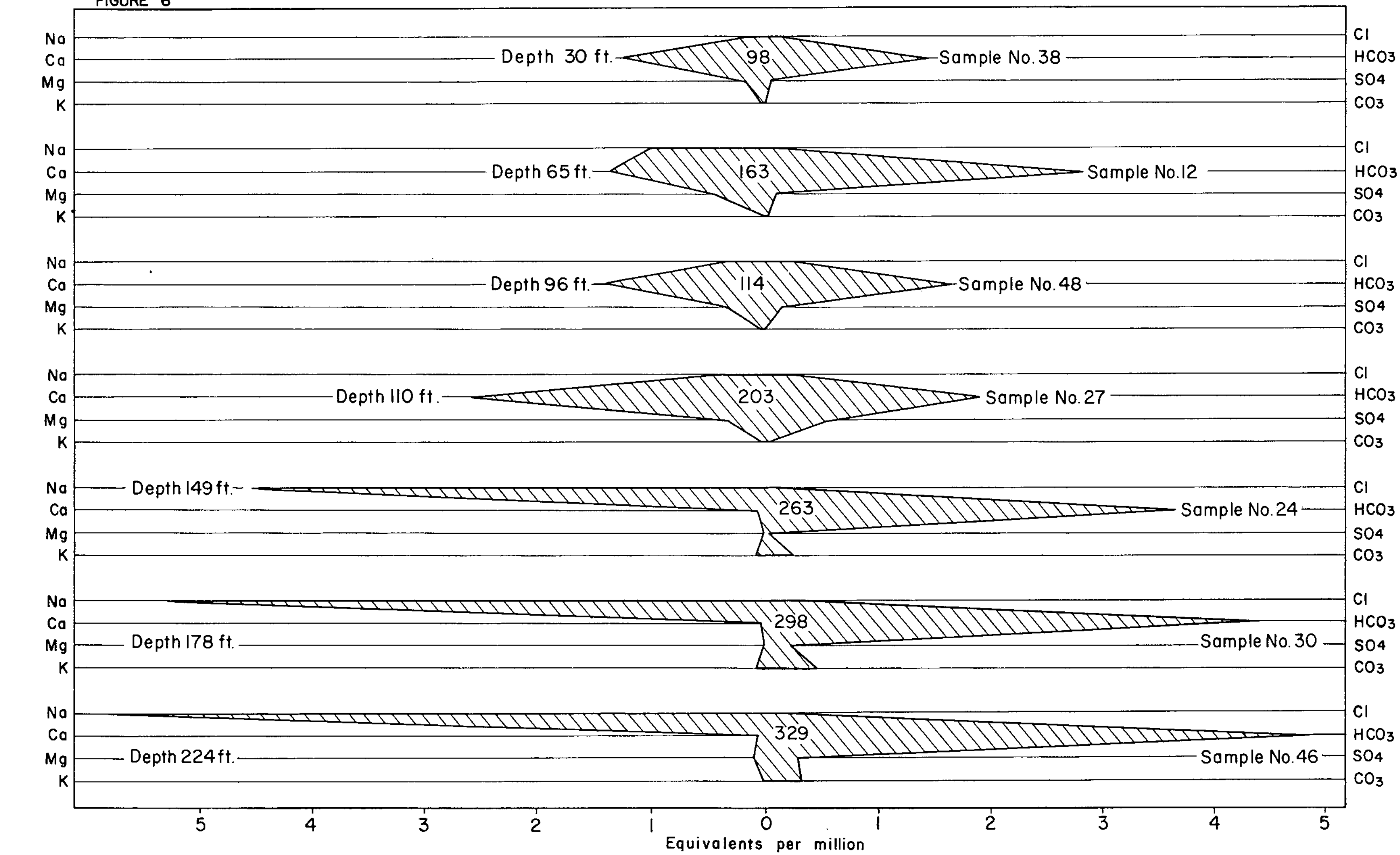
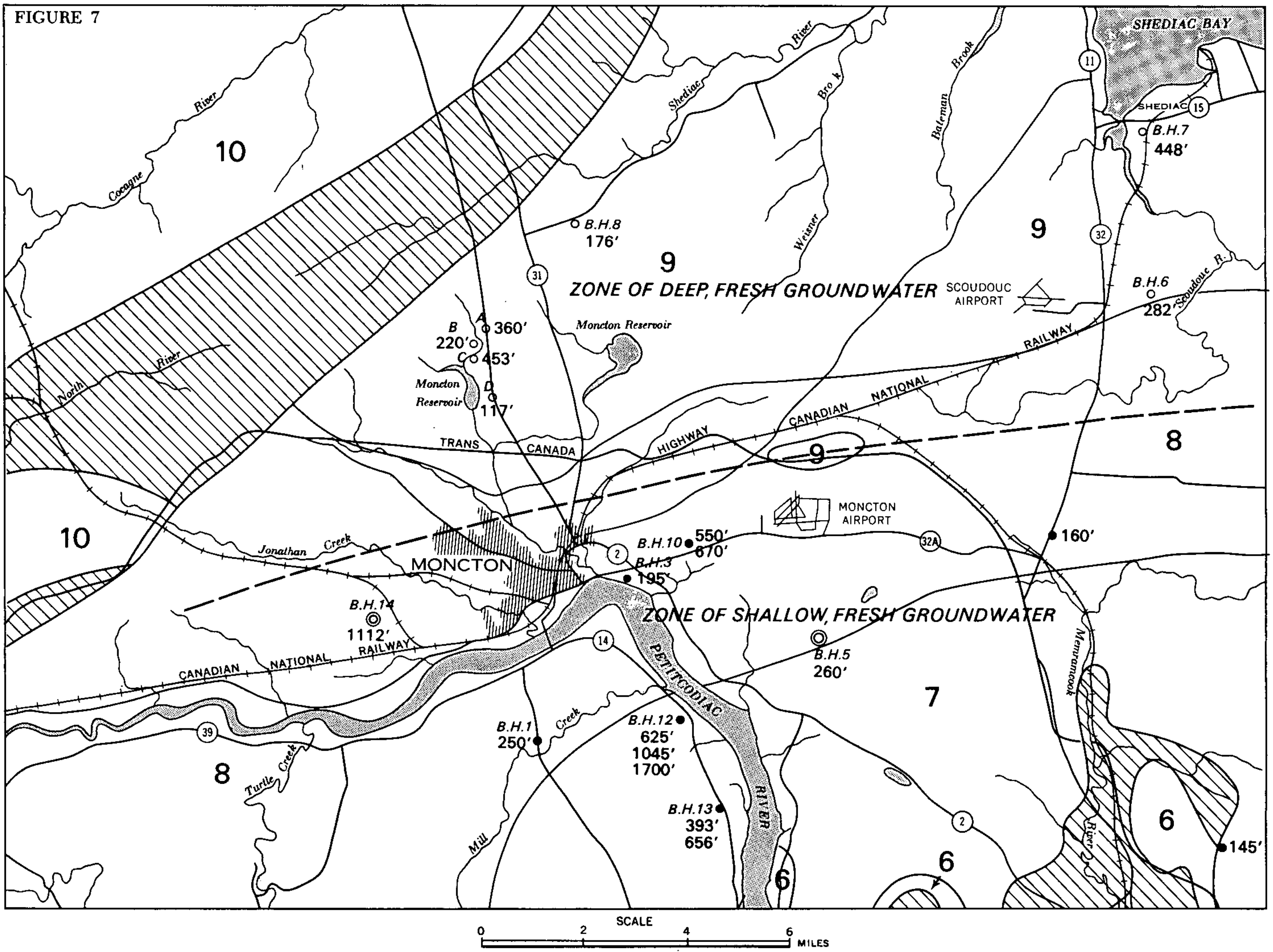


FIGURE 7



DEPTH OF FRESH-WATER FLOW SYSTEM

Depth in well at which salt water was encountered	● 250'
Depth of well with a low yield of fresh groundwater	◎ 1112'
Depth of well with a high yield of fresh groundwater	○ 448'
Boundary between zones of shallow and deep, fresh groundwater flow	— —
Geological boundary	——
Area of pre-Hopewell rocks	(hatched)
Rock unit	8
Borehole	B.H.6

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FIGURE 5

CHEMICAL ANALYSIS DIAGRAM

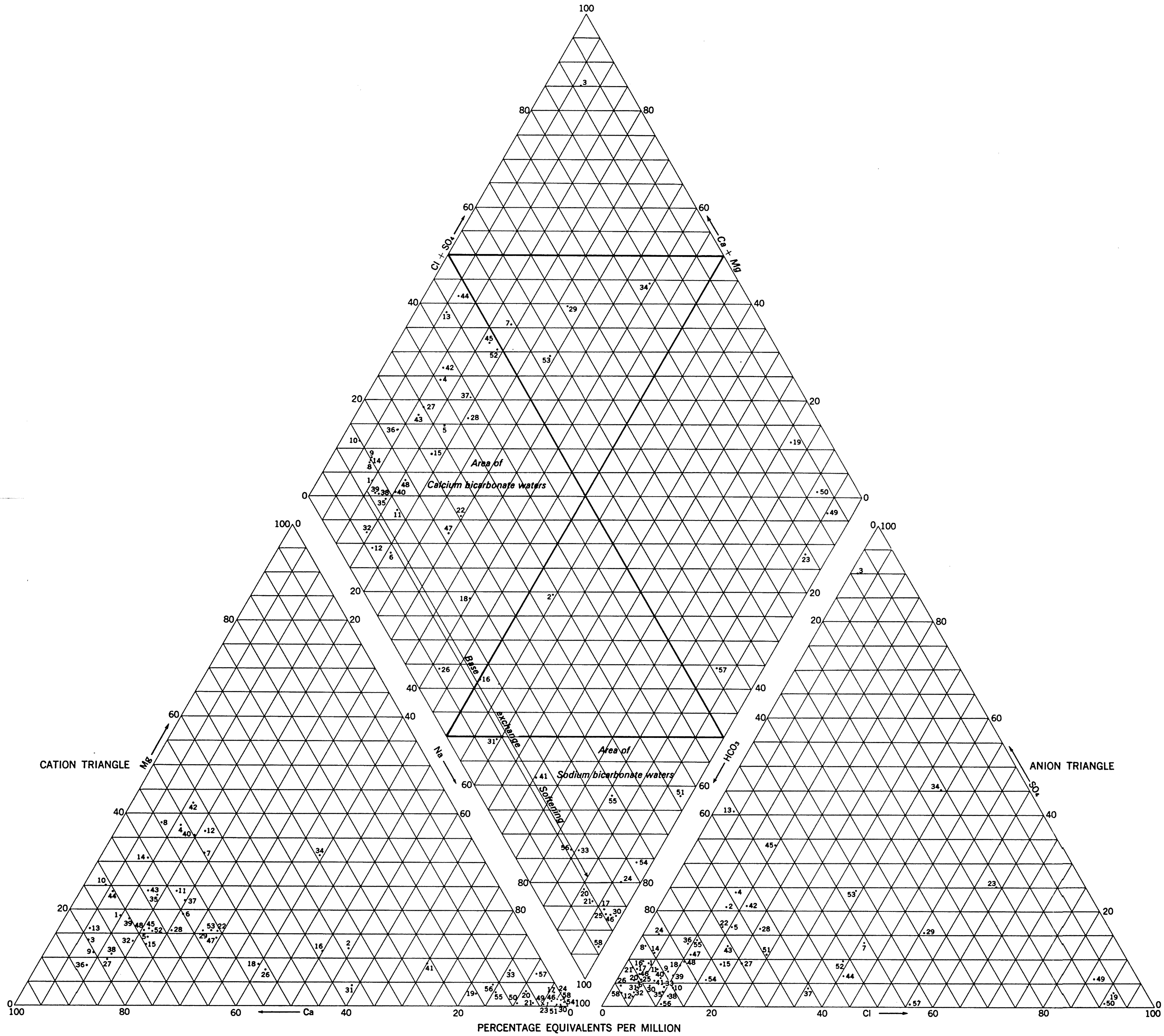

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Figure 8
Approximate Water-table Surface
Moncton map-area
New Brunswick

Scale: One Inch to One Mile = $\frac{1}{63,360}$

Miles

1 ½ 0 1 2 3

LEGEND

Well location (with elevation of well-water above mean sea-level) . . • 113

Piezometric contour in feet above mean sea-level (defined, approximate) . . . .

Flowing artesian well . . . . FA •

Spring . . . . ×

Roads, hard surface, all weather . . . .

Roads, loose surface, all weather . . . .

Roads, loose surface, dry weather . . . .

Cart track . . . .

Trail or portage . . . .

Railway . . . .

County boundary . . . .

Power transmission line . . . .

Building . . . .

Post Office . . . .

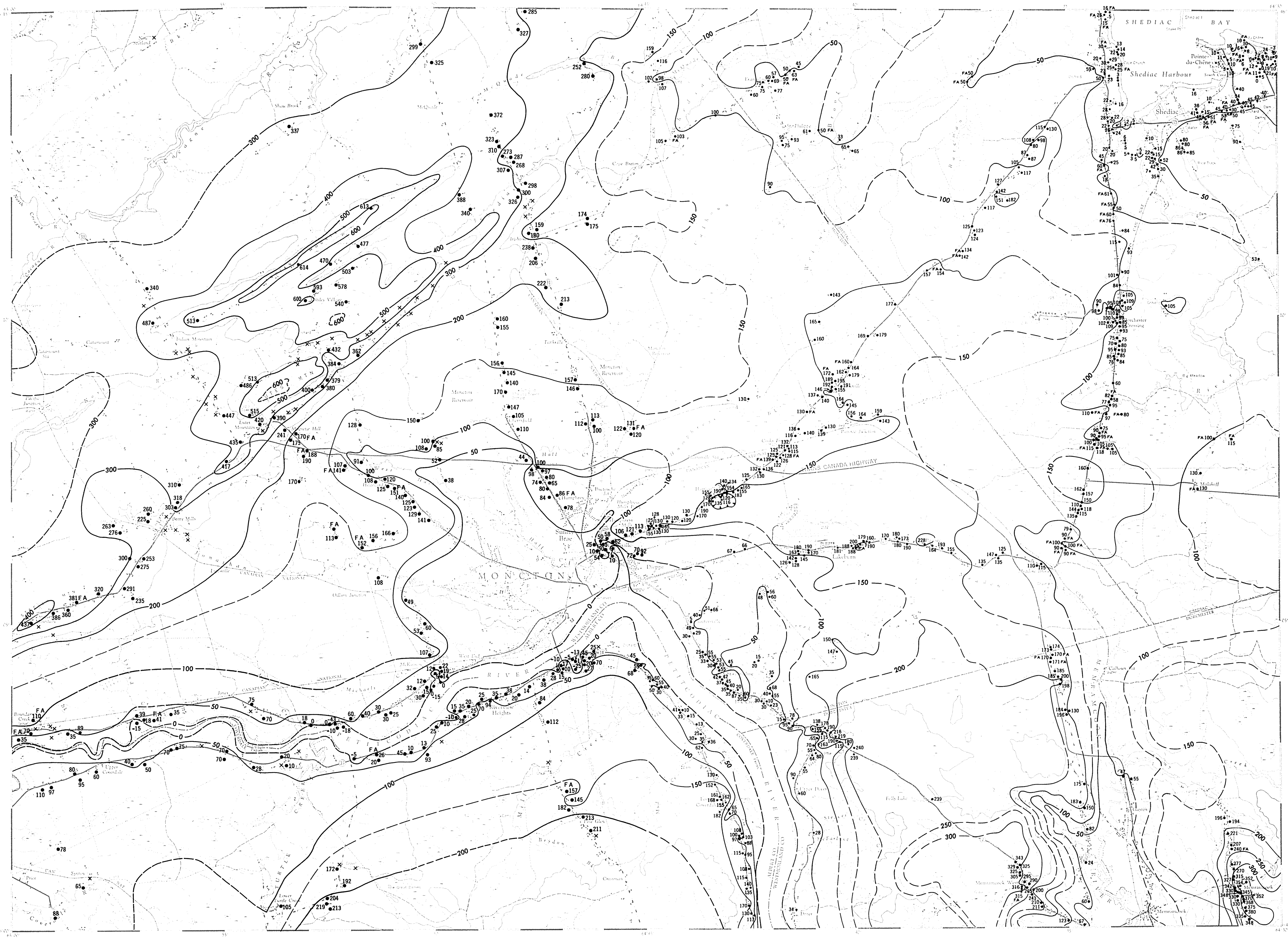
Intermittent stream . . . .

Marsh . . . .

Contours (interval 50 feet) . . . .

Base-map prepared by the Surveys and Mapping Branch, 1952

Approximate magnetic declination, 23°13' West, decreasing 2'.5 annually



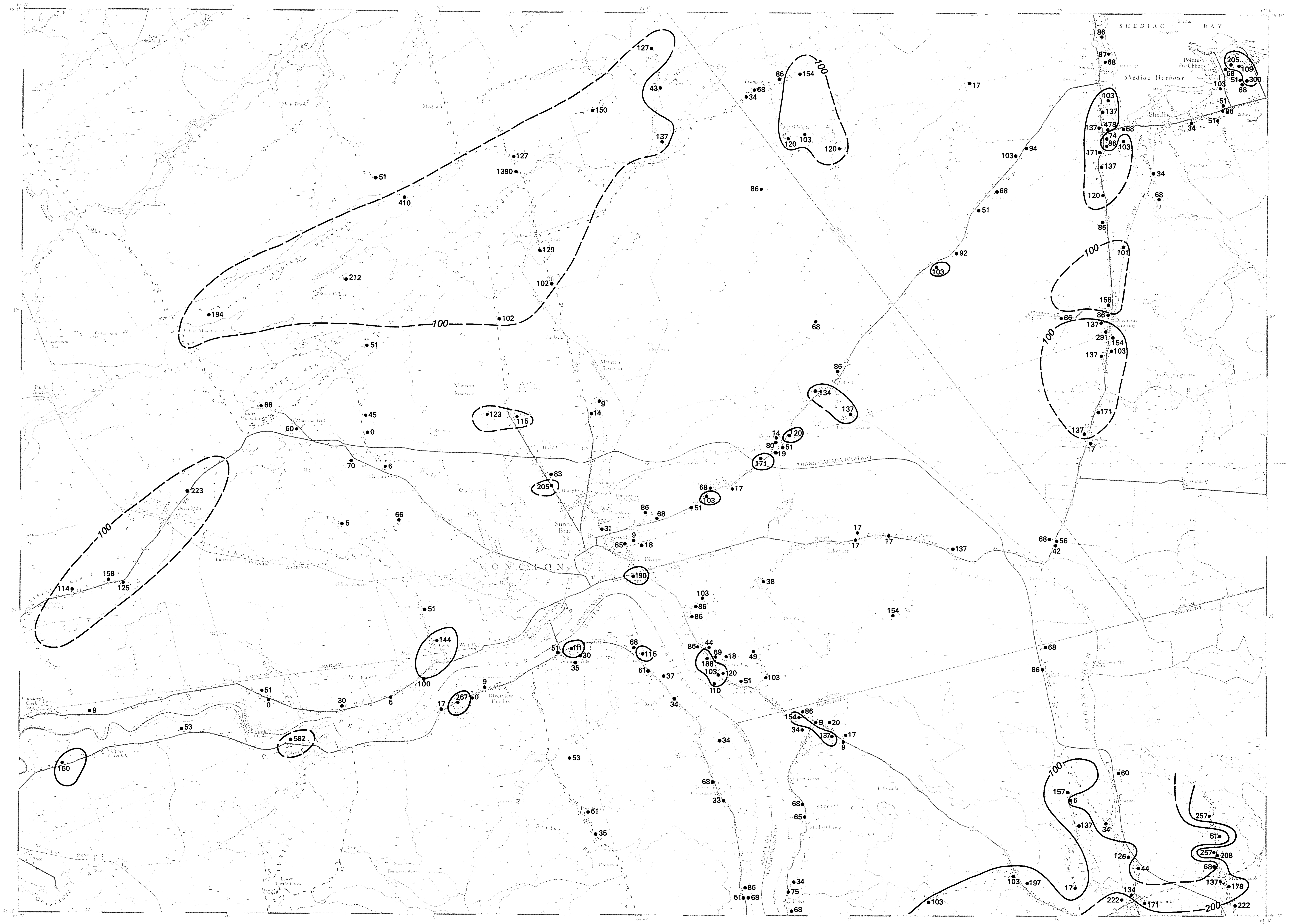


Figure 4
Total Hardness of the Groundwater

SCALE
0 1 2 MILES

our Showing the total hardness of the Groundwater in p.p.m. as Ca CO3 .... —100—
tion of total hardness determination in p.p.m. .... ●86

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Figure 1

Bedrock Geology and Aquifer test results of Moncton map-area New Brunswick

Scale: One Inch to One Mile = $\frac{1}{63,360}$

Miles: 1 ½ 0 1 2 3

LEGEND

PALAEOZOIC

PENNSYLVANIAN

9	RICHIBUCTO FORMATION yellowish orange to grey sandstone, minor red claystone	10	PETITCODIAC GROUP red and grey sandstone, claystone and some siltstone
8	SALISBURY FORMATION red claystone, siltstone, lesser amounts of sandstone and conglomerate		
7	BOSS POINT FORMATION yellowish orange to grey sandstone and rounded pebble conglomerate, red claystone		

MISSISSIPPIAN OR PENNSYLVANIAN

6	HOPEWELL GROUP red shale, red granite pebble conglomerate and breccia

MISSISSIPPIAN

4	MONCTON GROUP red and green siltstone, sandstone conglomerate and breccia	5	BOULDER CONGLOMERATE UNIT facies of 3, and contains parts of 2 and/or 4
3	ALBERT FORMATION grey shale, siltstone, and yellowish orange to grey sandstone		

DEVONIAN AND MISSISSIPPIAN

2	MEMRAMCOOK FORMATION red shale, siltstone, and some red and grey to green sandstone and conglomerate; 2a pebble conglomerate and grey to green sandstone

PALAEOZOIC AND/OR PRECAMBRIAN

DEVONIAN ? and/or earlier

1	BASEMENT COMPLEX sheared granite porphyry, greenstone, granite

Tidal deposits

Geological Boundary (approximate, assumed)

Fault (approximate)

Borehole BH12

Coefficient of transmissibility .... T gpm/ft

Coefficient of storage .... S

Specific capacity .... S.C. gpm/ft

Virtual radius

Aquifer test site

City of Moncton Water Well .... B

Geology by P. A. Carr 1961-63

Previous mapping by W. C. Gussow 1953 and G. W. H. Norman 1941