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HYDROGEOLOGY OF TAYLOR ISLAND
NEW BRUNSWICK

by

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Submitted in partial fulfillment
of the requirements for the degree
of Doctor of Philosophy

Faculty of Graduate Studies
The University of Western Ontario
London, Canada
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ABSTRACT

Sea-water intrusion into the Upper Sandstone aquifer at Shippegan, Taylor Island, New Brunswick is a lateral flow phenomena in a multi-layered aquifer-aquiclude system and an insular Ghyben-Herzberg fresh-water lens. Seaward flow through the transition zone of a sea-water intrusion wedge takes place during periods of high groundwater stage, whereas, reversals of gradient and inland migration of sea water takes place during periods of low groundwater stage, when the groundwater divide, produced by the pumping well cone of depression superimposed on the natural flow of fresh water to the sea, reaches the saline recharge boundary. Flow of brackish and saline water to the pumping well follows a "V" shaped pattern, the apex of which is the producing well, and the extremities of which are recharge boundary stagnation points.

Prognosis of sea water intrusion to a coastal production well can be made conservatively for the purposes of engineering safety by means of a digital model, if the aquifer is shallow and based by a thick aquiclude. A single fluid, fresh water, and a low-storage natural groundwater head configuration are assumed. Field determination of aquifer parameters is required. The response of a coastal aquifer to pumping can be carried out by monitoring piezometers located between the well field and the natural coastal transition zone.

Tidal response analysis of the Upper Sandstone aquifer by the Ferris method gives diffusivity values in agreement with pump-test determinations. Permeability values determined by both the tidal response and pump-test methods are of the same order of magnitude.

Cation-exchange occurs in the illite-chlorite double layer of the interstitial clay within the transition zone area of the Upper Sandstone aquifer. Potassium and sodium displace calcium, the exchange being more complete in more saline portions of the transition zone. Reduced acidity of fresh groundwater bordering acidic peat-water bogs is considered to be due to cation-exchange.

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CHAPTER I

1. INTRODUCTION

1.1 Purpose and Scope of Investigations

This investigation was undertaken for the purpose of studying the hydrogeological factors which are pertinent to the phenomena of sea-water intrusion into coastal aquifers as induced by production wells. The presence of a sea-water intrusion wedge at the town of Shippegan on Taylor Island, New Brunswick, made possible the measurement of the hydrogeologic parameters in a field prototype. The flow patterns of groundwater within the sea-water intrusion wedge near a municipal production well and in other control areas were determined periodically both in plan and in section. The distribution of the hydraulic characteristics of the principal aquifer, the Upper Sandstone, and the aquifers response to pumping was evaluated by using a digital model. The seasonal movement of isochlors in the sea-water intrusion wedge was examined.

The study was expanded to include ancillary aspects, such as cation-exchange phenomena within the sea-water intrusion wedge; the measurement of permeabilities of the principal aquifer by the tidal response method; a study of groundwater temperatures; and other features.

1.2 Description of Area, Location and Population

Taylor Island, on which the town of Shippegan is located, is a peninsula situated in northeastern New Brunswick, in the northeast quadrant of the National Topographic System map sheet Bathurst (21P) (Figure 1). Shippegan's position on Shippegan Sound, a channel which joins Chaleur Bay and the Gulf of St. Lawrence, makes it an important fishing and fish processing centre. The population of the town of Shippegan comprises about 1800 people, whereas the population of Taylor Island, including the town of Shippegan is in the neighbourhood of 2300 people.

1.3 Topography and Drainage

Taylor Island is extremely flat and devoid of relief features. The natural land surface rises imperceptibly from a few feet at the sea shore to a maximum elevation in the central portion of the island of between fourteen and fifteen feet. Recharge on the island is entirely from precipitation and the absence of surface drainage of any significance causes discharge to take place almost entirely by groundwater flow, except during the period of rapid snow melt in the early spring.

1.4 Climate

A 1966 to 1968, three-year monthly average of the precipitation and temperature record for the Department of

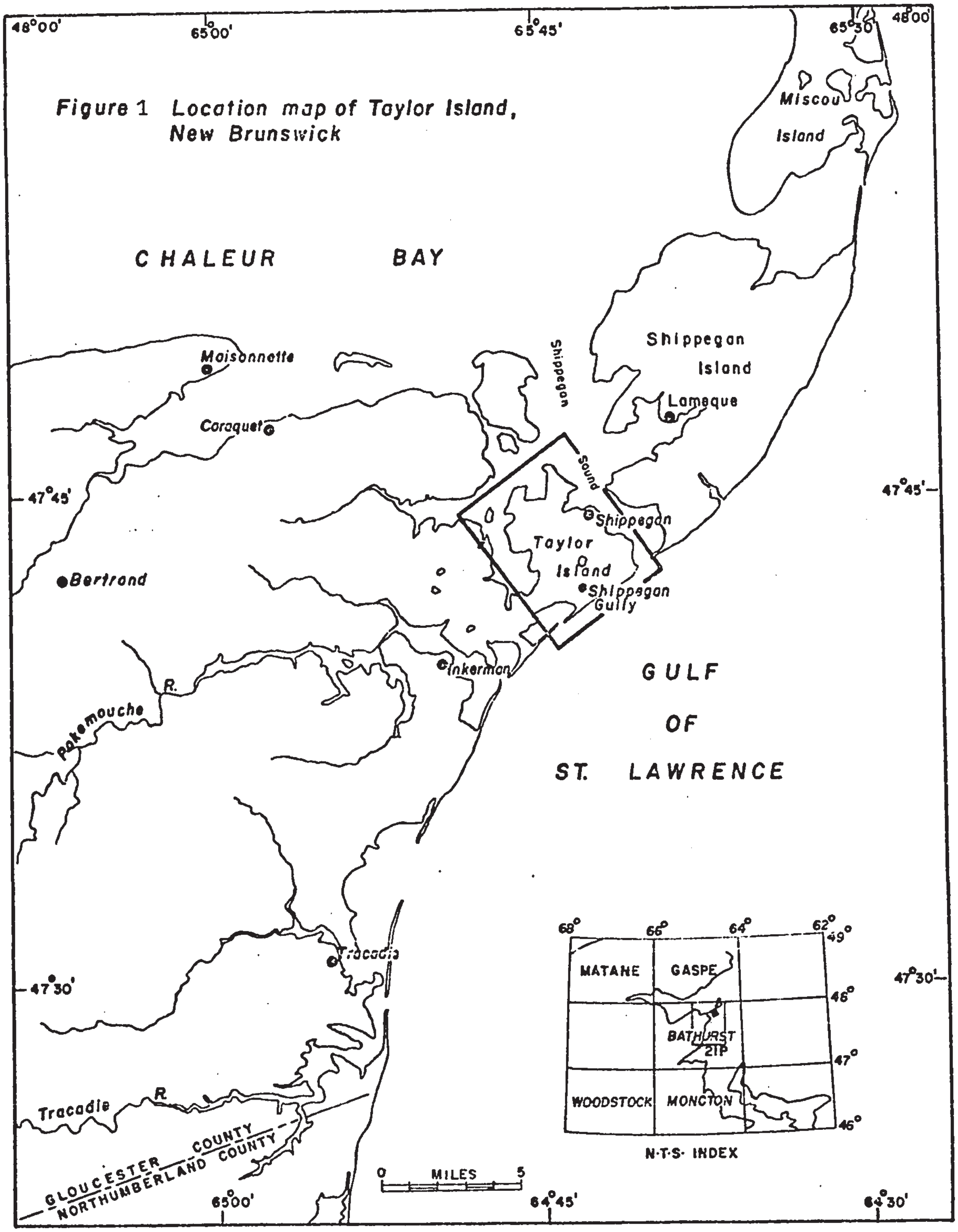


Figure 1 Location map of Taylor Island, New Brunswick

Transport meteorological station at Miscou Island, 34 miles from Shippegan, is shown in Figure 2. Precipitation is evenly distributed during the year with slightly higher precipitation occurring during the fall months than during the remainder of the year

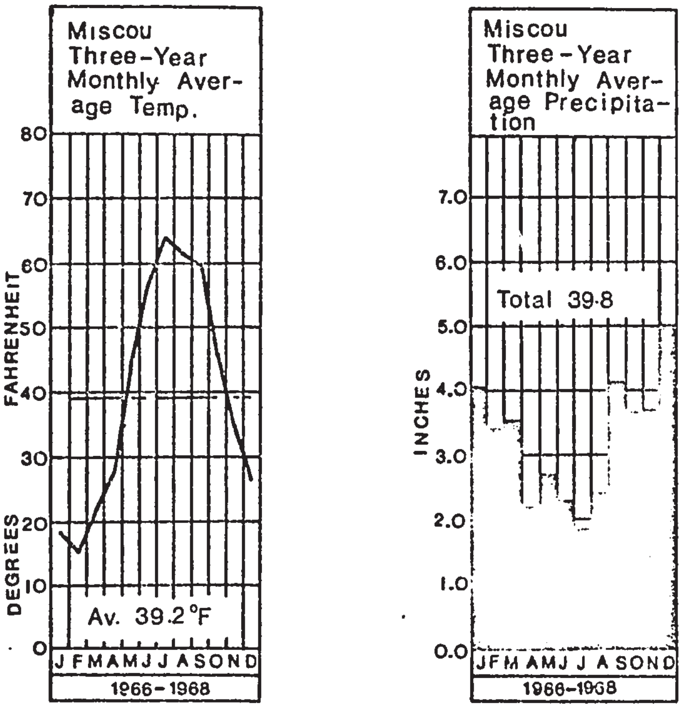
Total annual precipitation averages 39.8 inches and ranges between 36.7 and 44.9 inches. The three year mean annual temperature is 39.2° F., with mean monthly temperatures ranging between 14.9° F. in February and 64.6° F. in July.

The precipitation and temperature record at the newly established Shippegan meteorological station, for the period May 1969 to May 1970 is shown graphically in Figure 3. The monthly precipitation ranges from 6.1 inches in December to 1.43 inches in April, with the total annual precipitation for this period being 43.9 inches. The mean temperature for this period is 40.9° F.; the mean temperature for the coldest month (January) is 10.6° F.; and the warmest month (August) is 64.0° F.

1.5 Previous Investigations

Investigations of peat bogs on Taylor Island were made by Anrep (1923) and Auer (1930). In 1964, W.H. Crandall and Associates (1964), consulting engineers, were retained by the Atlantic Development Board to report on the water supply problem due to sea-water intrusion at the town of Shippegan.

Figure 2 Climatological data, Miscou Lighthouse, Miscou Island, New Brunswick



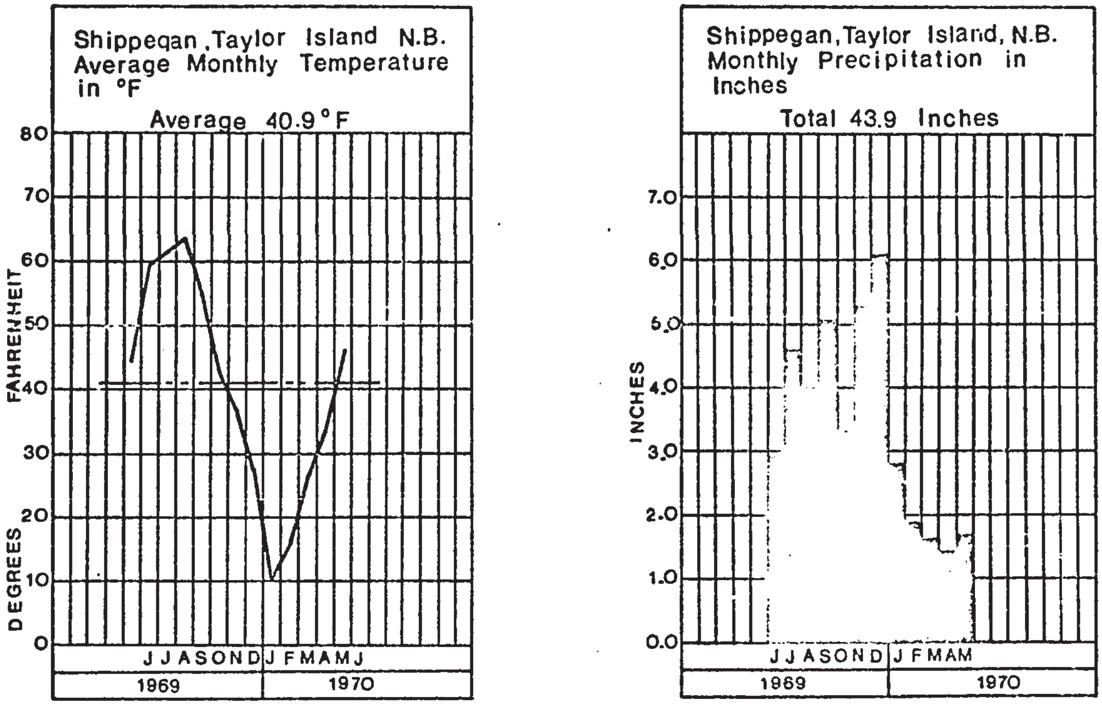


Figure 3 Climatological data, Shippegan, Taylor Island, New Brunswick

James F. MacLaren Ltd. (1969), consulting engineers, submitted a similar report to the Atlantic Development Board regarding the water supply problem.

1.6 Acknowledgements

This project was jointly sponsored by the Inland Waters Branch, Department of Energy, Mines and Resources, Ottawa, and by a N.R.C. grant to Dr. R.N. Farvolden of the Department of Geology, University of Western Ontario. The writer is indebted to Professor R.N. Farvolden, under whom the thesis was prepared and edited, and to Dr. P.A. Carr, Inland Waters Branch, under whom the project was initiated. Dr. Carr critically reviewed the tidal analysis field data.

Very able assistance was provided in the field by R.P. Romanelli in 1967 and 1968, and R. Hebert in 1969. Special thanks are due to Messrs. G.B. Scott and G. Cann of the Water Survey of Canada, Inland Waters Branch, who spirit-levelled all wells and piezometers reported. Chemical analyses were carried out by the Moncton water quality laboratory, Inland Waters Branch, and Mr. M.G. Cormier, of Shippegan. A number of drill logs, chemical analysis, and pump test field data and field help were kindly provided by Mr. L.V. Brandon and Mr. R. Benoit of the New Brunswick Department of Natural Resources, and Mr. T. Andrew of James F. MacLaren Ltd., consulting engineers. Porosity tests were carried out under Mr. A. Graves, of the Department of

Public Works, Ottawa. Drafting of figures was expertly done by Mrs. R. Ringsman, Department of Geology, University of Western Ontario. Assistance in computer programming was given by Mr. M.A. Cooper, Department of Geology, University of Western Ontario.

1.7 History of Sea-Water Intrusion

At present, the following water consuming industries on Taylor Island are located between Main Street and Shippegan Harbour within the town of Shippegan. Asterisked industries were in existence in 1964.

* Eagle Fisheries, Division of National Food Products Limited, fish processors, ice manufacturers.

Gully Fish and Food Products Co. Limited, fish processors.

* W.S. Loggie Limited, fish processors.

* A.C. Mallet and Sons Limited, ice manufacturers.

* Robichaud and Company Limited, a subsidiary of Connors Brothers, fish processors.

* Shippegan Cold Storage Limited, cold storage, food processors.

* Swim Brothers Limited, fish processors.

Between 1962 and 1964 the progressive salinization of fresh water producing wells located between Main Street and Shippegan Harbour took place (Figure 4). During the latter half of 1964, the supply of high-quality fresh water for the purpose of refrigeration, ice manufacturing, fluming, fish-plant clean-up, and sanitary purposes was severely restricted. By June 1964, the brackish sea-water intrusion front extended as far inland as Main Street, between 15th and 16th streets (Figure 4). During this same month, a sample pumped from the new test well 2, now municipal well 2, located 1800 feet inland from the shoreline of Shippegan Harbour (Figure 4), had a chloride content of 835 ppm. While producing fresh water from May to December 1966 and 1967, both municipal wells 2 and 3 produced brackish water in March 1967, and between July 25 and early November 1968. Water with as much as 593 ppm chloride was pumped during August 1968. To reduce the salinity of pumped water, fresh water was pumped from the Atlantic Peat Moss Company well 30 (Figure 4) into the municipal system. In August 1969 both well 33 and a new interim supply well 105, were put in production and municipal wells 2 and 3 were closed due to the hazard of saline-water penetration. At the same time, a new well field was under development, at well sites 4 W and 2 W (Figure 5). It is planned that with production from this field, all existing producing wells in the town, excepting about three hundred domestic wells in homes, will be phased out (James F. MacLaren Ltd., 1969).

FIGURE 4

LOCATION MAP OF OPEN WELLS AND PIEZOMETERS, SHIPPEGAN, NEW BRUNSWICK.

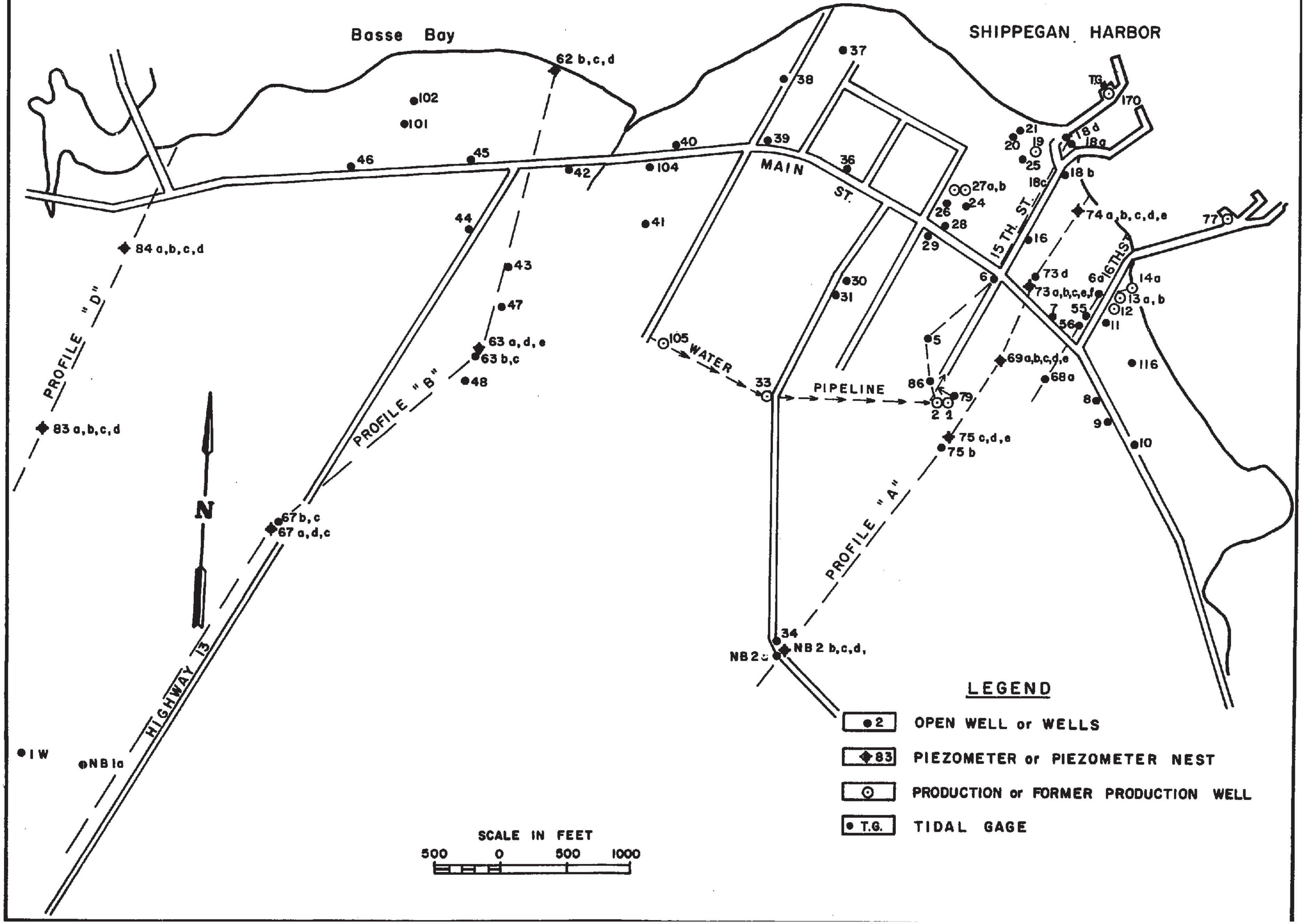
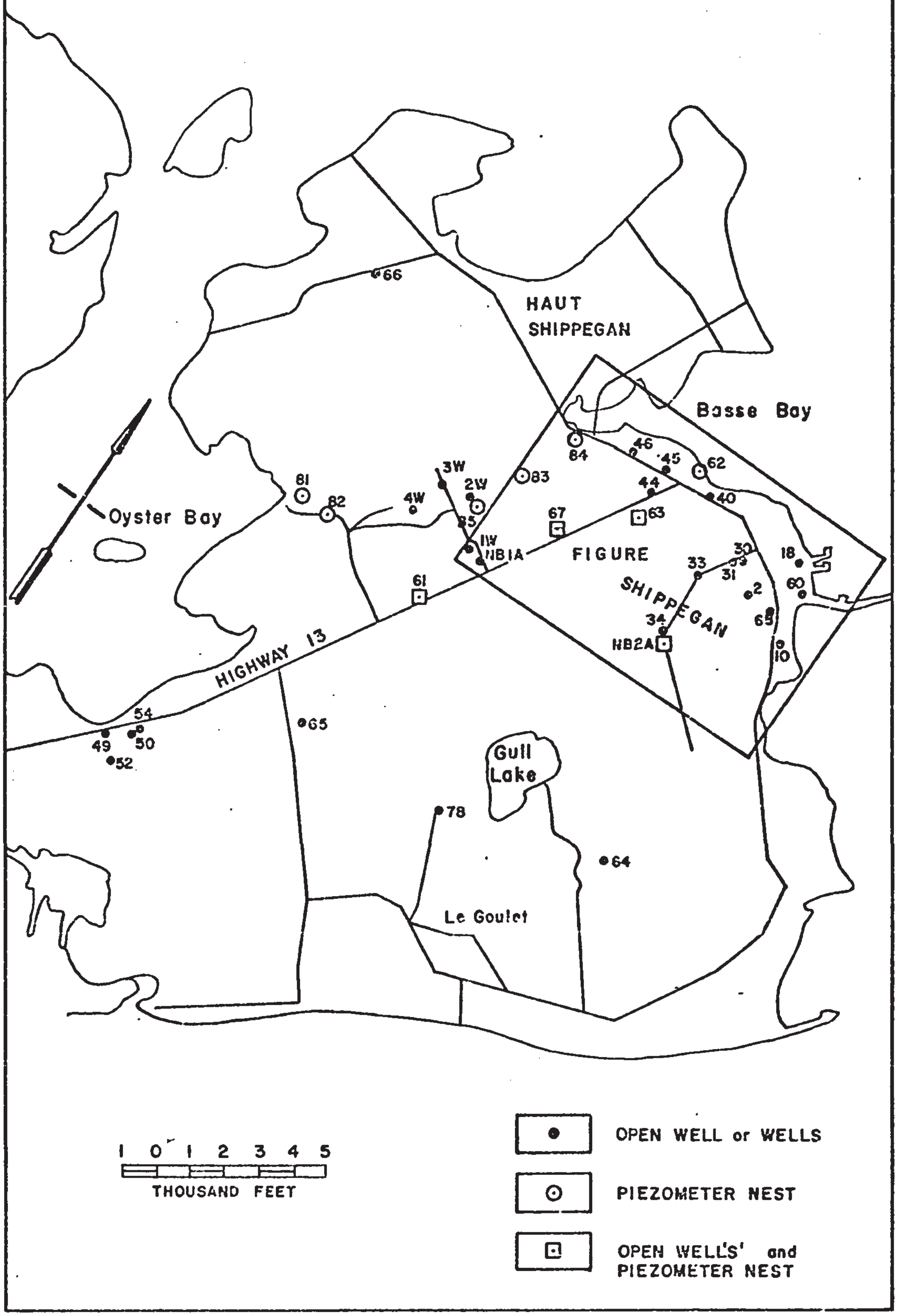


FIGURE 5 LOCATION MAP OF WELL AND PIEZOMETER SITES, TAYLOR ISLAND, N.B.



CHAPTER II

2. HYDROSTRATIGRAPHIC UNITS

2.1 Surficial Geology

A thin mantle of glacial drift, generally less than three feet thick, covers the bedrock of Taylor Island. The drift deposits consist of locally derived red-brown sandy till and brown, pebble-bearing clay till (Figure 6). A low ridge of sandy till and bedded outwash extends across the southern portion of Taylor Island. Clay till consisting largely of illite and chlorite underlies two large peat bogs, one of which is located immediately west of Basse Bay. The Gull Lake peat bog consists of partly lignified peat-forming sphagnum moss which attains depths of up to twenty-two feet (Anrep, 1932). X-ray diffraction traces of the clay portion of a sample of clay till indicate that it consists of illite, degraded illite or vermiculite and chlorite (Figure 7).

2.2 Mississipian - Pennsylvanian Stratigraphy

The red-bed section which underlies a thin mantle of glacial drift on Taylor Island is part of the eastern plain of New Brunswick, a region of flat lying Pennsylvanian strata. These rocks form the New Brunswick platform

FIGURE 6: Surficial geology, Taylor Island, New Brunswick

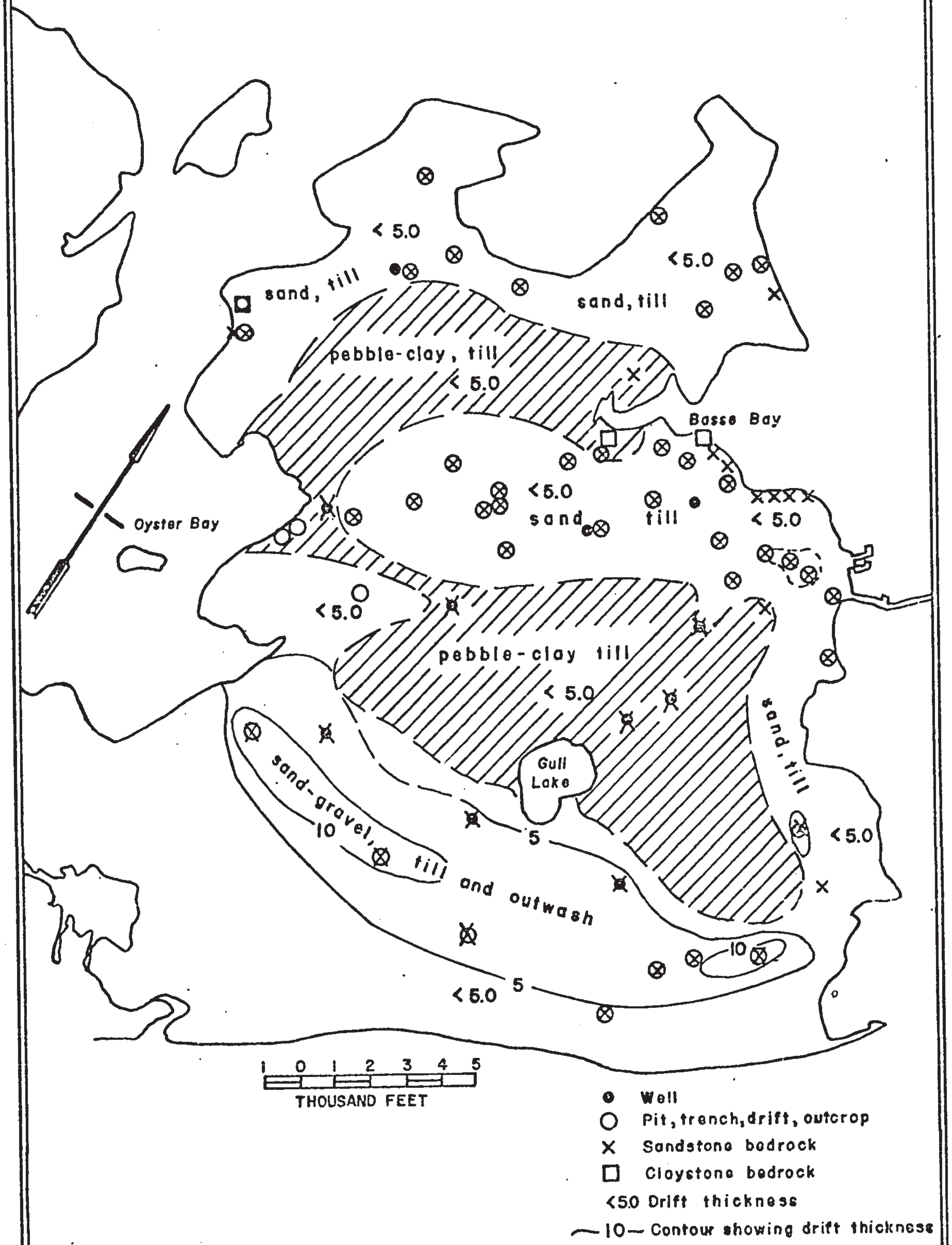
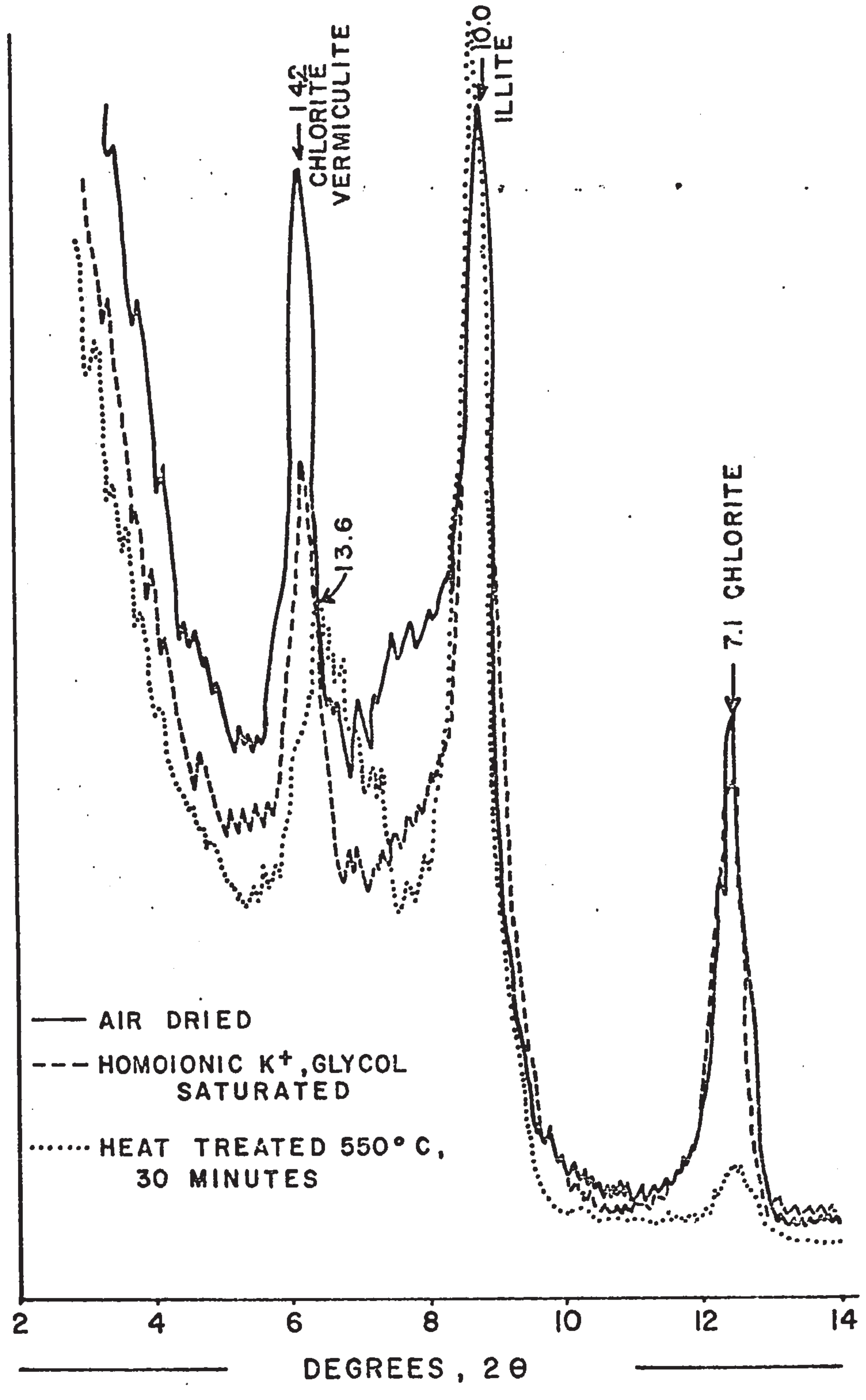


Figure 7: X-ray diffraction traces, Pliestocene clay till, Taylor Island, New Brunswick (centrifuge oriented)



and lie with regional unconformity on the Ordovician and Silurian formations which were metamorphosed and deformed during the Acadian orogeny.

Clifton and Bathurst Formations

The strata at Taylor Island are part of the Clifton Formation, which is exposed on the north shore of New Brunswick between Janeville, 35 miles west of Taylor Island and Miscou Island, 16 miles northeast of Taylor Island. Alcock (1936, pp. 94-95) described the Clifton Formation at Clifton, located 32 miles west of Taylor Island. This formation overlies the Bathurst formation of red sandstone, shale and conglomerate with apparent conformity; both formations are regarded as one series.

The Clifton Formation consists principally of grey sandstone and shale but gradually passes upward into a sequence of purplish-red shale, sandstone and conglomerate. The Clifton Formation is undisturbed and lies with a regional eastward dip of a very low order which is probably the original dip. The apparent thickness of the formation is at least 700 feet; however, the top of the formation is not defined, nor is the complete formational section known. Fossil plants in the Clifton Formation (Gussow, 1953) indicate that it is of Westphalian C or Picton age. Correlation of the formation with others of the Picton group shown in Figure 8, is based upon miospore zones of M.B. Barrs and P.A. Hacquebard (1967) and plant species correlations by

Gussow (1953). The shaded area represents the absence of sediment as a result of either non-deposition or erosion. A question mark indicates that no data are available to substantiate the presence of younger or older ages in that particular rock sequence.

Taylor Island Section

At Taylor Island, that part of the Clifton Formation intersected by borehole N.B. 2A (Figure 9) consists of the following alternating units and subunits of non-marine sandstone and claystone.

TABLE 1

TAYLOR ISLAND STRATIGRAPHIC SECTION,
WELL N.B. 2A, SHIPPEGAN, NEW BRUNSWICK

UNIT		SUBUNIT	THICKNESS IN FEET	
I	Upper Sandstone		78	
		Ia Upper Claystone		5
II	Middle Claystone		63	
		IIa Middle Sandstone		16
III	Lower Sandstone		55	
IV	Lower Claystone		48	
V	Grey Sandstone and Claystone		52	
VI	Grey Claystone		10	
		Total	306	

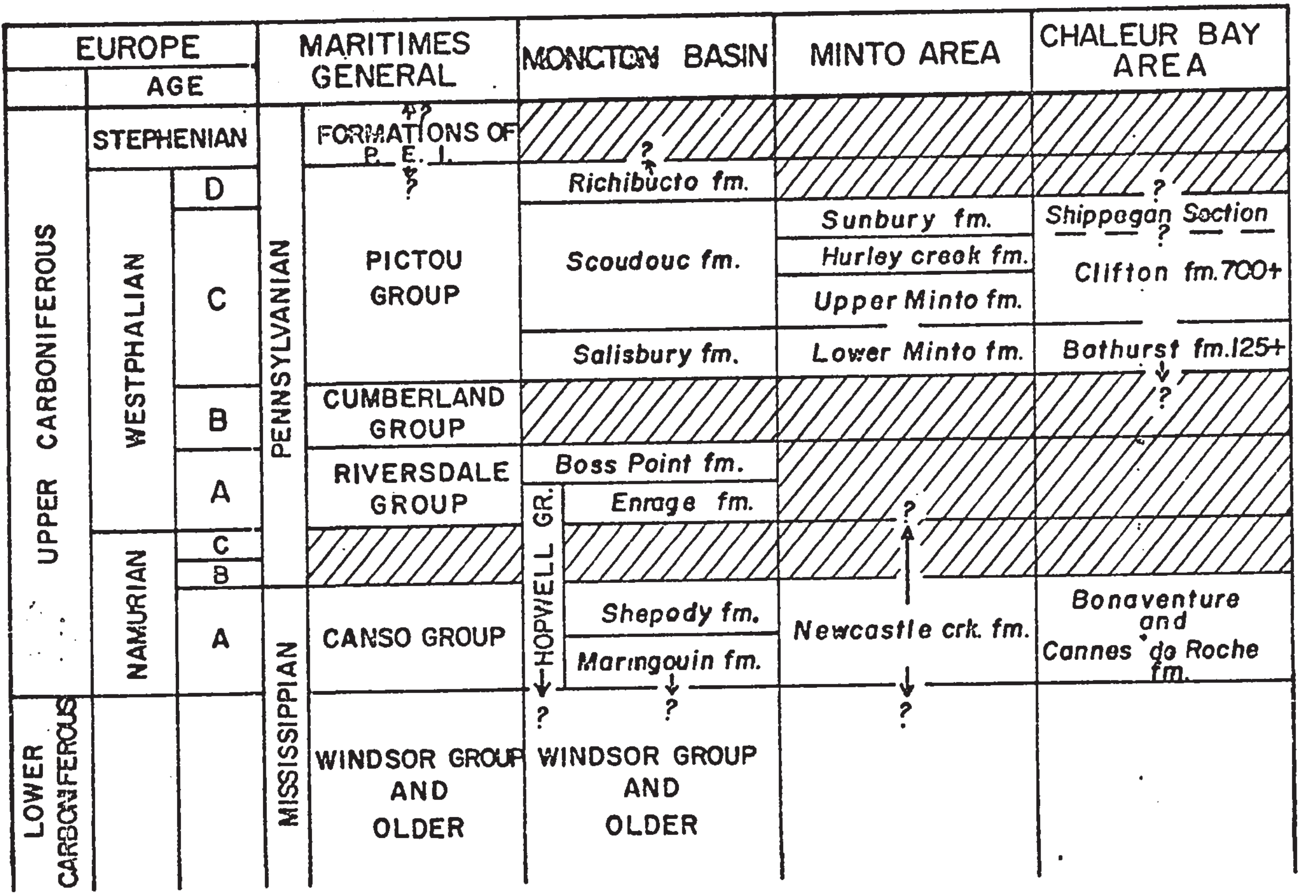
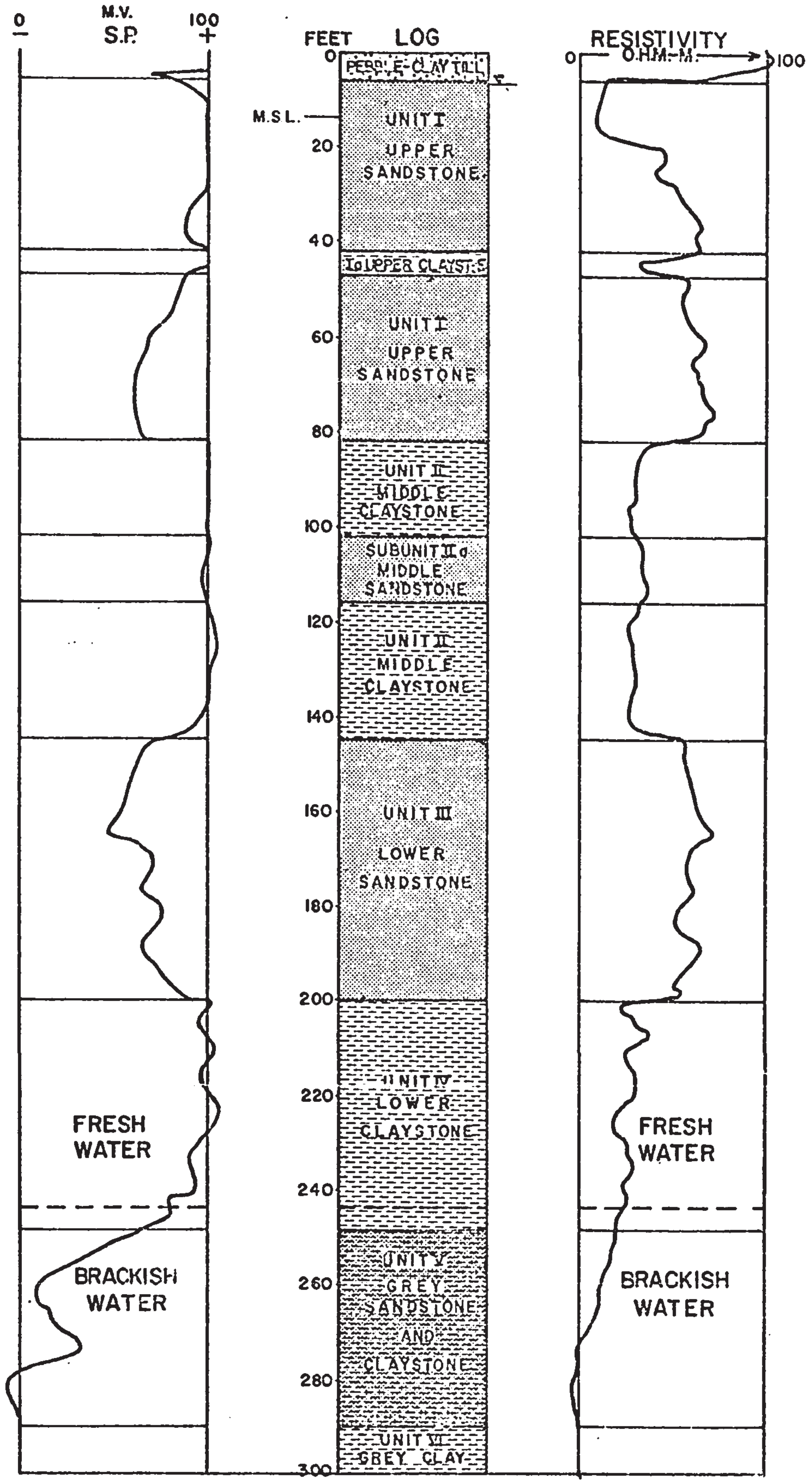


Figure 8: Correlation of some of the Upper Carboniferous formations of the Atlantic region

Figure 9: Electric Log of Taylor Island Section, Borehole N.B. 2[A]
(New Brunswick Water Authority)



2.3 Lithological Description of Units, Upper Sandstone (Unit I)

The Upper Sandstone forms the bedrock over almost all of Taylor Island and is the principal source of fresh water on the island. Structural contours of the lower surface of the Upper Sandstone indicate a dip to the southeast at an angle of less than one degree. Thickness of this unit increases from zero to more than 120 feet in the southwest portion of Taylor Island. The contact of the Upper Sandstone with the underlying Middle Claystone unit is exposed along the southern shore of Basse Bay (Figure 10).

In outcrop, the Upper Sandstone is a red-brown to grey, flaggy to massive-bedded sandstone, which shows local fluvial cross-bedding. At the Department of Fisheries, oyster-culture station on Oyster Bay, vertically ribbed and jointed stems of the Pennsylvanian plant Calamites sp. were found.

In thin section the Upper Sandstone is a subgreywacke and consists of subangular to subrounded, well sorted grains of quartz, potash and plagioclase feldspar 0.1 to 2.0 millimeters in diameter, set in an argillaceous matrix consisting of quartz-bearing silt and micaceous clay. Accessory minerals include hematite, magnetite and phlogopite. Point counts of a number of thin sections give the following mineral composition:

Mineral	Percent Composition
quartz	39
feldspar	10
quartz, silt	25
clay	21
hematite, magnetite	4
phlogopite	1

X-ray diffraction traces of the clay matrix fraction from samples of the Upper Sandstone indicate that the clay is a mixture of illite and chlorite (Figures 11, 12).

Grain size analysis of the detritus of the sandstone (Figure 13) shows that it is a well-sorted, fine to coarse grained sandstone. Eighteen porosity tests carried out on ten samples of Upper Sandstone gave an average porosity of 0.13 with a range from 0.03 to 0.25 (Table 2). Storage coefficients or specific yields of the unconfined portion of the Upper Sandstone at two pump-test sites give a mean value of 0.16 (Table 3).

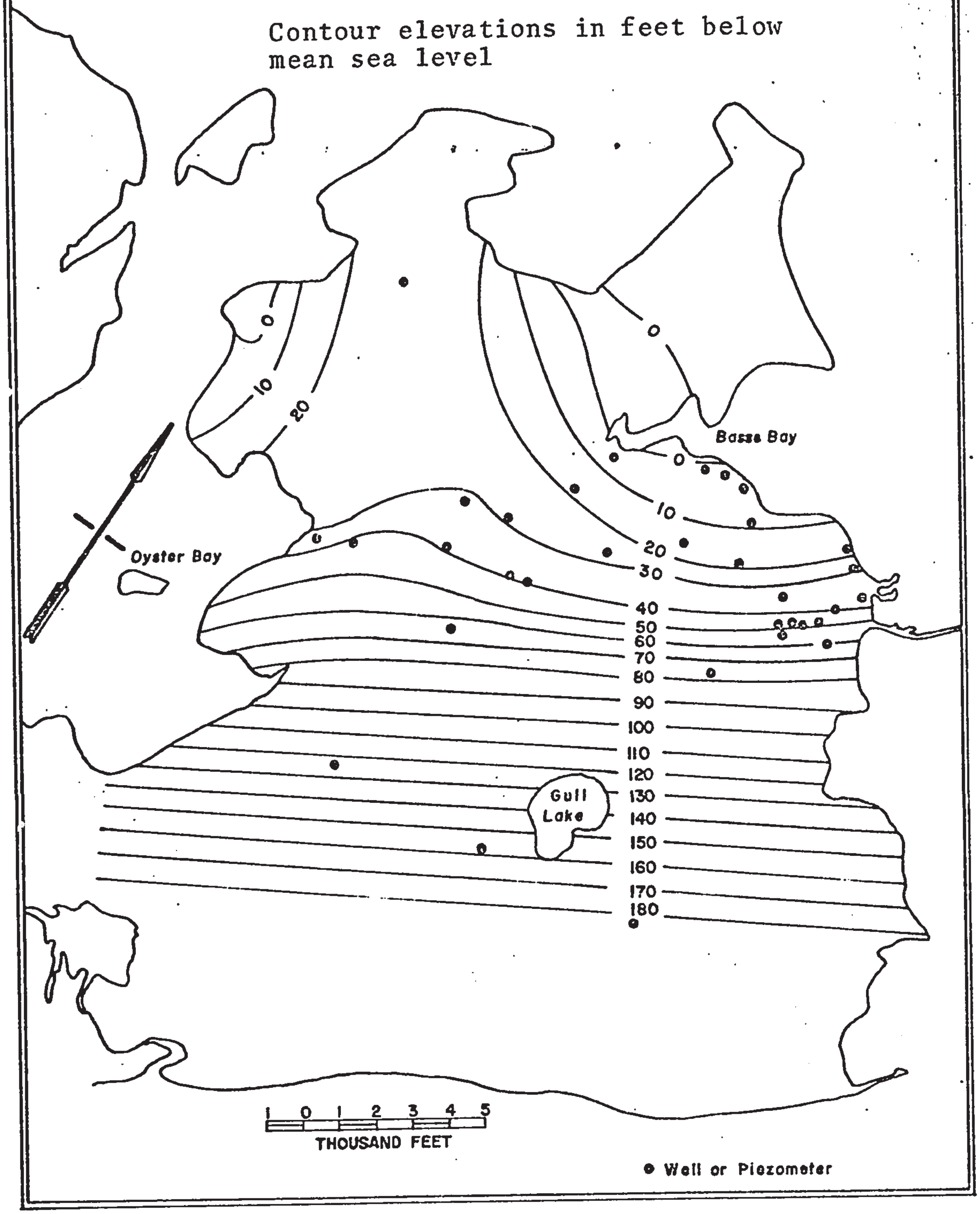
Field permeabilities of the Upper Sandstone range from 5.1 x 10^3 to 5.25 x 10^4 imperial gallons per day per square foot (Figure 29).

Upper Claystone (Subunit Ia)

A red-brown claystone bed 2 to 6.5 feet thick lies within the Upper Sandstone Unit I, in that area defined by wells NB 2A, 30, 60, and 68. The presence of the clay stratum effectively confines the aquifer and the aquifer responds accordingly to pumping. This subunit appears as

Figure 10: Structural contour map of bottom of Upper Sandstone (Unit I), Taylor Island, New Brunswick

Contour elevations in feet below mean sea level



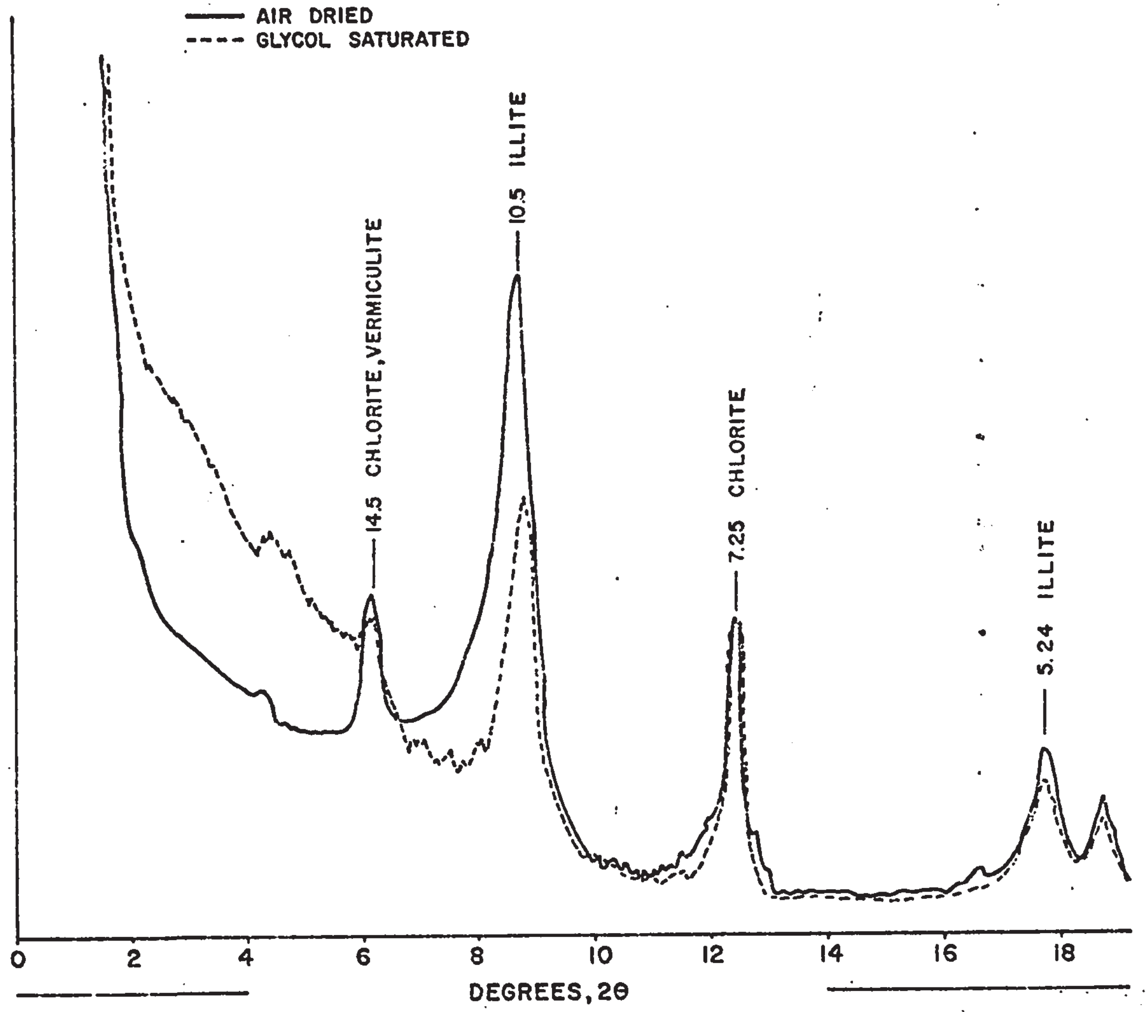


Figure 11: X-ray diffraction traces of matrix clay from Upper Sandstone (Unit I), Taylor Island, New Brunswick

Figure 12: X-ray diffraction traces of matrix clay from Upper Sandstone (Unit I), Taylor Island, New Brunswick

(centrifuge oriented)

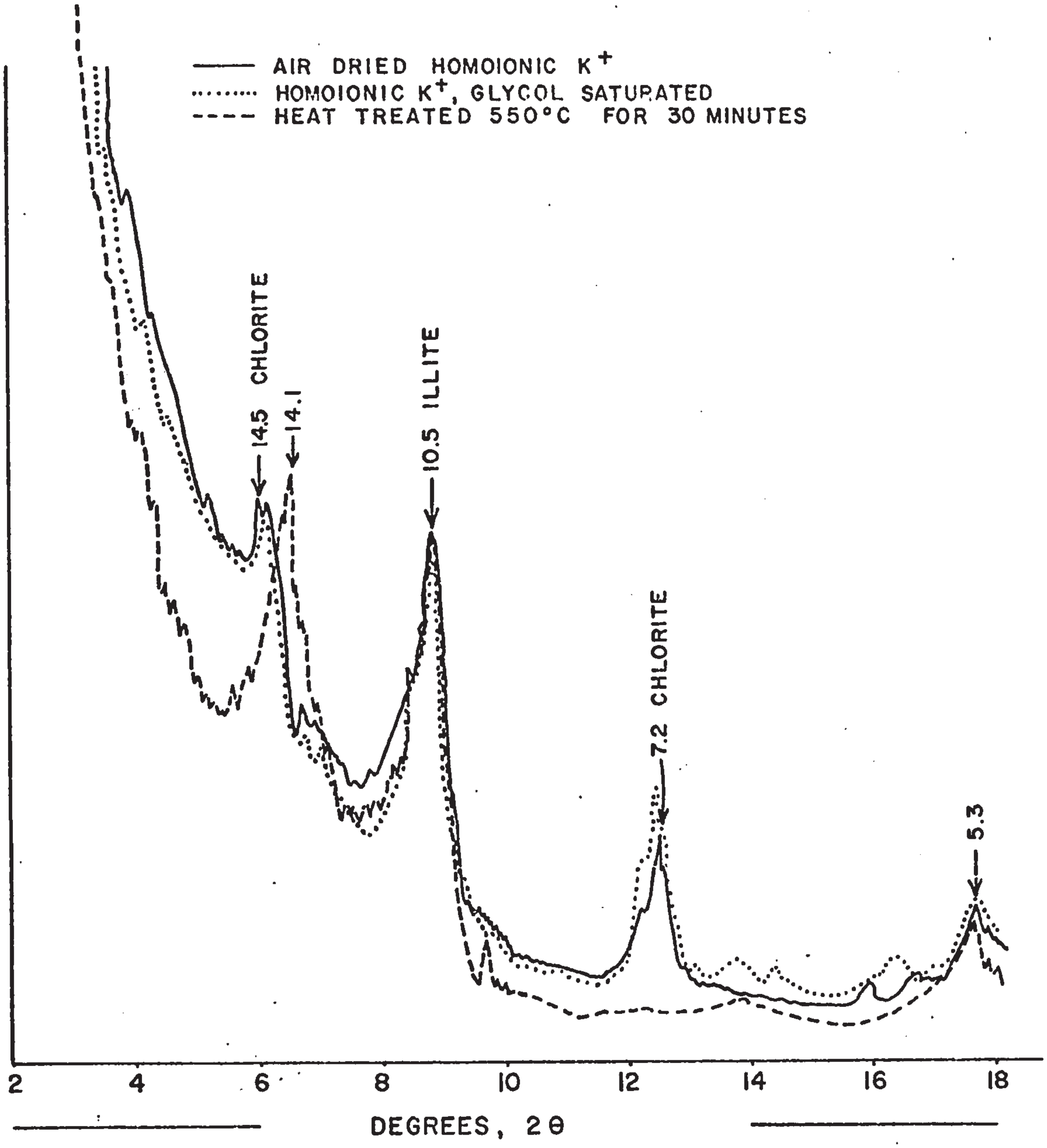


Figure 13:

Grain size distribution of Upper Sandstone (Unit I) with clay-silt fraction removed

DATE FEB. 1965
BOREHOLE NO. I
SAMPLES NO. 25,35,45,55 FT.
LOCATION SHIPPEGAN, N.B.

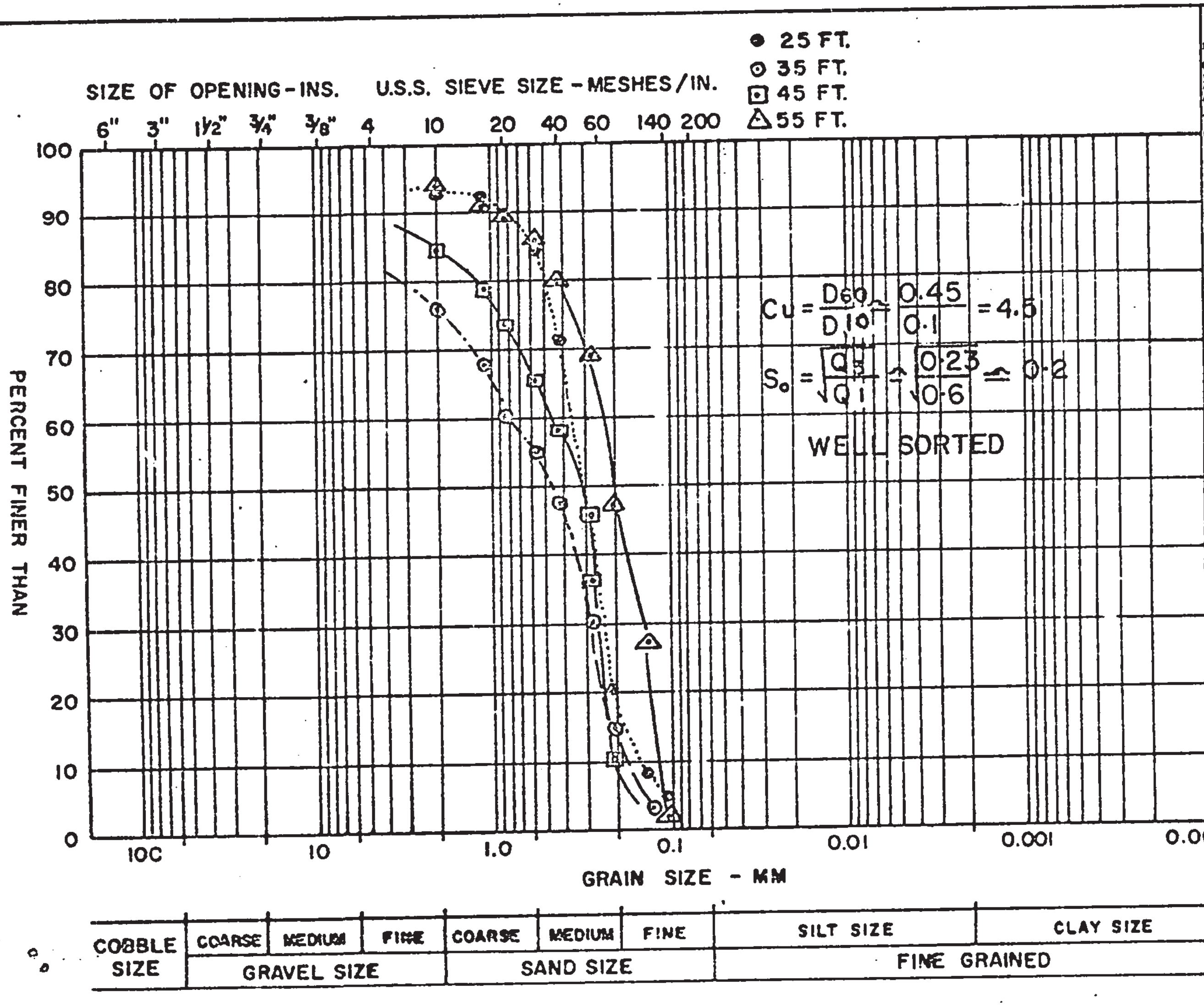


TABLE 2

POROSITIES OF SAMPLES OF UPPER SANDSTONE (UNIT I), TAYLOR ISLAND, NEW BRUNSWICK

Sample Location or Number of Well or Piezometer	Porosity %
78A	6.7
78A	6.7
61B	3.0
68A	8.1
68A	4.8
68A	7.1
Rousells gravel pit, Shippegan Gully	9.2
Gravel pit, Haut Shippegan	9.6
Near 2	8.4
Town of Shippegan	13.9
Town of Shippegan	14.4
Near 4WA	13.3
Near 4WA	5.6
Near 61	24.4
Near 61	24.0
Near 61	23.3
Near 78	23.7
Near 78	25.0
mean	12.92%
standard deviation	0.08

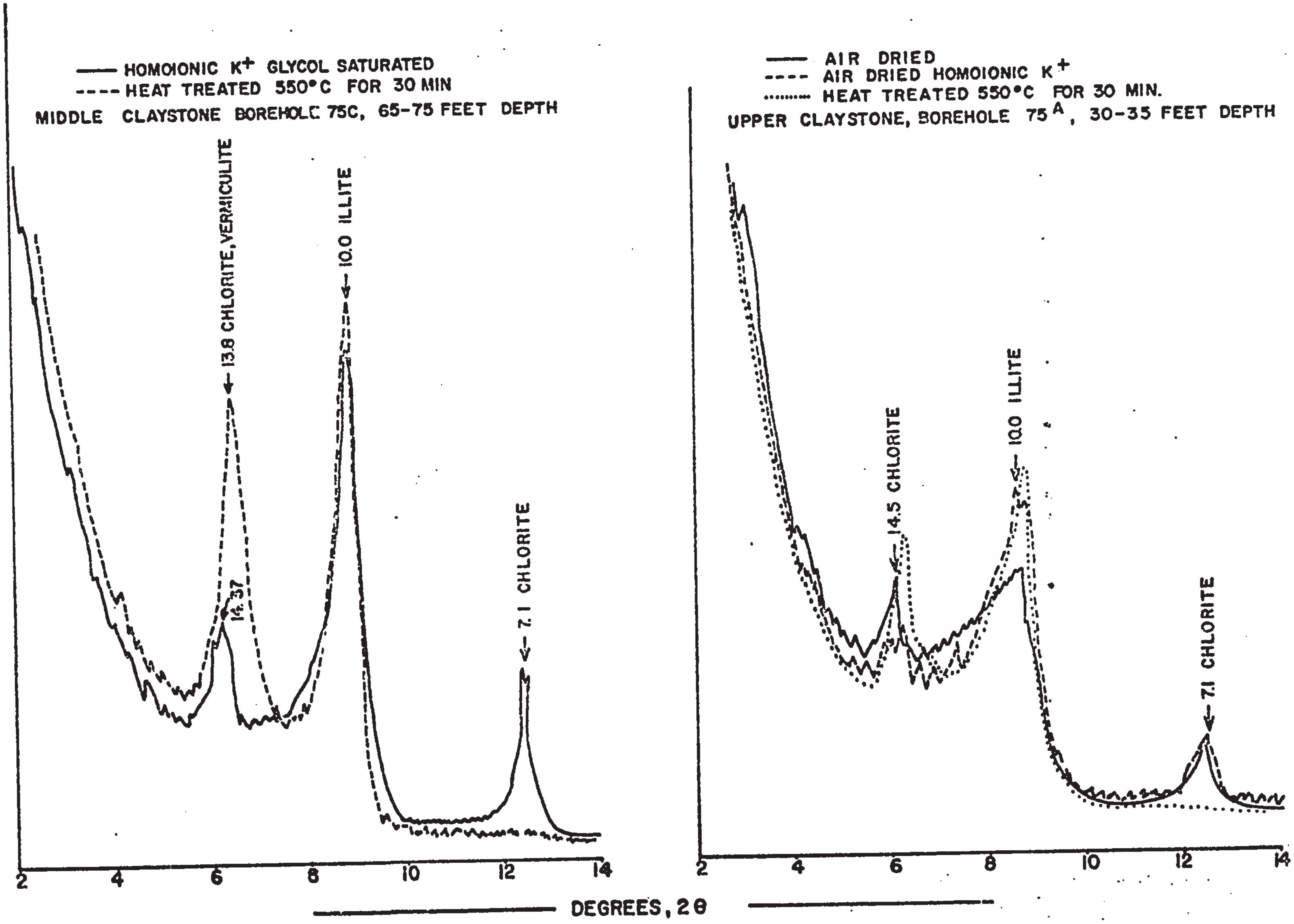


Figure 14: X-ray diffraction traces of Middle and Upper Claystone Units, Taylor Island, New Brunswick (centrifuge oriented)

a well-defined peak on self potential and resistivity borehole logs (Figure 9). X-ray diffraction traces of the clay indicate that it consists of illite and chlorite (Figure 16b).

Middle Claystone (Unit II)

The Middle Claystone unit consists of 48 to 90 feet of bright red to brown claystone (Figure 15). Structural contours of the bottom of this unit show that it dips at about two degrees to the south (Figure 16). Drill cuttings of the Middle Claystone are plastic when wetted and remoulded. X-ray diffraction traces (Figure 14a) show that the clay portion of the unit consists of illite, degraded illite or vermiculite and chlorite. Slug tests carried out in piezometers placed in the unit show that it is an effective aquiclude with a permeability of 3.48×10^{-8} cm./sec. or 6.14×10^{-4} imperial gpd/foot^2.

Units III to VI including unit IIa appear to be similar physically to the Upper Sandstone and Middle Claystone units, as an alternating sandstone and claystone sequence.

Figure 15: Isopach Map of Middle Claystone (Unit II), Taylor Island, New Brunswick

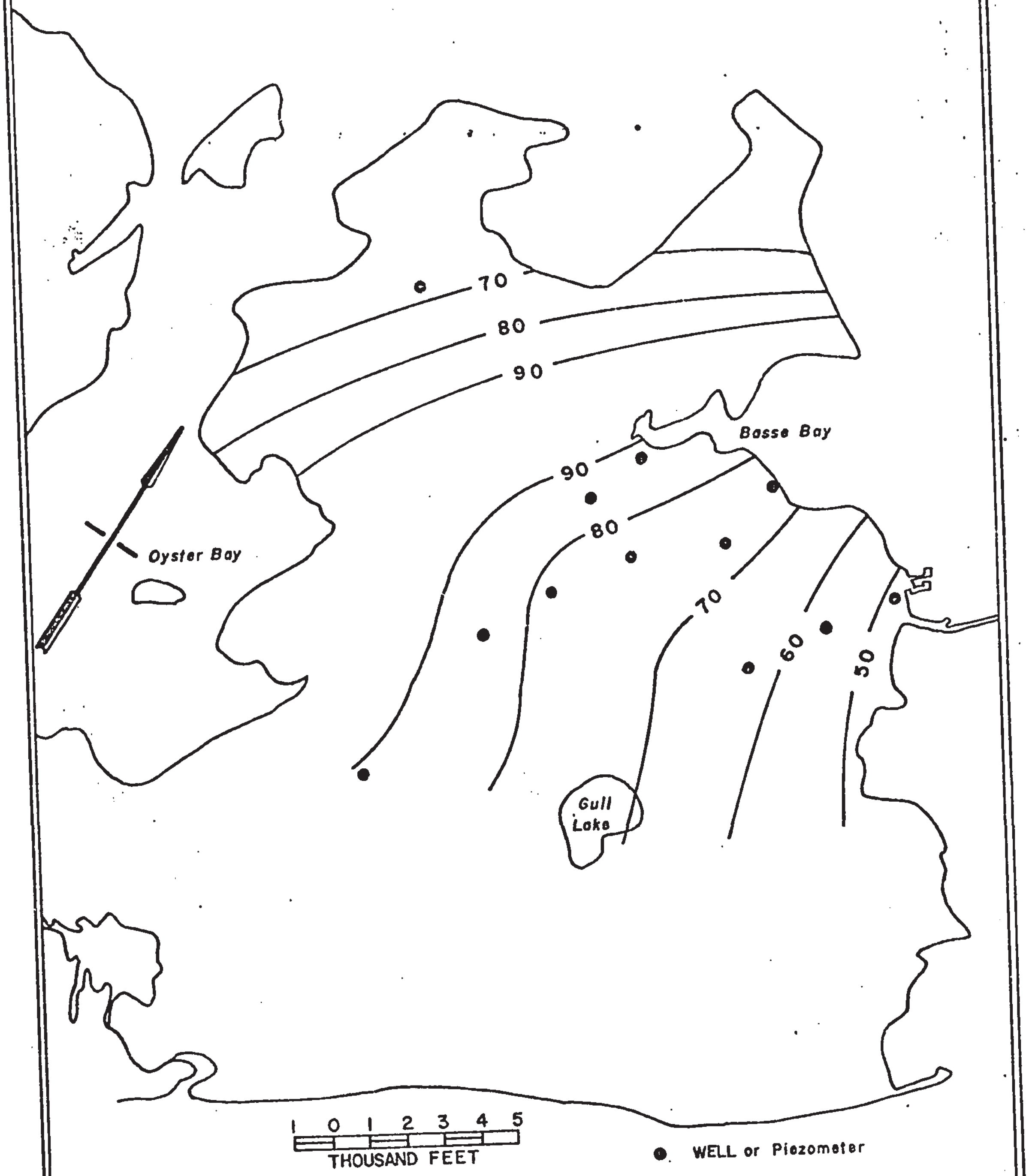
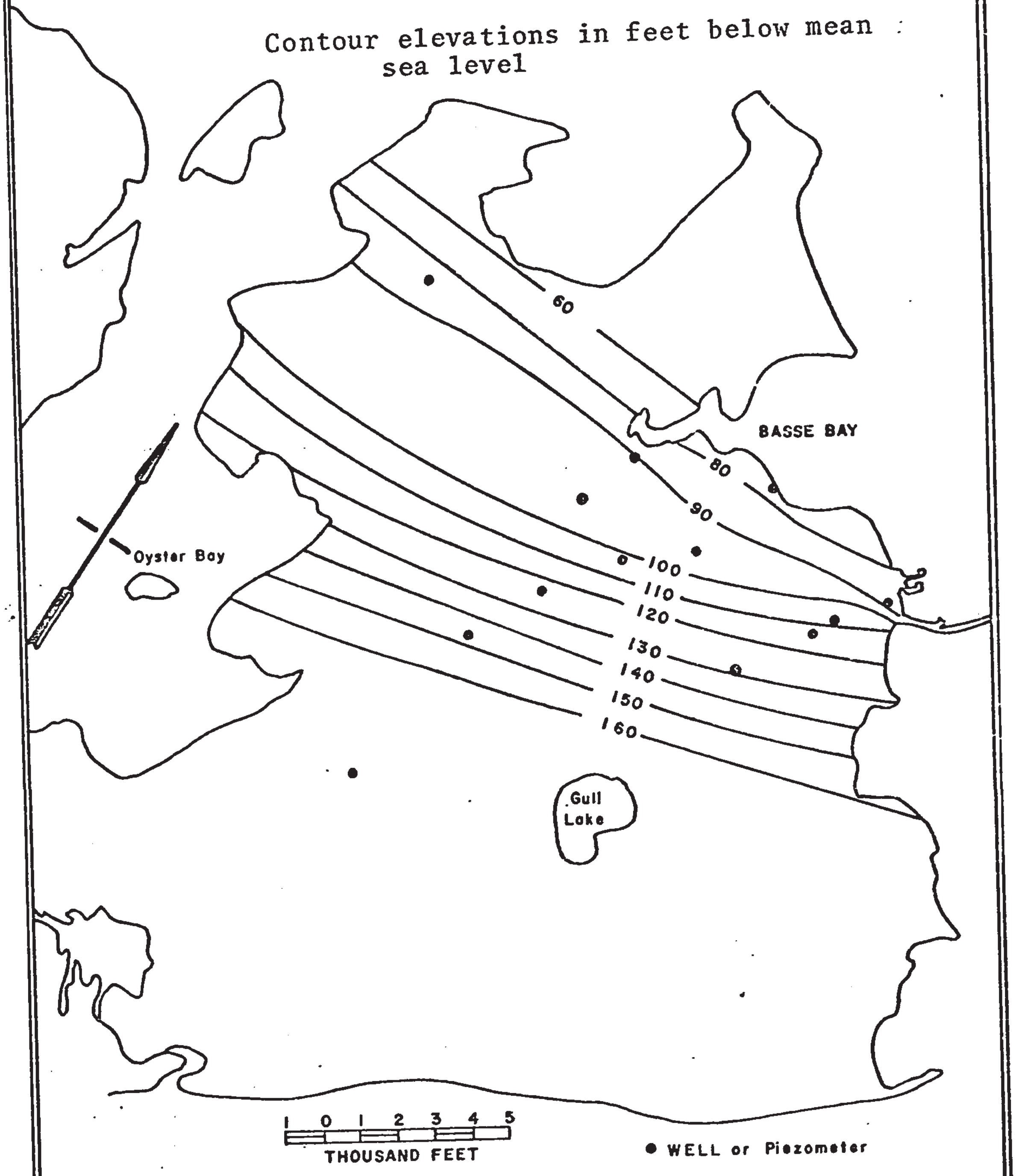


Figure 16: Structural Contour Map of bottom of Middle Claystone (Unit III), Taylor Island, New Brunswick

Contour elevations in feet below mean sea level



CHAPTER III

3. THEORY OF GROUNDWATER FLOW

3.1 Potential Theory

The potential energy of groundwater due to elevation may be measured as total groundwater head, which is the sum of elevation head Z, and pressure head P, of point "i", the bottom termination point of a piezometer (Hubbert, 1940, 1953). The expression for total groundwater head is:

$$H = Z + \frac{P}{\rho g} \qquad \text{(eqn. 3 - 1)}$$

where:

H = elevation of groundwater level referred to an arbitrary standard datum such as mean sea level in feet.

Z = elevation of point "i" referred to an arbitrary standard datum or mean sea level in feet.

P = pressure head of groundwater at point "i" in $lb._f/ft.^2$

ρ = groundwater density in $lb._m/ft.^3$

g = acceleration due to gravity = 32.2 $ft./sec.^2$

Hence the magnitude of groundwater potential is indicated by height H, of the rise of groundwater in the piezometer above the standard datum, and it is numerically equal to Φ, the force potential, where:

$$\Phi = gH = gZ + \frac{P}{\rho} \qquad \text{(eqn. 3 - 2)}$$

The laminar flow of fresh groundwater is governed by Darcy's Law, written as follows:

$$Q/A = q = -K\frac{dH}{dl} = \frac{-K}{g}\frac{d\Phi}{dl} \qquad \text{(eqn. 3 - 3)}$$

where: Q = total discharge in imperial gallons per day.

A = cross-sectional area in $ft.^2$

q = specific discharge in imperial gallons per day per ft.

l = length of flow path in ft.

K = hydraulic conductivity or permeability in imperial gallons per day per $ft.^2$

Φ = force potential in $ft.^2/sec.^2$

Of course other unit systems may be used.

3.2 Specific Discharge of a Non-Homogeneous Liquid in an Isotropic Media

A generalized form of Darcy's equation expressing specific discharge for steady flow of a non-homogeneous liquid (varying density and viscosity) is given by the following equation:

$$q_{i\,1(2,3)} = \frac{-k_{i1}}{\mu_i}\left(\frac{\partial P_i}{\partial X_{1(2,3)}} + \rho_i g\frac{\partial Z_i}{\partial X_{1(2,3)}}\right) \qquad \text{(eqn. 3 - 4)}$$

where: subscripts 1, 2 and 3 refer to the vector velocities in the X, Y, and Z directions respectively, with the X and Y coordinates horizontal and Z vertical.

ρ_i = density of fluid at point "i" .

q_i = specific discharge or vector velocity at point "i" .

k_i = directional intrinsic permeability at point "i" .

μ_i = dynamic viscosity at point i.

g = acceleration due to gravity.

Z_i = elevation of the point i measured positively upwards.

P_i = pressure at i ; or more simply according to Lusczynski. (1961, p. 4250)

$$q_i = -\frac{k_i}{\mu_i} g \left[\frac{\nabla P_i}{g} + \rho_i k \right] \qquad \text{(eqn. 3 - 5)}$$

where: ∇ = gradient operator.

k_i = intrinsic permeability of medium at i.

k = unit vector directed upward along a vertical.

Equations derived from equation (3 - 5) Lusczynski (1961) are particularly useful for determining the hydraulic gradients and specific discharge components in the horizontal directions and vertical direction in a system of fresh, brackish, saline and sea-water, found in a transition zone.

In groundwater of variable density, horizontal gradients are defined by fresh-water heads, where H_{if}, the fresh-water head, is the height of rise of fresh-water from point i in a piezometer, referred to standard datum. The fresh-water will rise to a level high enough to balance the existing pressure at i. Horizontal velocity components q_1 and q_2 along the X and Y directions respectively are given by: Lusczynski (1961).

$$q_{(1,2)} = -k_{i(1,2)} \frac{g}{\mu_i}\left[\rho_f \frac{\partial H_{if}}{\partial X_{(1,2)}}\right] \qquad \text{(eqn. 3 - 6)}$$

$$q_{(1,2)} \doteq -K_{i(1,2)} \frac{\mu_f}{\mu_i} \cdot \frac{\partial H_{if}}{\partial X_{(1,2)}} \qquad \text{(eqn. 3 - 7)}$$

where: $k_{i(1,2)}$=coefficient of intrinsic permeability at "i" in the X or Y direction.

$K_{i(1,2)}$=permeability or hydraulic conductivity at point "i" in the X or Y direction.

ρ_f = density of fresh-water.

Hydraulic gradients along the vertical are defined by environmental - water heads, H_{in} , where the environmental - water head at point in a piezometer, is the fresh-water head H_{if} , in the piezometer, reduced by an amount corresponding to the difference of salt mass in fresh-water and that in the formation adjacent to the piezometer between point "i" and the top of the zone of saturation. Lusczynski (1961) shows that the vertical specific discharge along the Z direction can be expressed as:

$$q_3 = -k_{i3} \frac{g}{\mu_i}\left[\rho_f \frac{\partial H_{in}}{\partial Z_3}\right] \qquad \text{(eqn. 3 - 8)}$$

$$q_3 \doteq -K_{i3} \frac{\mu_f}{\mu_a}\left[\frac{\Delta H_{in}}{\Delta Z_3}\right] \qquad \text{(eqn. 3 - 9)}$$

where: k_{i3}= coefficient of intrinsic permeability at "i" in the Z direction.

K_{i3}= permeability or hydraulic conductivity at point "i" in the Z direction.

μ_i= dynamic viscosity at point "i".

μ_a= the average dynamic viscosity between two points, one vertically above the other and closely separated by distance ΔX_3.

ΔH_{in}= the difference of environmental-water heads between two points one vertically above the other.

Equations relating point-water head, fresh-water head, and environmental-water head are given by Lusczynski (1961).

For practical purposes, the dynamic viscosities, μ_s of sea-water and μ_f of fresh-water, may be considered equal, being 3.26×10^{-5}, and 3.19×10^{-5} lb_f second per square foot respectively. The density of sea-water is 1.025 kilograms per litre, with a salt content of approximately 30 grams per litre, compared to a density of 1.00 kilograms per litre for fresh-water. In the transition zone, the maximum error in calculating the horizontal specific discharge by employing environmental-water heads instead of fresh-water heads will be 2.5 percent of the correct fresh-water head (Equation 3 - 6) or the difference in specific densities given above.

The hydraulic conductivity or specific fluid conductivity, K , is a property of both the porous media and fluid where:

$$K = \frac{k \rho g}{\mu} \qquad \text{(eqn. 3 - 10)}$$

(Hubbert, 1940, p. 819)

In the transition zone, the maximum error in measurement of K due to the flow of sea-water and fresh-water through the same porous media will be $\rho_s - \rho_f = 0.025$ or 2.5 percent.

The maximum total error in assuming a single fresh-water fluid system according to the above is 0.05 or five percent. This source of error is smaller than that of permeability determinations. However, if natural fresh-water heads and gradients are small, this error difference can be important in determining directions of flow.

3.3 Transient Flow in the Transition Zone

An exact solution for transient flow of fresh-water, transitional water and sea-water to a coastal well would require the computation of density and viscosity of pore-water at each node or unit cell in the system as a function of time as well as the transient phreatic surface resulting from pumping and non-steady recharge. Hydrodynamic dispersion phenomena associated with flow would be predicted in such a model. No mathematical solution of this problem presently exists and it appears that its analytical or numerical solution will challenge the ingenuity of mathematicians working in this field.

3.4 Production Well in an Artesian Aquifer with a Sloping Piezometric Surface and Recharge Boundary

The depression cone, as defined by piezometric heads, of a production well in an artesian aquifer, expands radially outward from the well with pumping time. At a constant rate of discharge, Q, the development of the cone depends upon the rate of recharge to the aquifer, the aquifer characteristics and boundary conditions. With sufficient time the depression cone will expand radially to a distance at which the rate of discharge is nearly in equilibrium with the rate of recharge. At this time the depression cone will approach a steady configuration. If the original piezometric surface is sloped so that a natural uniform rectilinear flow of undisturbed groundwater moves in the -X direction (Figures 17 and 18), the flow lines in the region surrounding the production well are found by vector addition of flow-lines due to radial flow to the well and parallel flow-lines of undisturbed groundwater as shown in Figure 17. A limiting flow-line or divide will be formed at a distance, Yo from the X axis and a stagnation point will be formed by converging flow-lines at point S.P. on the limiting flow-line.

In the practical problem of flow to a production well in an artesian aquifer with a sloping piezometric surface and recharge boundary, the relationship between aquifer characteristics and other parameters may be deduced by considering a production discharge of rate -Q, located at

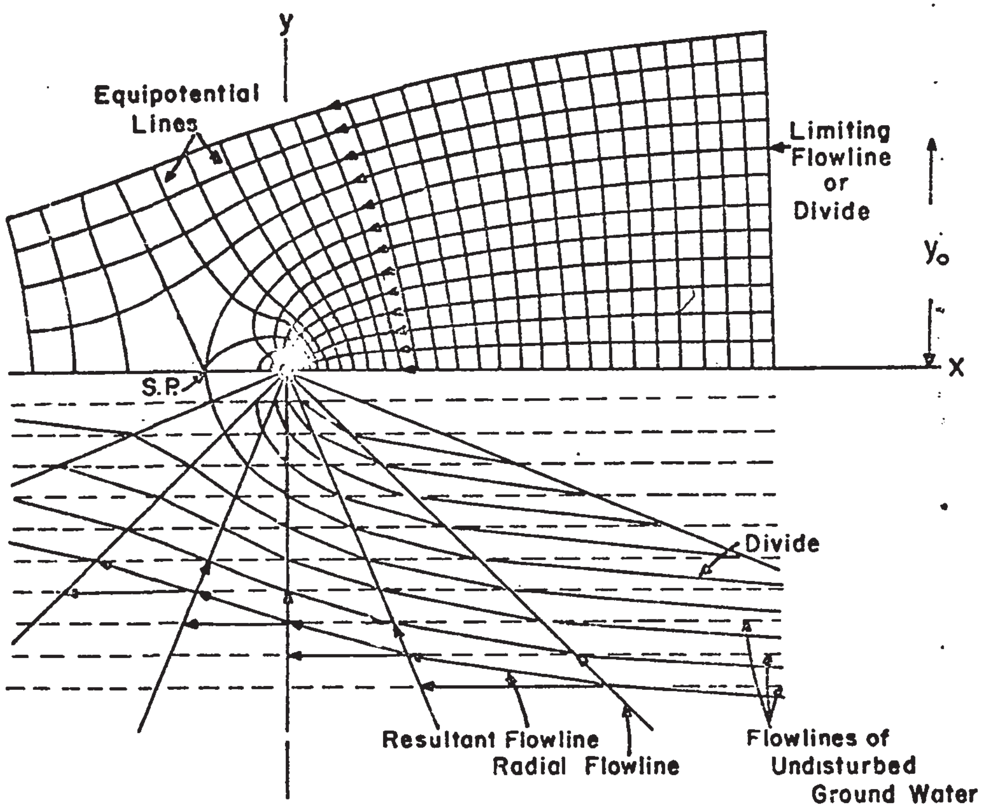


Figure 17: Flow net of an artesian well in a uniform flow field with a sloping piezometric surface

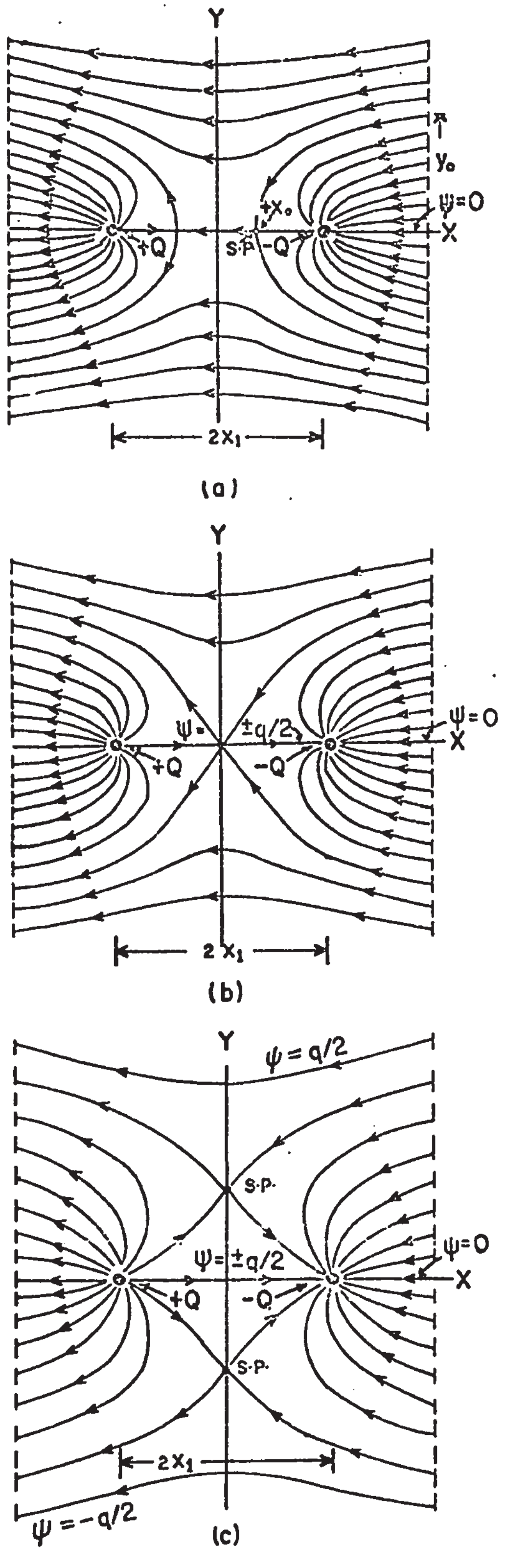


Figure 18 A production well and image well in a uniform flow field (a) $q/\pi x_1 V_0 < 1$, (b) $q/\pi X_1 V_0 = 1$, limiting case, (c) $q/\pi x_1 V_0 > 1$, recharge occurs in triangular area between stagnation points, S.P., steady confined flow, (Jacob, 1950)

distance $+X_1$ from the recharge boundary, $(X = 0)$, and an image well which recharges at rate $+Q$, located at distance $-X_1$, from the recharge boundary (Jacob, 1950, p. 348). For steady flow between a production and image well the distribution of groundwater heads will be:

$$h = H + \left[\frac{-Q}{4\pi K b} \log_e \frac{(X-X_1)^2 + y^2}{(X+X_1)^2 + y^2}\right] \quad \text{(eq. 3 - 11)}$$

where: h = groundwater head in feet.

Q = discharge rate of pumping well in ft.^3/minute.

K = permeability or hydraulic conductivity of artesian aquifer in ft./minute.

H = groundwater head before pumping started in feet.

b = thickness of aquifer in feet.

The rate of uniform undisturbed groundwater flow or specific discharge to the recharge boundary (at $X=0$) is Vo. In Figure 18, three situations are presented. Firstly, in Figure 18a, the pumping rate, $-Q$, is not large enough and the specific discharge of flow, Vo, is not small enough to cause the flow divide and stagnation point to reach the recharge boundary at $X = 0$. In Figure 18b, the natural groundwater specific discharge, Vo, is balanced by the opposing specific discharge induced by the pumping and image wells at $(X = 0, Y = 0)$, where the stagnation point is located. In the third situation, Figure 18c, the pumping rate, $-Q$, is so large compared to Vo, that two stagnation points develop on the Y-axis and recharging water crosses the recharge boundary and flows to the pumping well. The area occupied by recharging water is the triangular section between the two stagnation points on the Y-axis and the pumping well. Water from two sources, that due to natural rectilinear flow to the right of the Y-axis and that due to recharge to the left of the Y-axis, are separated by the flow-line between the stagnation points and the pumping well.

Equations for determining the location of distance to the flow divide, Yo, the stagnation points, S.P., the stream function ψ, and proportion of recharge q_r in Q, are given by Jacob (1950). The critical value of q at which the stagnation point reaches the recharge boundary is given by:

$$V_0 = \frac{q}{2\pi X_1} - \frac{-q}{2\pi X_1} = \frac{Q}{\pi X_1 b} \quad \text{(eq. 3 - 12)}$$

where q = specific discharge due to pumping
V_0 = specific discharge due to natural flow

Hence recharge through the recharge boundary occurs when $\left(\frac{q}{\pi X_1 V_0}\right)$ is greater than unity. In Figure 18a, $\left(\frac{q}{\pi X_1 V_0}\right)$ is negative and in Figure 18b, $\left(\frac{q}{\pi X_1 V_0} = 1\right)$ and in Figure 18c, $\left(\frac{q}{\pi X_1 V_0} > 1\right)$

3.5 Safe Sustained Yields from Coastal Wells

Modern digital computer solutions for aquifer response are capable of showing the expansion of flow divides in relationship to recharge boundaries. In shallow coastal aquifers, where flow vectors are horizontal, as on Taylor Island, the prognosis of sea-water intrusion can be adequately and conservatively determined by assuming a complete freshwater fluid system and a low stage groundwater surface representative of periods when discharge from the aquifer far exceeds recharge to the aquifer (Section 6-1).

Steady flow to a producing well from the groundwater flow divide of the cone of depression should be in the freshwater area at some safe distance from the sea coast. In the case of an unconfined aquifer (as the Upper Sandstone along profile "D", Figures 30 and 45), the steady-state radius of the flow divide r_d , can be approximated by assuming a constant uniform recharge rate by vertical accretion through each unit area to the water table, $\dot{W}$, of 20 inches per year. From the equation: (Jacob, 1950, p. 381)

$$r_d = \sqrt{\frac{Q}{\pi \dot{W}}} \qquad \text{(eqn. 3 - 13)}$$

and assuming a constant pumping rate Q of 500 imperial gallons per minute (4.23×10^7 ft.^{3}/year), the radius of the cone of depression, r_d, is 2,850 feet. For a safe sustained yield at rate Q, the pumping well should be located at least one mile from the sea coast, to allow for expansion of the cone during periods when discharge to the sea far exceeds recharge to the aquifer. Monitoring of groundwater flow and quality between the cone of depression and the seacoast can be carried out during these periods by means of piezometers (as shown in Figures 45 and 46).

CHAPTER IV

4. AQUIFER ANALYSES

4.1 General

A number of pump tests were carried out by the author, W.H. Crandall and Associates (Management Ltd.), consulting engineers and James F. MacLaren Limited, consulting engineers, on wells fully penetrating the Upper Sandstone aquifer. The field data were processed in order to determine the aquifer characteristics, which include the coefficients of transmissibility, permeability, and storage. A study of the specific yield of the Upper Standstone aquifer and permeability of the Middle Claystone aquiclude was made.

Definitions

The coefficient of transmissibility, T, of an aquifer is defined as the rate of flow of water in gallons per day through a vertical strip of the aquifer, one foot wide, extending over the full saturated thickness, under a hydraulic gradient of one foot per foot, at the prevailing temperature of water. The field coefficient of permeability of an aquifer, K, is defined as the rate of flow of water, in gallons per day, through a cross-sectional area of one square foot of aquifer, under a hydraulic gradient of one foot per foot at the prevailing temperature of water. Transmissibility is equivalent to the saturated thickness of the aquifer, b, times the permeability, K. The coefficient of storage, S, is defined as the volume of water the aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. Specific storage, Ss, of an aquifer, is defined as the volume of water released or taken into storage per unit volume of aquifer per unit decline of head. It is equivalent to the quotient of the storage coefficient to the thickness of the aquifer. Diffusivity is defined as the quotient of the coefficients of transmissibility to storage, or the quotient of permeability to specific storage.

4.2 Formulas for Determining Aquifer Characteristics

The following formulas were used in pump test analysis.

A. The non-equilibrium formula for non-leaky artesian aquifers, and constant discharge conditions, introduced by Theis (1935) and described by Walton (1962) was employed for distance-drawdown field data.

The equations are:

$$s = (114.6\ Q/T)\ W(u) \qquad \text{(eqn. 4 - 1)}$$

$$u = \frac{1.56\ r^2 s}{T.t} \qquad \text{(eqn. 4 - 2)}$$

where: s = drawdown in observation well in feet.

Q = discharge in imperial gallons per minute.

T = coefficient of transmissibility in imperial gallons per day per foot.

r = distance from observation well to pumped well in feet.

S = coefficient of storage.

t = time after pumping started in days.

Example: Figures 19, 20, 21.

B. The Jacob (1946) modified non-leaky artesian formula, a variant of the Theis formula, was employed as described by Walton (1962). The expressions are:

for time-drawdown field data:

$$T = 264\ Q/\Delta s \qquad \text{(eqn. 4 - 3)}$$

$$S = \frac{T t_0}{2.78\ r^2} \qquad \text{(eqn. 4 - 4)}$$

where: Δs = drawdown change per logarithmic cycle of time, in feet.

t_0 = intersection of straight line slope of data points with zero drawdown axis, in days.

Example: Figures 22, 23.

and for distance drawdown data:

$$T = 527.7\ Q/\Delta s \qquad \text{(eqn. 4 - 5)}$$

$$S = \frac{T t}{2.78\ r_0^2} \qquad \text{(eqn. 4 - 6)}$$

where: Δs = drawdown change per logarithmic cycle of r, in feet.

r_o = intersection of straight-line slope of data points with zero drawdown axis in feet.

Example: Figure 24.

and

$$t_{sl} = 135 \times 10^5 r^2 (S/T) \qquad \text{(eqn. 4 - 7)}$$

where: t_{sl} = time after pumping starts before semi-logarithmic time-drawdown or distance drawdown data points will yield a straight line, in minutes.

C. In some pump tests, time recovery measurements following the cessation of pumping were used with the Jacob modification of the Theis non-equilibrium formula (Cooper, H.H. Jr., and C.E. Jacob, 1946) as described in "Ground Water and Wells" (1966). The equations are:

$$T = 264\, Q/\Delta s \qquad \text{(eqn. 4 - 8)}$$

$$S = \frac{Tt_o}{2.78\, r^2} \qquad \text{(eqn. 4 - 9)}$$

where: Δs= the change of water level (recovery) per log cycle of time.

s = drawdown from static water level before pumping, calculated from the time-drawdown data curve extended into the recovery period.

t_o = intersection of the straight line slope with the zero recovery axes in feet.

Example: Figure 25.

D. The residual drawdown method described in "Ground Water and Wells" (1966), employs the following equation:

$$T = \frac{264Q}{\Delta s'} \log t/t' \qquad \text{(eqn. 4 - 10)}$$

where: T = coefficient of transmissibility in imperial gallons-per day-per foot.

t = time after pumping starts in minutes.

t' = time after pumping stops in minutes.

s' = residual drawdown measured from the static water level to the recovery level during the recovery period, in feet.

$\Delta s'$ = change in residual drawdown per logarithmic cycle of values of t/t^1.

Example: Figure 26.

E. The coefficients of transmissibility and storage of the unconfined portion of the Upper Sandstone aquifer were determined by the type-curve graphical method devised by Boulton (1963) and described by Prickett (1965). Early time-drawdown data fits the type-curve to the left of the value r/D, (Figure 27), which is the "type A" curve and is essentially the same as the set of leaky artesian curves given by Walton (1962). Later time-drawdown data fits the non-leaky artesian type-curve to the left of the value r/D, which is termed the "type Y" curve (Figure 27). The coefficient of storage computed from the "type Y" curve will be in the water table range (0.01 to 0.30), and is the specific yield of the aquifers, Sy. It can be used to predict the long-term effects of aquifer development.

The equations are as follows:

$$s = 114.6\,(Q/T)\,W(u_{ay}, r/D) \qquad \text{(eqn. 4 - 11)}$$

$$u_a = \frac{1.56\, r^2 S}{Tt} \qquad \text{(eqn. 4 - 12)}$$

$$u_y = \frac{1.56\, r^2 S_y}{Tt} \qquad \text{(eqn. 4 - 13)}$$

$$\alpha = (r/D)^2\, \frac{\frac{1}{u_y} \times 1440}{4t} \qquad \text{(eqn. 4 - 14)}$$

twt = (see graph in Prickett 1965, p. 11)

where:

s = drawdown in observation well in feet.

r = distance from pumped well to observation well in feet.

Q = discharge in imperial gallons per minute.

t = time after pumping started in days.

T = coefficient of transmissibility in gallons per day per foot.

S = volume of water instantaneously released from storage per unit horizontal area, which is the effective early-time coefficient of storage (ratio).

S_y = coefficient of storage associated with delayed gravity drainage of interstices (specific yield), fraction.

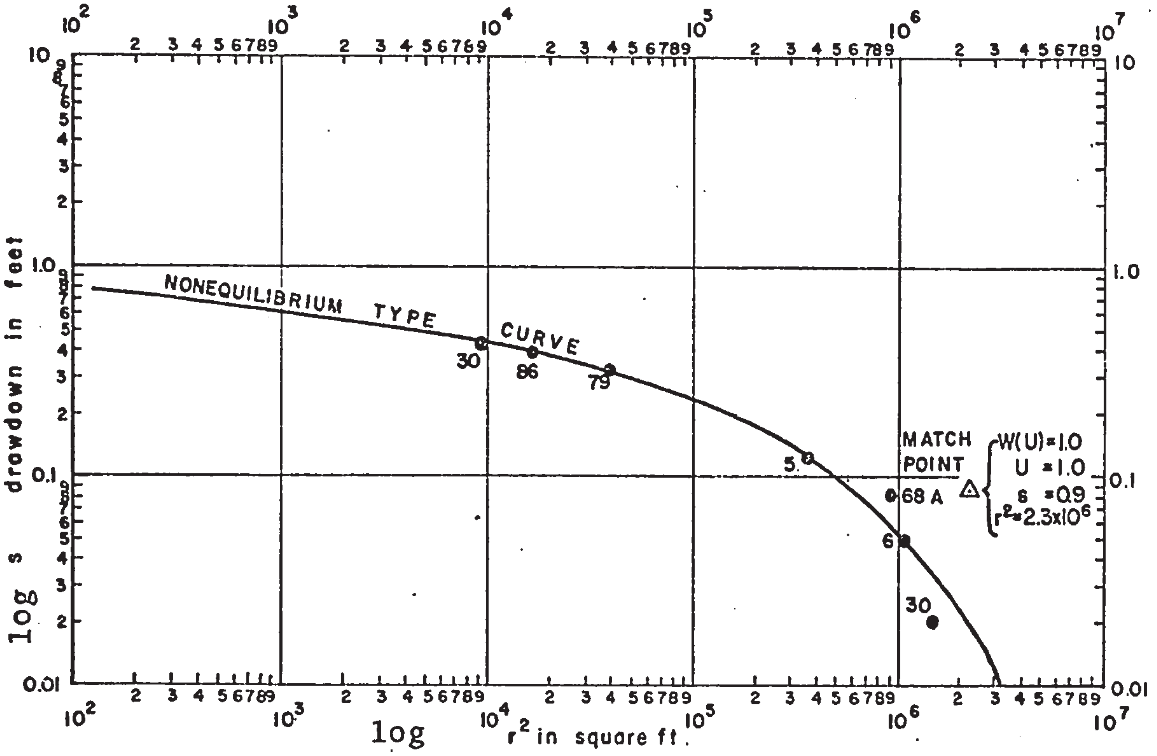
α = reciprocal of delayed index, minutes.

$W(u_{ay}, r/D)$ = well function for water table aquifers.

twt = time from start of pumping at which the effects of delayed gravity drainage are negligible and true water table conditions exist.

Examples: Figures 27, 28.

Figure 19: Distance-drawdown graph of pump test at Well 2, Shippegan municipal water supply



PUMP TEST ON WELL 2, STARTED AUG. 16, 1969 9:10 H.R

PUMPING RATE $Q = 380$ IMP. GAL./MIN.

UPPER SANDSTONE (UNIT I), AQUIFER THICKNESS

$b = 57$ FT.

TIME $t = 10$ MIN.

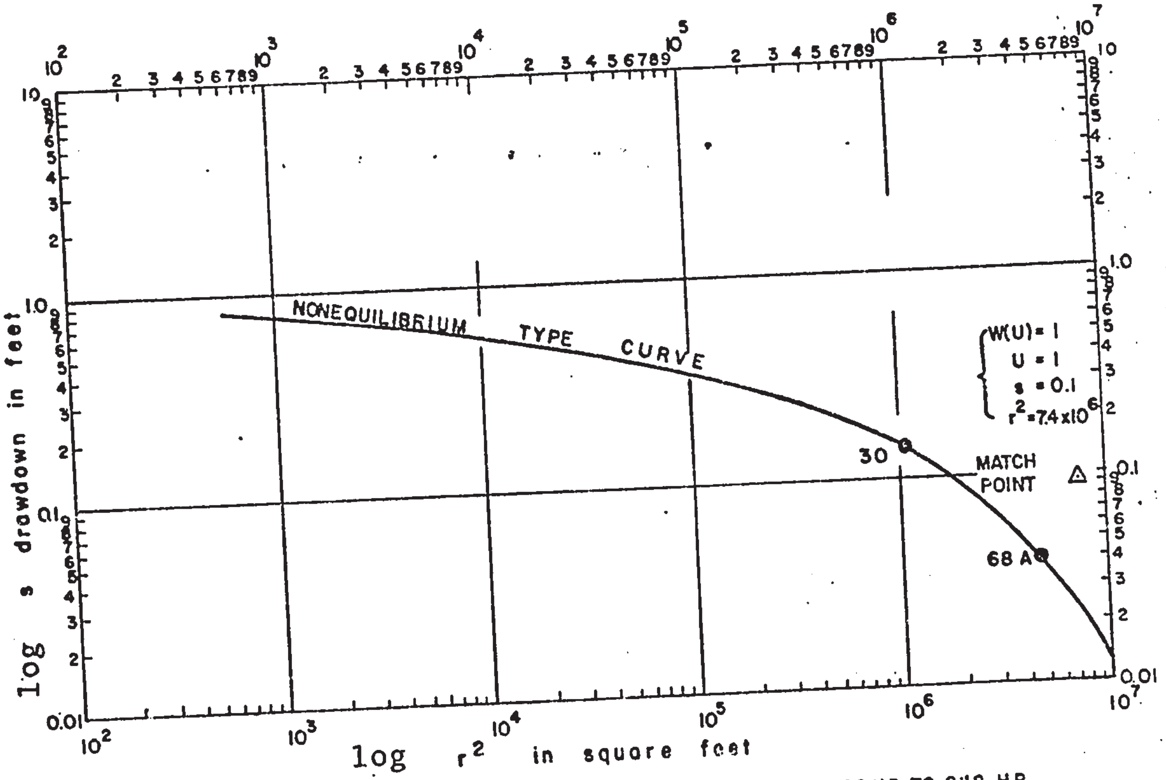
$$T = \frac{114.6\,Q\,W(U)}{s} = \frac{114.6 \times 380 \times 1.0}{9 \times 10^{-1}} = 4.83 \times 10^{5}\ \frac{\text{imp. gal.}}{\text{day-ft.}}$$

$$K = \frac{T}{b} = \frac{4.83 \times 10^{5}}{5.7 \times 10} = 8.49 \times 10^{3}\ \frac{\text{imp. gal.}}{\text{day-ft.}^{2}}$$

$$S = \frac{Tut}{1.56\,r^{2}} = \frac{4.83 \times 10^{5} \times 1.0 \times 10}{1.56 \times 2.3 \times 10^{6} \times 1.44 \times 10^{3}} = 9.36 \times 10^{-4}$$

$$\frac{T}{S} = 5.2 \times 10^{8}$$

Figure 20: Distance-drawdown graph of pump test at Well 3, Atlantic Peat Moss Co., Shippegan



PUMP TEST ON PUMPING WELL 33, ATLANTIC PEAT MOSS, CO, 8:00 HR. TO 8:18 HR., AUG. 19, 1969

PUMPING RATE Q = 210 IMP.-GAL. / MIN.

DISTANCES OF OBSERVATION WELL FROM 33, r

WELL 30, r = 1046 FT.
WELL 68A, r = 2150 FT.
TIME, t = 18 MIN.

UPPER SANDSTONE (UNIT I), AQUIFER THICKNESS, b = 47 FT.

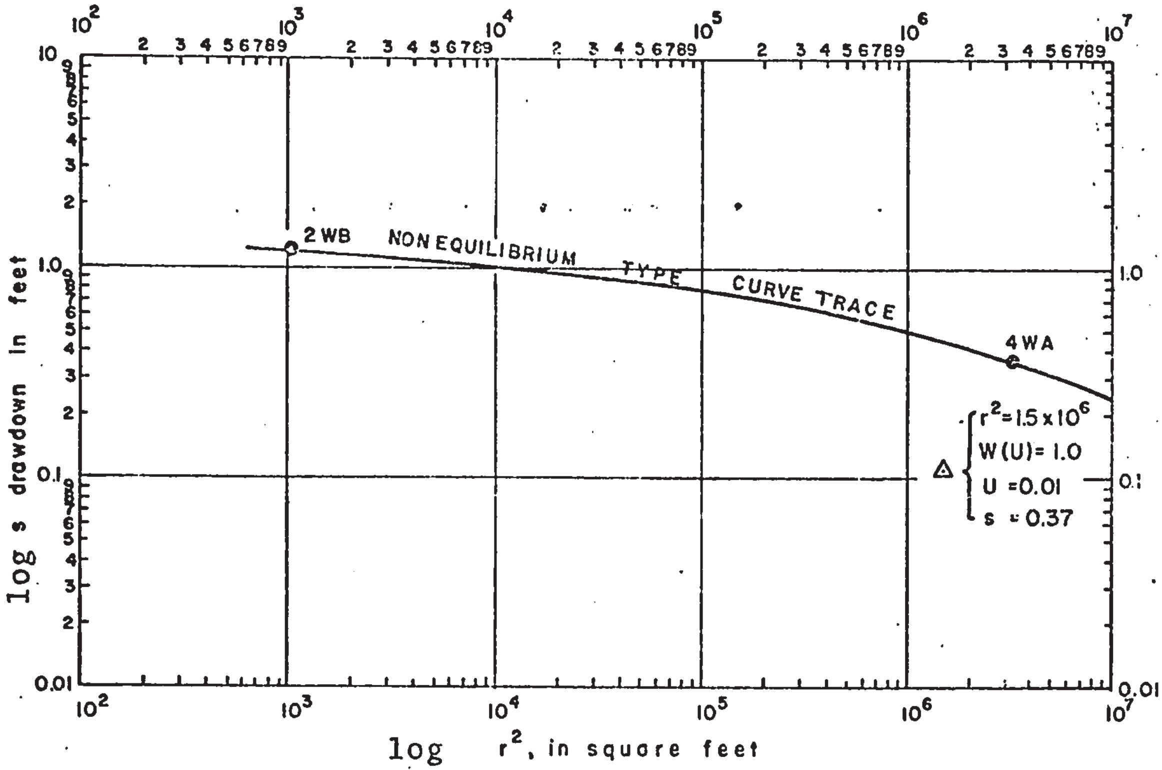
$$T = \frac{114.6\ Q\ W(U)}{s} = \frac{1.146 \times 10^2 \times 2.1 \times 10^2}{1 \times 10^{-1}} = 2.4 \times 10^5 \frac{\text{imp.gal}}{\text{day-ft.}}$$

$$K = \frac{T}{b} = \frac{2.4 \times 10^5}{4.7 \times 10} = 5.1 \times 10^3 \frac{\text{imp.gal.}}{\text{day-ft.}^2}$$

$$S = \frac{Tut}{1.56 r^2} = \frac{2.4 \times 10 \times 1 \times 1.8 \times 10}{1.56 \times 7.4 \times 10^6 \times 1.44 \times 10^3} = 2.6 \times 10^{-4}$$

$$\frac{T}{S} = \frac{2.4 \times 10^5}{2.6 \times 10^{-4}} = 9.2 \times 10^8$$

Figure 21: Distance-drawdown graph of pump test at water reservoir site



PUMP TEST ON RESERVOIR SITE 320 FT. NORTH OF WELL 2 WB, 14:15 HR. DEC. 28, 1969 TO 13:48 HR. JAN. 3, 1970.

DISTANCES OF OBSERVATION WELLS FROM PUMP, r
2 WB = 320 FT.
4 WA $\simeq$ 1800 FT.

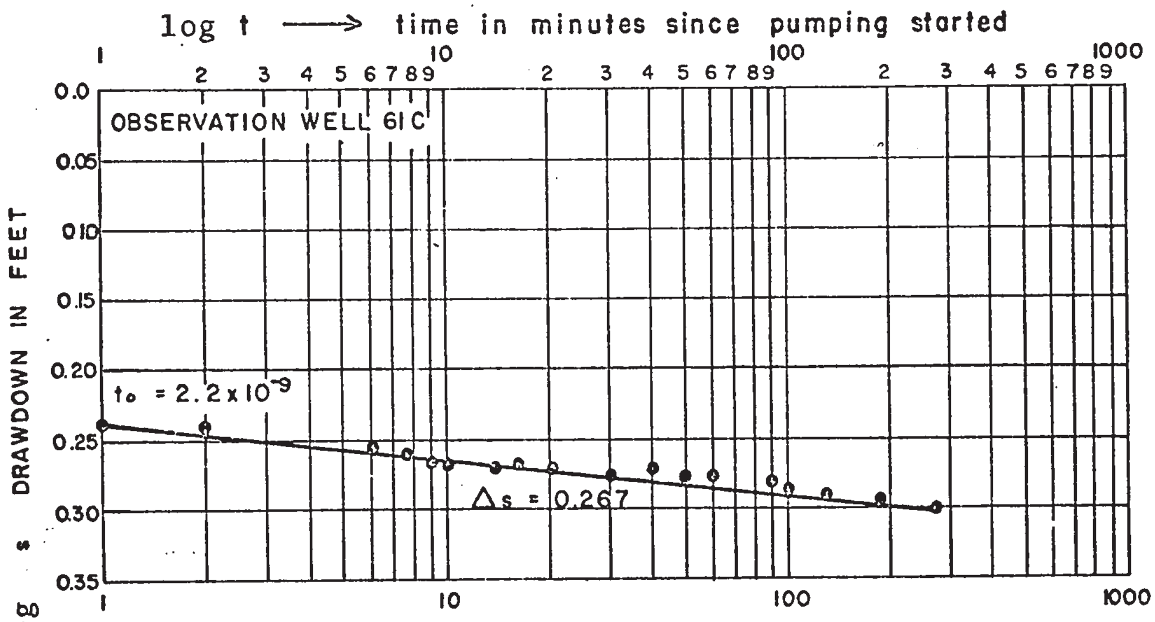
UPPER SANDSTONE, (UNIT I), THICKNESS b = 38 FT. UNCONFINED.
Q = 4000 IMP. GAL./MIN.
t = 4320 MIN.

$$T = \frac{114.6\,Q\,W(U)}{s} = \frac{114.6 \times 4000}{3.7 \times 10^{-1}} = 1.24 \times 10^6 \frac{\text{IMP. GAL}}{\text{DAY-FT.}}$$

$$K = \frac{T}{b} = \frac{1.24 \times 10^6}{38} = 3.3 \times 10^4 \frac{\text{IMP. GAL}}{\text{DAY-FT.}^2}$$

$$S_Y = \frac{TUt}{1.56 r^2} = \frac{1.24 \times 10^6 \times 1 \times 10^{-2} \times 4.32 \times 10^3}{1.56 \times 1.5 \times 10^6 \times 1.44 \times 10^3} = 1.59 \times 10^{-2} = 0.015$$

Figure 22: Time-drawdown graph of pump test at Well 61B



PUMP TEST ON PUMPING WELL 61 B, 13:15 HR. AUG. 8 TO 13:55 HR. AUG. 9, 1968.

PUMPING RATE Q = 53 IMP. GAL./MIN.

DISTANCE FROM OBSERVATION WELL 61C TO 61B, r = 49.0 FT.

UPPER SANDSTONE (UNIT I), AQUIFER THICKNESS, b = 71.5 FT.

$$T = \frac{264Q}{\Delta s} = \frac{264 \times 53}{.0267} = 5.3 \times 10^5 \ \frac{\text{imp.gal}}{\text{day-ft.}}$$

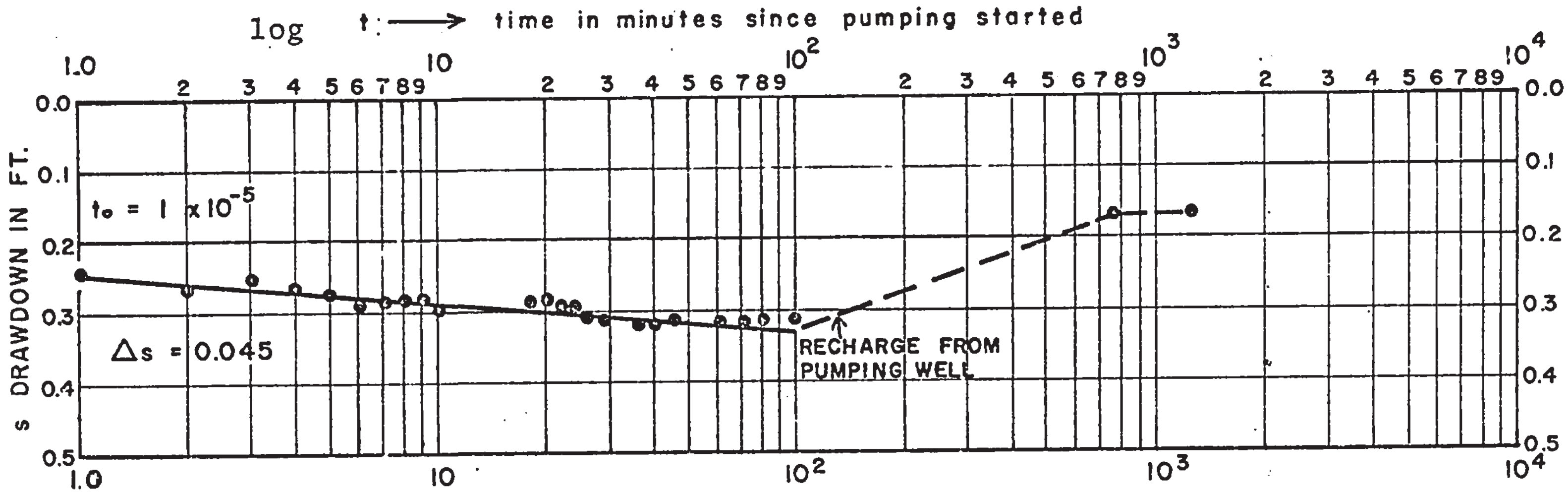
$$K = \frac{T}{b} = \frac{5.3 \times 10^5}{7.15 \times 10} = 7.3 \times 10^3 \ \frac{\text{imp.gal.}}{\text{day-ft.}}$$

$$S = \frac{T t_o}{2.78 r^2} = \frac{5.3 \times 10^5 \times 2.2 \times 10^{-9}}{2.78 \times (4.90)^2 \times 1.44 \times 10^3} = 1.2 \times 10^{-3}$$

$$\frac{T}{S} = \frac{5.3 \times 10^5}{1.2 \times 10^{-3}} = 4.4 \times 10^8$$

$$t_{sl} = \frac{1.35 \times 10^5 \times r^2 S}{T} = 0.53 \text{ minute}$$

Figure 23: Time-drawdown graph of pump test at Well 4WP



PUMP TEST ON WELL 4 WP, 19:42 HR, AUG. 4 TO 10:15 HR. AUG. 6, 1969
PUMPING RATE Q = 334 IMP. GAL./ MIN.
DISTANCE OF OBSERVATION WELL 4 WA TO 4 WP, r = 38.6 FT.
UPPER SANDSTONE (UNIT I), THICKNESS b = 35 FT.

$$T = \frac{264\,Q}{\Delta s} = \frac{2.64 \times 10^2 \times 3.34 \times 10^2}{4.5 \times 10^{-2}} = 1.96 \times 10^6 \ \frac{\text{imp.gal.}}{\text{day-ft.}}$$

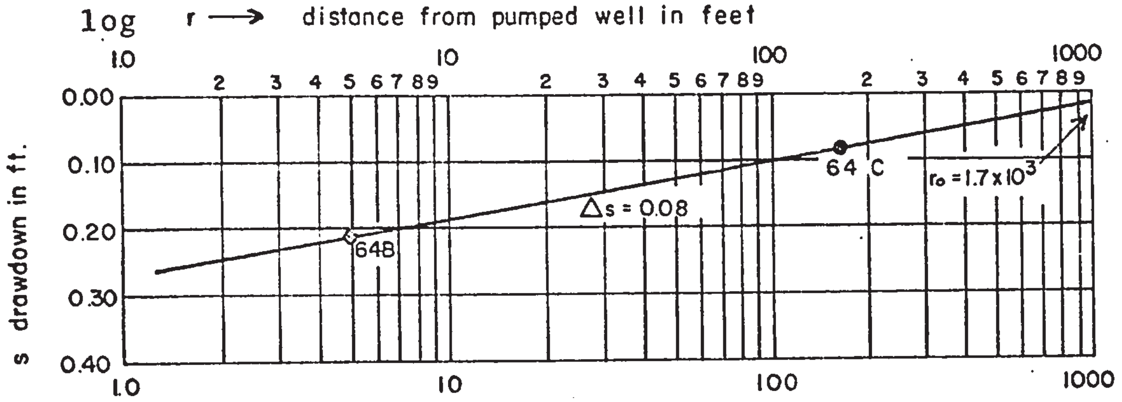
$$K = \frac{T}{b} = \frac{1.96 \times 10^6}{3.5 \times 10} = 5.6 \times 10^4 \ \frac{\text{imp.gal.}}{\text{day-ft.}^2}$$

$$S = \frac{T\,t_o}{2.78 r^2} = \frac{1.96 \times 10^6 \times 1 \times 10^{-5}}{2.78 \times 1.5 \times 10^3 \times 1.44 \times 10^3} = 3.3 \times 10^{-6}$$

$$\frac{T}{S} = 5.95 \times 10^{11}$$

$$t_{sl} = 1.35 \times 10^5 \, r^2 \frac{S}{T} = 3.4 \times 10^{-4} \text{ min.}$$

Figure 24: Distance-drawdown graph of pump test at Well 64D



PUMP TEST ON PUMPING WELL 64 D, 8:35 HR. AUG.19, TO 9:15 HR. AUG.20, 1968

PUMPING RATE Q = 58 IMP. GAL. / MIN.

DISTANCES OF OBSERVATION WELLS FROM 64 D, r

WELL 64 B = 5 FT.

WELL 64 C = 167 FT.

UPPER SANDSTONE (UNIT I) AQUIFER, THICKNESS

b = 45 FT., UNCONFINED

TIME t = 1180 MIN.

$$T = \frac{527.7Q}{\Delta s} = \frac{527.7 \times 58}{0.08} = 3.82 \times 10^{5} \, \frac{\text{imp. gal.}}{\text{day-ft.}}$$

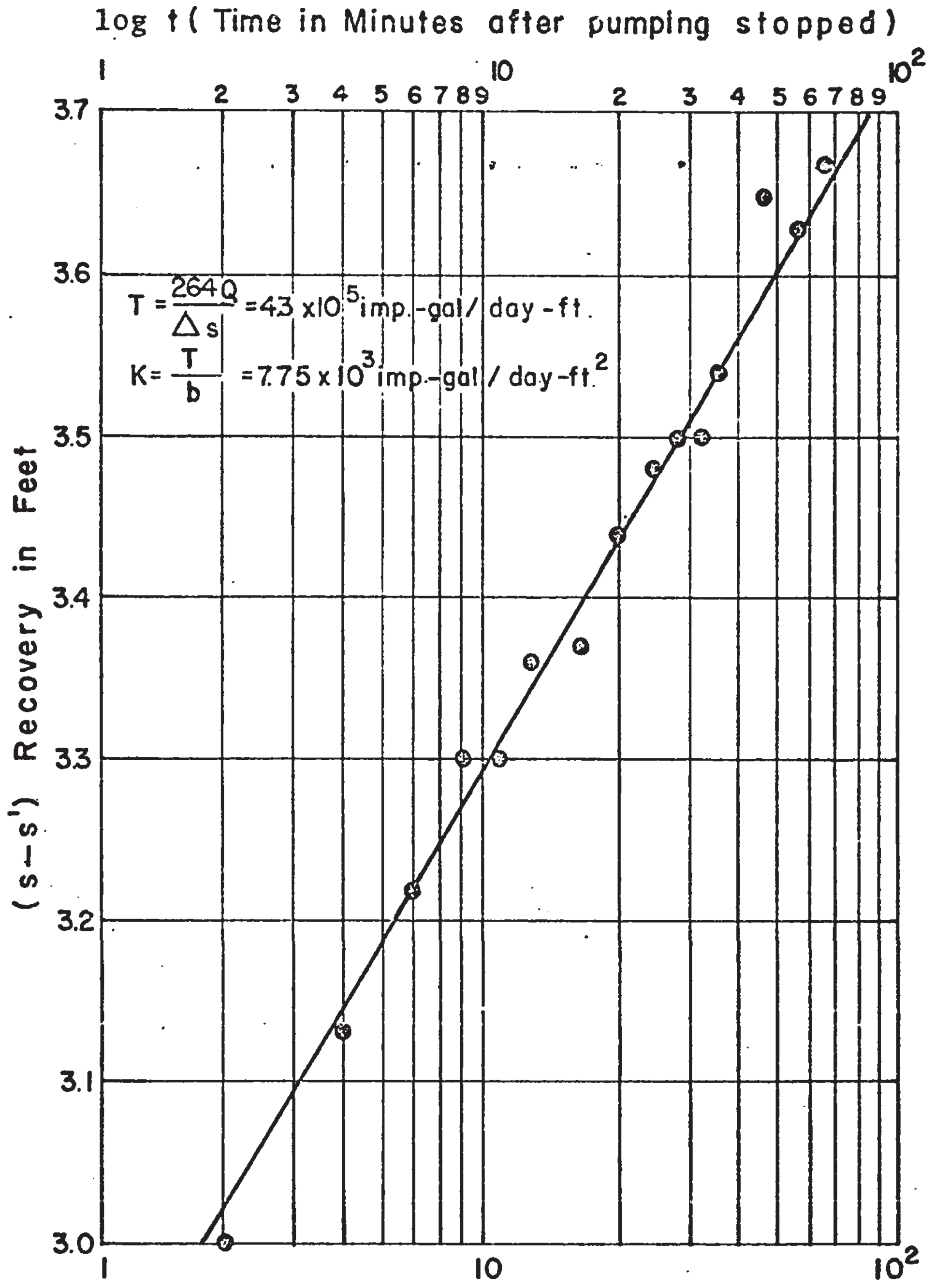
$$K = \frac{T}{b} = \frac{3.82 \times 10^{5}}{45} = 8.5 \times 10^{3} \, \frac{\text{imp. gal.}}{\text{day.-ft.}}$$

$$S = \frac{Tt}{2.78 \, r_o^2} = \frac{3.82 \times 10^{5} \times 1180}{2.78 \times (1.7 \times 10^{3})^2 \times 1440} = 0.039$$

$$\frac{T}{S} = 9.8 \times 10^{6}$$

$$t_{sl} = \frac{1.35 \times 10^{5} \, r^2 \, S}{T} = \frac{1.35 \times 10^{5} \times 4 \times 10^{4} \times 3.9 \times 10^{-2}}{3.82 \times 10^{5}} = 550 \text{ min.}$$

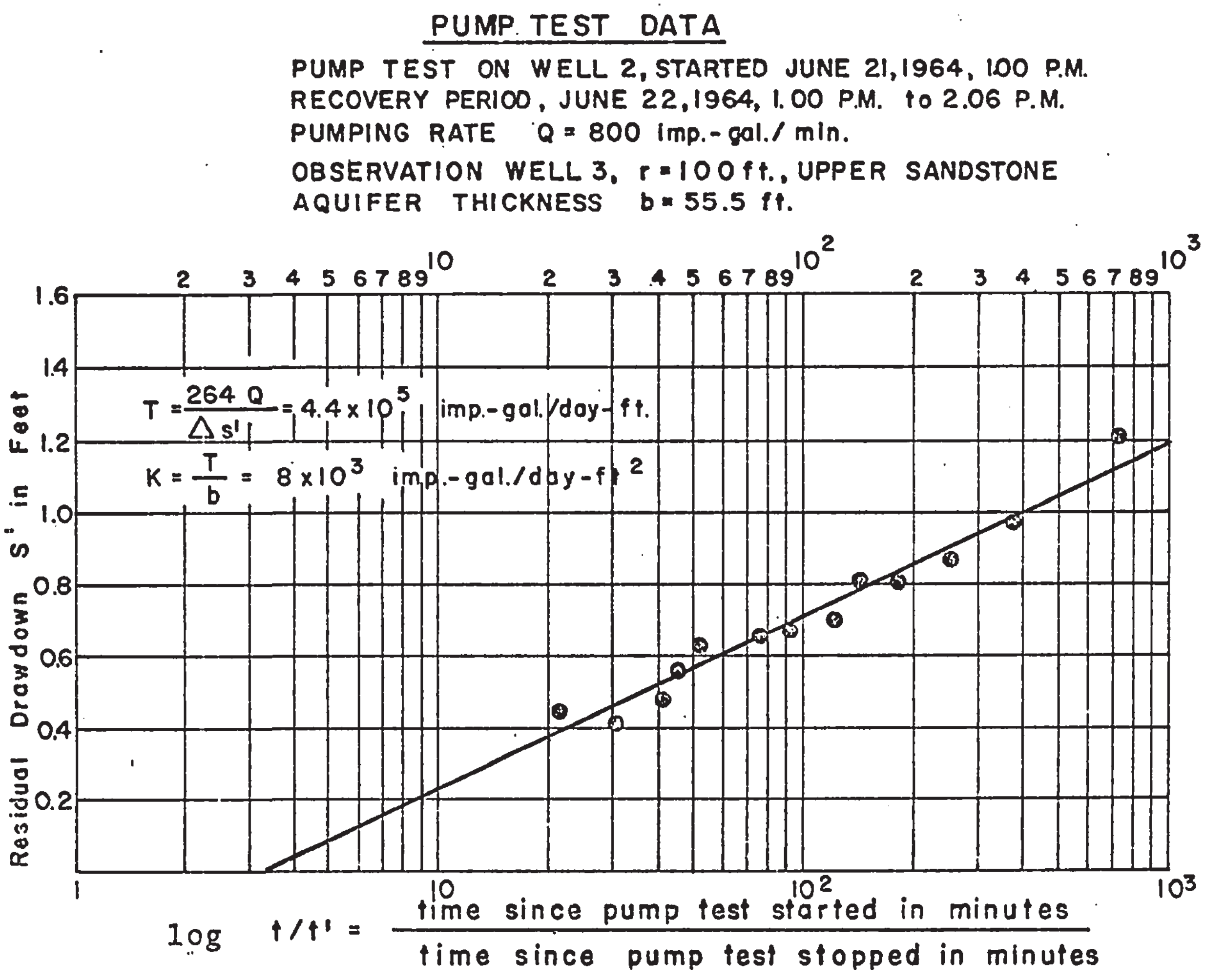
Figure 25: Time-recovery graph of pump test at Well 2



PUMP TEST DATA

Pump test on Well 2, started June 18, 1964, 6:19 P. M., Recovery Period June 22, 1964, 1:00 P.M. to 2.06 P.M. Pumping Rate Q = 900 imp.-gal./min. Observation Well 1, r = 50 ft. Upper Sandstone Aquifer, Thickness b = 55.5 ft.

Figure 26: Graph of residual drawdown against log t/t^1, for pump test at Well 2



PUMP TEST DATA

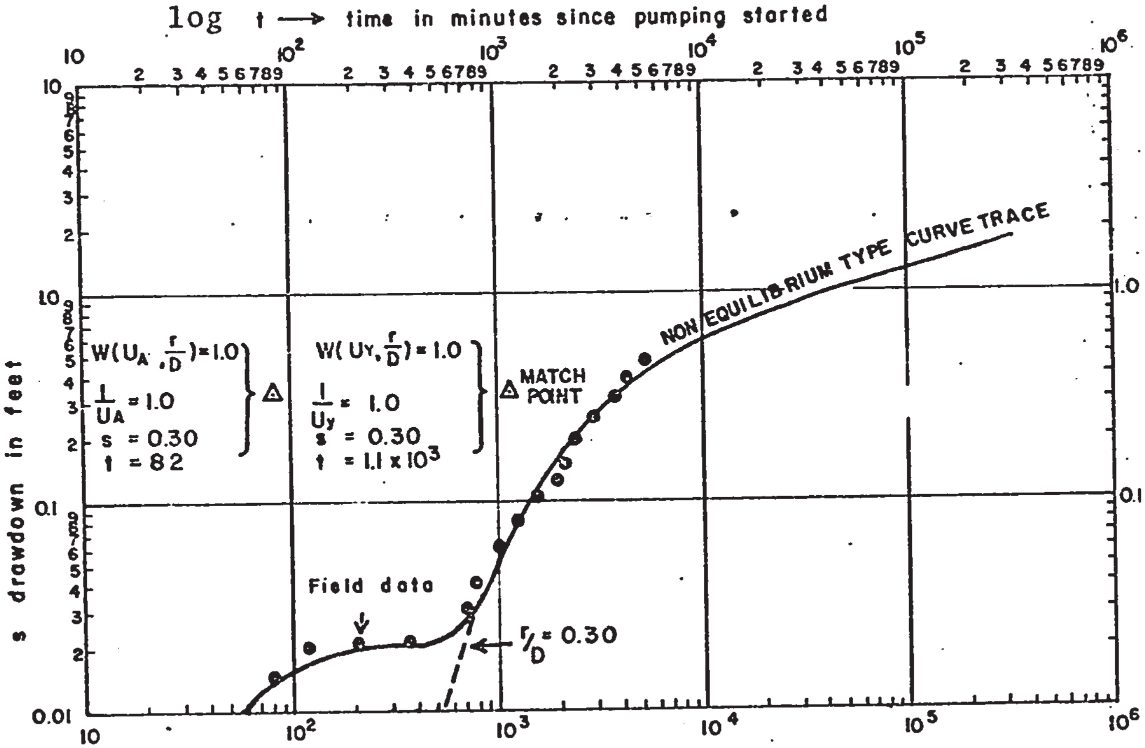
PUMP TEST ON WELL 2, STARTED JUNE 21, 1964, 1.00 P.M.
RECOVERY PERIOD, JUNE 22, 1964, 1.00 P.M. to 2.06 P.M.
PUMPING RATE $Q = 800$ imp.-gal./min.
OBSERVATION WELL 3, $r = 100$ ft., UPPER SANDSTONE
AQUIFER THICKNESS $b = 55.5$ ft.

$$T = \frac{264\,Q}{\Delta s'} = 4.4 \times 10^5 \text{ imp.-gal./day-ft.}$$

$$K = \frac{T}{b} = 8 \times 10^3 \text{ imp.-gal./day-ft}^2$$

$$\log\ t/t' = \frac{\text{time since pump test started in minutes}}{\text{time since pump test stopped in minutes}}$$

Figure 27: Time-drawdown graph of pump test at reservoir site



PUMP TEST ON RESERVOIR SITE 320 FT. NORTH OF WELL 2 WB,
14:15 HR. DEC. 28, 1969 TO 13:48 HR. JAN. 3, 1970.

PUMPING RATE Q = 4 000 IMP. G.P.M.

DISTANCE OF OBSERVATION WELL 4 WA. FROM RESERVOIR SITE
$r \simeq 1800$ FT.

UPPER SANDSTONE, (UNIT I), THICKNESS $b = 38$ FT, UNCONFINED.

$$T_A = \frac{114.6\,Q\,(W_{AY}, \frac{r}{D})}{s} = 1.53 \times 10^6 \,\frac{\text{imp. gal.}}{\text{day-ft.}}$$

$$T_Y = \frac{114.6\,Q\;W(U_{AY}, \frac{r}{D})}{s} = \frac{1.146 \times 10^2 \times 4 \times 10^3 \times 1}{3 \times 10^{-2}} = 1.53 \times 10^6 \,\frac{\text{imp. gal.}}{\text{day-ft.}}$$

$$K = \frac{T}{b} = 4.0 \times 10^4 \,\frac{\text{imp. gal}}{\text{day-ft.}^2}$$

$$S = \frac{T U_A t}{1.56 r^2} = 1.7 \times 10^{-2}$$

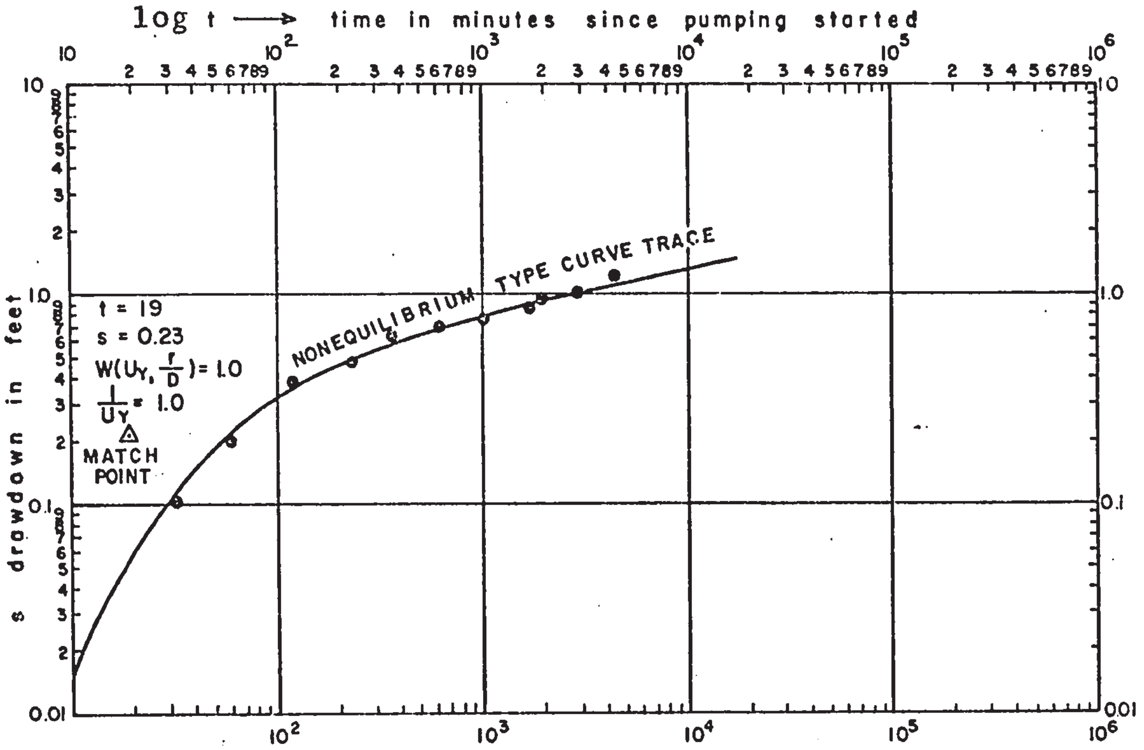
$$S_Y = \frac{T U_Y t}{1.56\, r^2} = \frac{1.52 \times 10^6 \times 1 \times 1.1 \times 10^3}{1.56 \times (3.25 \times 10^6)\,1440} = 0.23$$

$$\alpha = \frac{(\frac{r}{D})^2 \frac{1}{U_r}}{4t} = \frac{9}{4 \times 1.1 \times 10^3} = 2.04 \times 10^{-3} \text{ MIN.}^{-1}$$

$$\text{DELAY INDEX} = \frac{1}{\alpha} = 49 \text{ MIN.}$$

$$\alpha \frac{t_{wt}}{\alpha} = t_{wt} = 4.7 \times 10^3 \text{ MIN.}$$

Figure 28: Time-drawdown graph of pump test at reservoir site



PUMP TEST ON RESERVOIR SITE 320 FT. NORTH OF WELL 2 WB, 14:15 HR. DEC. 28, 1969 TO 13:48 HR., JAN. 3, 1970.

PUMPING RATE Q = 4,000 IMP. G./P.M.

DISTANCE OF OBSERVATION WELL 2 WB, FROM RESERVOIR SITE, r = 320 FT.

UPPER SANDSTONE, (UNIT I), THICKNESS b = 38 FT, UNCONFINED.

$$T = \frac{114.6\, W(U_{AY}, \frac{r}{D})}{s} = \frac{114.6 \times 4000 \times 1}{2.3 \times 10^{-1}} = 2 \times 10^{6}\ \frac{\text{imp.gal.}}{\text{day-ft.}}$$

$$K = \frac{T}{b} = \frac{2 \times 10^{6}}{38} = 5.25 \times 10^{4}\ \frac{\text{imp.gal.}}{\text{day-ft.}^2}$$

$$S_Y = \frac{T U_Y t}{1.56 r^2} = \frac{2 \times 10^{6} \times 1.9 \times 10}{1.56 \times (7.24 \times 10^{4}) \times 1.44 \times 10^{3}} = 0.23$$

4.3 Hydraulic Properties of the Upper Sandstone (Unit I)

The field coefficient of permeability, K, of the Upper Sandstone aquifer determined by the foregoing pump test analyses varies by approximately one order of magnitude (Figure 29). The mean permeability in the vicinity of Shippegan town is 9.08×10^3 imperial gallons per day per square foot, and the mean permeability in the vicinity of the new municipal well field is 4.54×10^4 imperial gallons per day per square foot (Table 3, Figure 29). The storage coefficients of the Upper Sandstone aquifer determined from pump test analyses varies considerably. In the vicinity of Shippegan town, the mean value is 5.86×10^{-4}, whereas in the vicinity of the new well field, it is 0.160 (Table 3). Within the town of Shippegan, the artesian response of the Upper Sandstone aquifer to pumping of well 2, and the magnitude of the storage coefficient indicate that the Upper Sandstone aquifer is effectively confined below the Upper Claystone (Subunit 1a), an aquiclude which is shown in Figures 51 and 54. On the other hand, at the new municipal well field (Figures 5 and 45), the Upper Claystone aquiclude is not present, and consequently the Upper Sandstone aquifer is under water-table conditions.

The extreme high permeability of the unconfined portion of the Upper Sandstone aquifer and its high storage coefficient appear to be due to flow through a ubiquitous highly integrated fracture system. Judging from the grain

Figure 29: Permeabilities, K, of Upper Sandstone (Unit I) in imperial gallons per day per square foot and storage coefficients, S, determined by pump tests

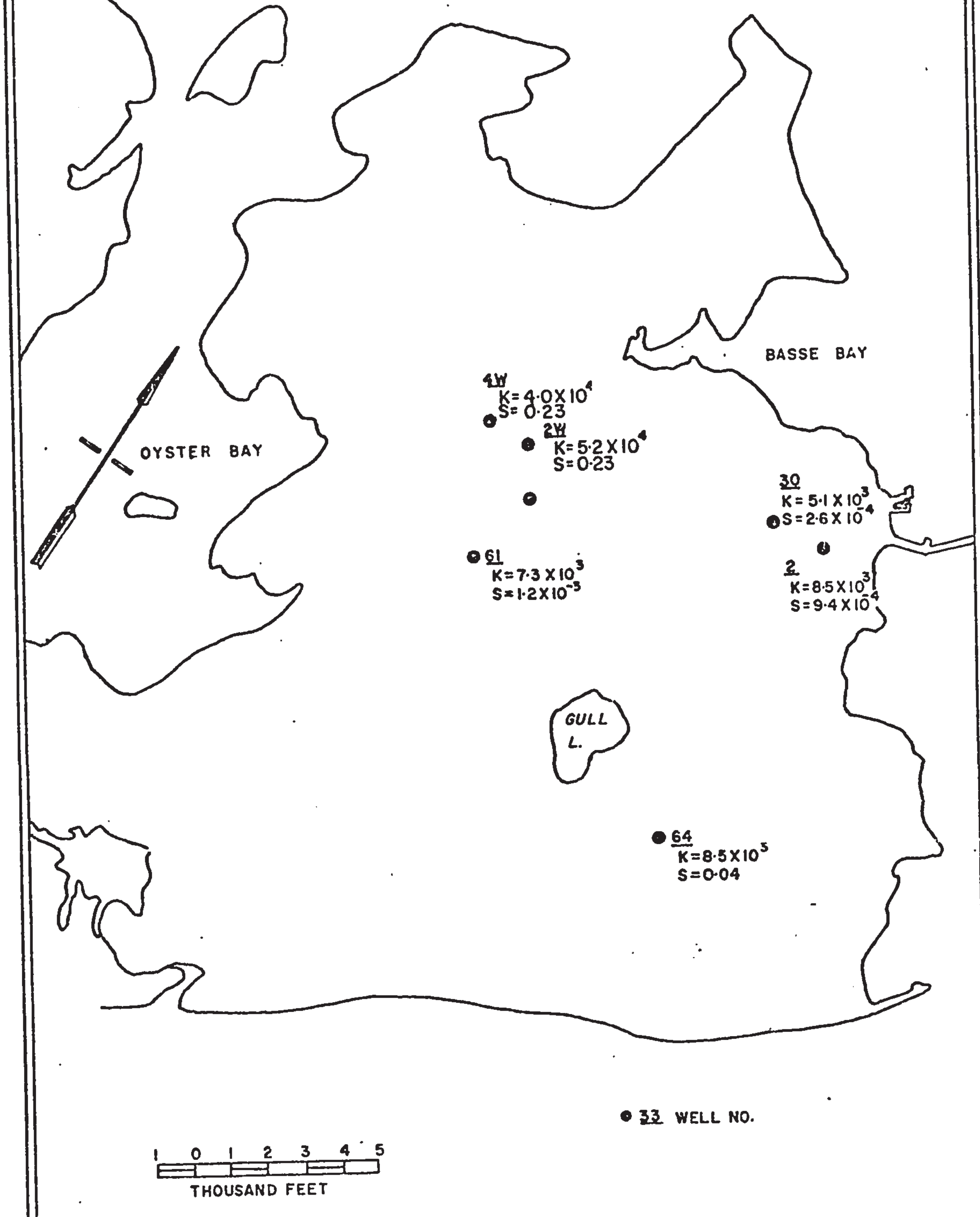


TABLE 3

VALUES OF AQUIFER CHARACTERISTICS OF UPPER SANDSTONE AND PUMP TEST DATA,

TAYLOR ISLAND, NEW BRUNSWICK

Town of Shippegan Production Wells Partly Confined

Pumping Well	Date	Pumping Rate Q. Imp. Gpm.	Observation Well	Distance of Observation Well	Method	Upper Sandstone Aquifer Thickness b, Ft.	Permeability K. Imp. G.P.D. Per Sq. Ft.	Coefficient of Storage S, Ratio	Diffusivity T/S Imp. G.P.D. Per Ft.	Figure	Operator W.H. Crandall and Associates
2	June 22, 1964	900	1	50 ft.	Time Recovery	55.5	7.75×10^3			26	"
2	June 18, 1964	656	1	50	Time Recovery	55.5	1.36×10^4				"
2	June 20, 1964	760	1	50	Residual Drawdown	55.5	1.15×10^4				"
2	June 22, 1964	800	2		Residual Drawdown	55.5	7.57×10^3				"
2	June 22, 1964	800	3	100	Residual Drawdown	55.5	8.00×10^3			27	"
2	June 20, 1964	760	3	100	Residual Drawdown	55.5	1.06×10^4				"
2	Aug. 16, 1969	380	30,6,68A, 5,3,86,79		Distance Drawdown	57.0	8.49×10^3	9.36×10^{-4}	5.2×10^8	20	"
33	Aug. 16, 1969	210	68A,30		Distance Drawdown	47.0	5.1×10^3	2.6×10^{-4}	9.2×10^8	21	"
							Mean 9.08×10^3	Mean 5.86×10^{-4}	Mean 7.2×10^8		
61B	Aug. 8, 1968	53	61C	49	Time Drawdown	71.5	7.3×10^3	1.2×10^{-3}	4.4×10^8	23	Author
64D	Aug. 19, 1968	58	64B,64C		Time Drawdown	45	8.5×10^3	3.9×10^{-2}	9.8×10^6	25	Author

Town of Shippegan New Well Field - Unconfined

Pumping Well	Date	Pumping Rate Q. Imp. Gpm.	Observation Well	Distance of Observation Well	Method	Upper Sandstone Aquifer Thickness b, Ft.	Permeability K. Imp. G.P.D. Per Sq. Ft.	Coefficient of Storage S, Ratio	Diffusivity T/S Imp. G.P.D. Per Ft.	Figure	Operator
2W Reservoir Site	Jan. 1, 1969	4000	4WA,ZWB		Distance Drawdown	37	3.3×10^4	1.59×10^{-2}	7.8×10^7	22	J.F. MacLaren Ltd.
2W Reservoir Site	Dec. 28, 1969	4000	2WB	320	Time Drawdown	38	5.25×10^4	2.3×10^{-1}	8.7×10^8	29	"
2W Reservoir Site	Dec. 28, 1969	4000	4WA	1800	Time Drawdown	38	4.0×10^4	2.3×10^{-1}	6.65×10^8	28	"
4WP	Aug. 4, 1969	334	4WA	38.6	Time Drawdown	35	5.6×10^4	--	--	24	"
							Mean 4.54×10^4	Mean 1.59×10^{-1}	Mean 5.37×10^8		
							Grand Mean 1.93×10^4	Grand Mean 0.07	Grand Mean 5.21×10^8		

size and fabric of rock specimens, intergranular flow must be minor and fracture-flow must account for the aquifer being hydraulically comparable to a gravel.

Spurious time-drawdown data from a number of pump tests was not considered in the analyses. The reason for the error was that pumped water was discharged within a few hundred feet from the pumped well, and within 10 to 100 minutes after pumping started the discharged water percolated downward and recharged the aquifer. A rise of groundwater levels as shown in Figure 23 or a declining rate of drawdown on a log time-drawdown plot was recorded in these instances with continued pumping.

4.4 Hydraulic Properties of the Middle Claystone (Unit II) and Leakage During Pump Tests

Inflatable packer-type reducers, designed by Lissey (1967), were installed in piezometers 85B and 85C, in order to determine the permeability of the middle Claystone (Unit II) (Figures 30 and 31). The reducers decrease the basic piezometer time lag to reach equilibrium, and thereby increase the piezometer sensitivity by a reduction factor

d_1^2/d_2^2 Hvorslev (1951)

where:

d_1 = diameter of the standard 2-inch piezometer standpipe.

d_2 = diameter of the plastic measuring tube placed in the piezometer standpipe.

Figure 30: Profile sections "A", "B", "C" and "D" of piezometer nests and wells, Taylor Island, New Brunswick

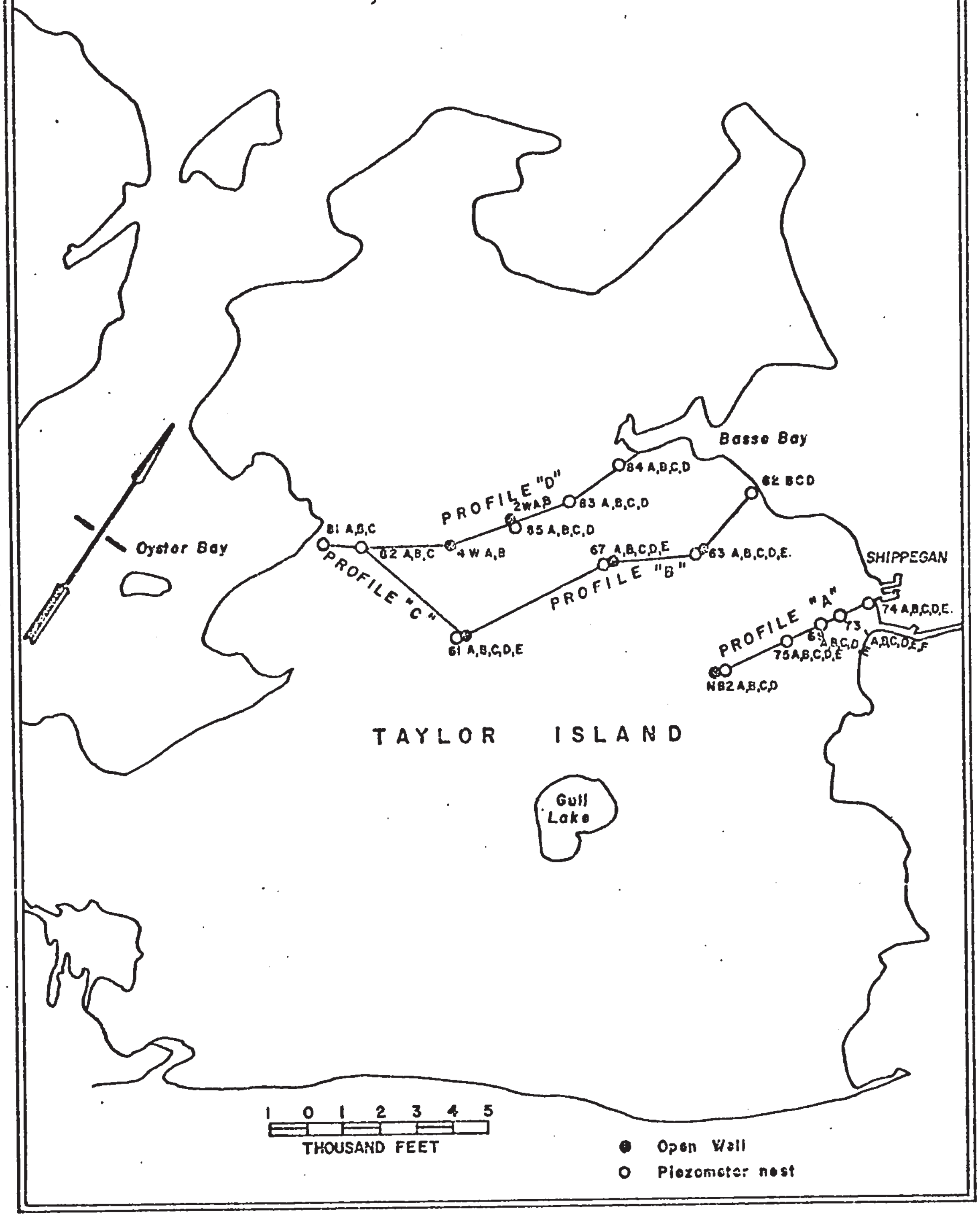
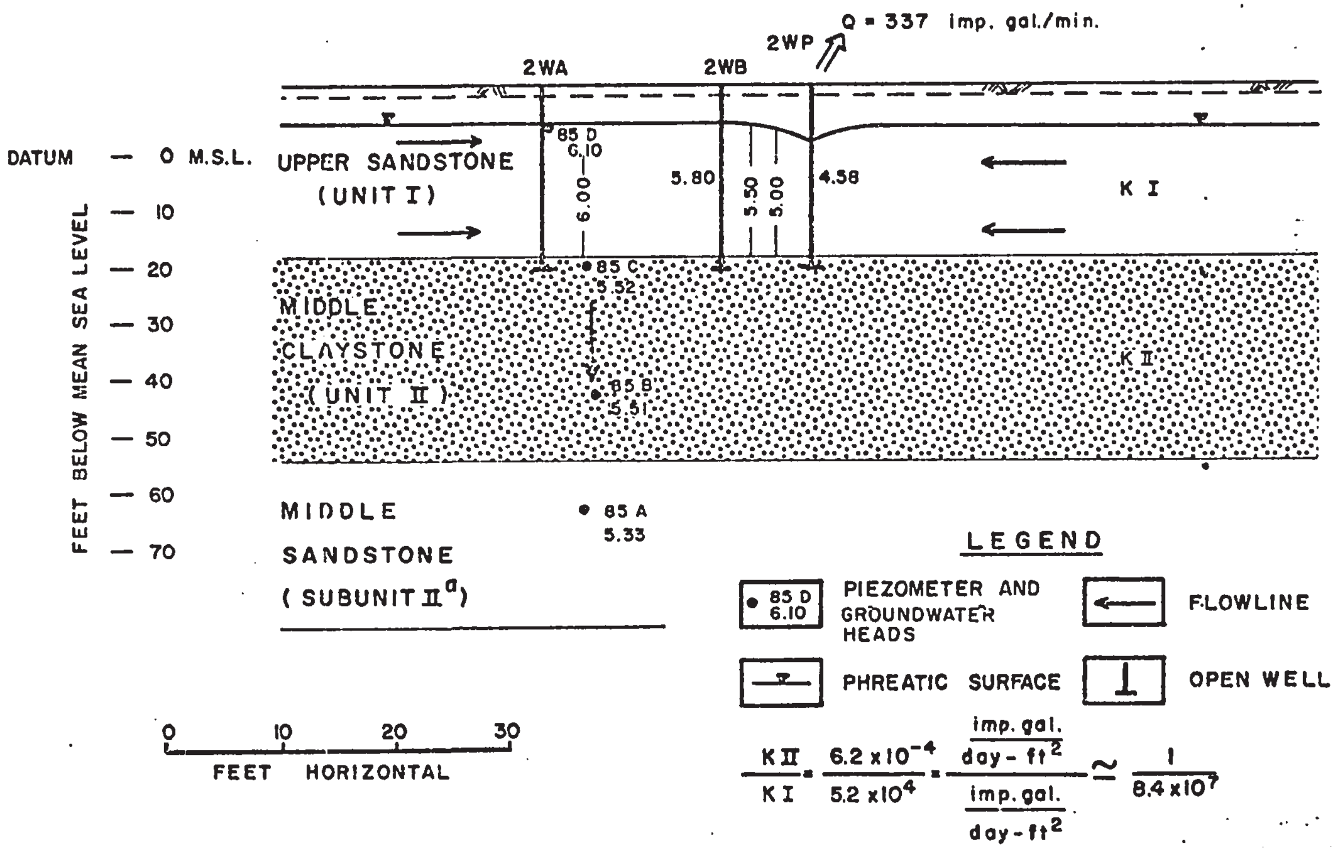


Figure 31: Pump test at well 2WP, July 23, 19:33 hr. to July 25, 20:22 hr., 1969. Groundwater heads at t = 2220 minutes after pumping started in feet above mean sea level



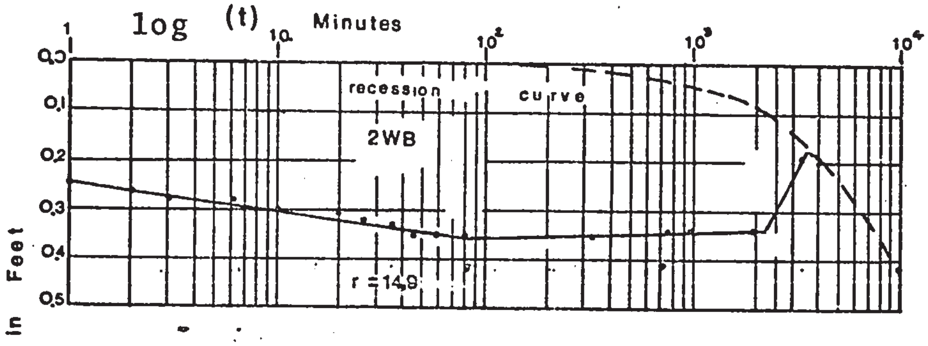
Changes of pore water pressure in low permeability claystone or shale formations are recorded with a minimum time lag because of the small volume of water required to respond to changes of pore water pressures in a small diameter measuring tube. In reduced piezometers 85B and 85C, time lag required to record total pore-water pressure changes is 0.96 days, and the reduction factor is 61.0. The response time for the 2-inch standpipe piezometers is therefore 58.5 days.

The Hvorslev (1951) method of calculating permeability from basic time lag measurements, assuming an isotropic media, gave permeability values of 3.48×10^{-8} and 3.49×10^{-8} cm. per second at piezometers 85B and 85C respectively.

The response of piezometers 85B and 85C to pumping in well 2WP was evaluated in order to determine whether upward leakage through the Middle Claystone unit into the Upper Sandstone would occur. Well 2WP was pumped at a steady rate of 337 imperial gallons per minute. The observed groundwater head distribution after 2,220 minutes of pumping is shown in Figure 31. Drawdowns in observation wells 2WA, 2WB, and piezometers 85D, 85C, 85B, and 85A, are shown in Figures 32 A, B, C, D, E, and F.

Groundwater head declines are greatest in piezometers 85C, near the upper surface of the Middle Claystone unit. The rate of groundwater head decline of about 0.13

Figure 32A: Response of observation well 2WB to pumping of well 2WP



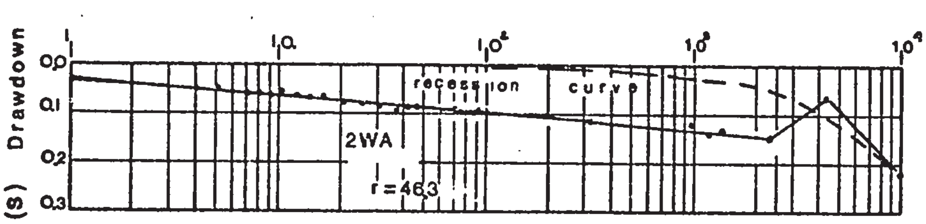
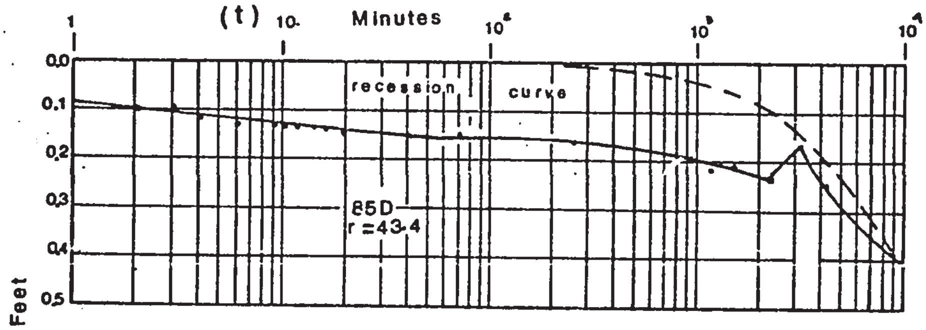


Figure 32B: Response of observation well 2WA to pumping of well 2WP

Figure 32C: Response of piezometer 85D to pumping of well 2WP



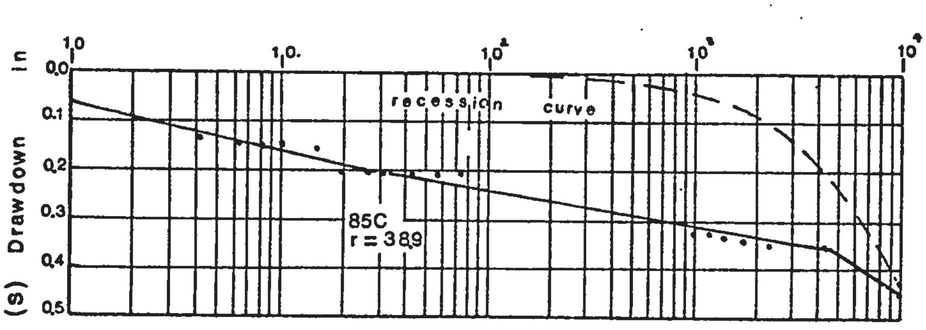
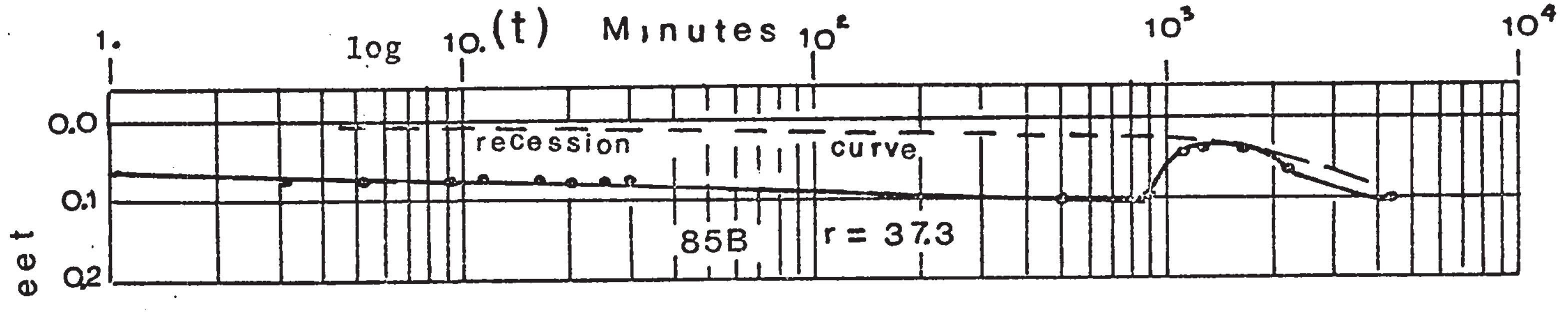


Figure 32D: Response of piezometer 85C to pumping of well 2WP

Figure 32E: Response of piezometer 85B to pumping of well 2WP



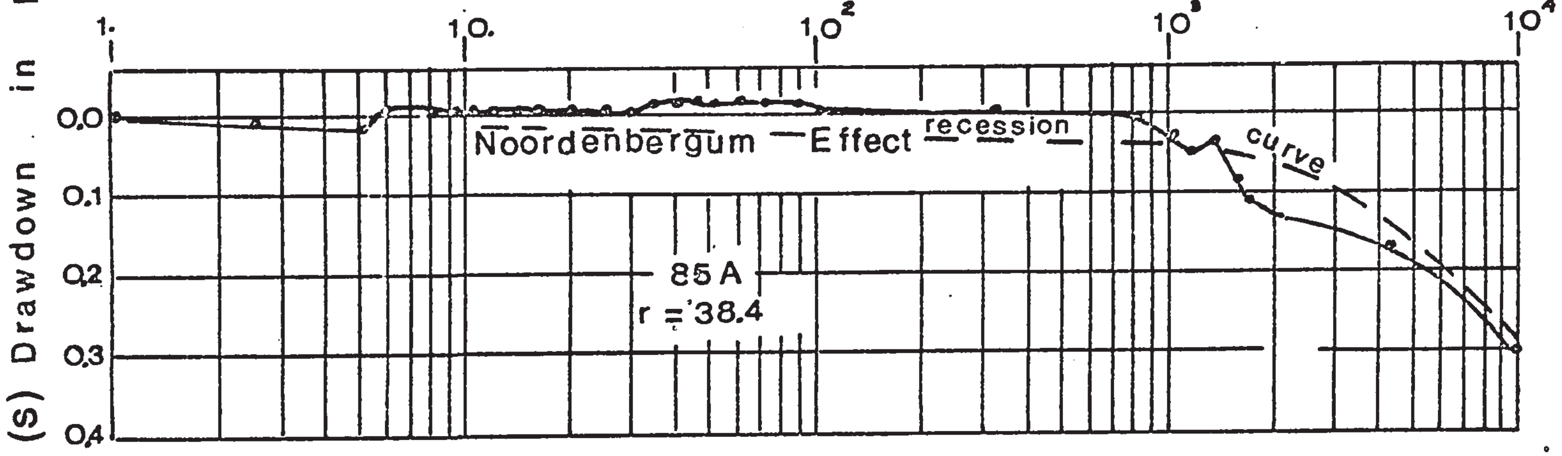


Figure 32F: Response of piezometer 85A to pumping of well 2WP feet per hour in piezometer 85C is consistent with the basic time lag response. The previous slug test gave groundwater head declines of up to 0.24 feet per hour during the initial period head decline, after water was poured into the measuring tube.

After 2,220 minutes of pumping, vertical downward, gradients in the Middle Claystone which existed before the pump test still existed as is shown in Figure 31. Considering that the permeability of the clay is 3.48×10^{-8} cm. per second or 6.2×10^{-4} imperial gallons per day per square foot and the gradients which existed during the pump test, leakage to the Upper Sandstone aquifer with a permeability of 5.25×10^{4} imperial gallons per day per square foot and specific yield of 0.23 (Figure 29), is negligible. Consequently, the assumption that the Upper Sandstone is underlain by an impermeable base and is non-leaky, is valid for the purpose of calculating aquifer characteristics by pump test methods.

No theoretical solutions are available for salt-water coning in multi-layered aquifer-aquiclude systems, with high permeability contrasts. However, the possible problem of sea-water coning into the Upper Sandstone aquifer, appears to be of little importance compared to the real problem of lateral intrusion of sea-water, due to the reduction of fresh-water heads in the Upper Sandstone aquifer by excessive pumping.

4.5 Noordenbergum Effect

A rise of groundwater heads observed in the Middle Sandstone aquifer (Figure 32F) is a phenomena known as the Noordenbergum effect. It was first observed near Noordenbergum, in the Netherlands, during pumping from an upper aquifer which is separated from a lower aquifer by a semi-impermeable layer. Verruijt's (1969) mathematical development predicts the initial rise of groundwater heads in the lower aquifer, within the first hour of pumping, and a subsequent decline toward a steady state when the water has had enough time to flow out of the lower aquifer.

The physical explanation for this phenomena is that frictional forces radially directed toward the pumping well are exerted on the soil particles of the upper aquifer in the horizontal direction of flow. These forces are accompanied by horizontal displacements within the soil, so that shear stresses act on the aquiclude below the upper aquifer. The effective compressive component of this shear stress, directed obliquely downward, causes a decrease of pore volume within the lower aquifer and pore water pressures rise accordingly.

4.6 Determination of Specific Yields of the Upper Sandstone Aquifer

Specific yield is the ratio of the volume of water which will drain freely from a material to the total volume. The specific yield and specific retention of an aquifer together equal the porosity.

A method of estimating specific yields of the Upper Sandstone aquifer, based on water-level response to precipitation, is dependent upon the critical selection of favorable recharge periods when soil-moisture deficiencies and evapotranspiration are small enough to be considered negligible. On Taylor Island precipitation during these periods is effectively converted to groundwater storage since surface runoff and surface detention near the wells analysed are insignificant. Groundwater level recorders show that infiltration rates are high, and storage increases are recorded by rising water levels generally within thirty to forty minutes after heavy precipitation begins. The depth of soil, a porous sand till, is less than three feet (Figure 6), and the depth to the water table is less than ten feet at the well sites analysed. The relationship described above is given for the time of the recharge period by the following equation.

$$P = R + ET + \Delta H . S_y + \Delta S.M. + \Delta S_w \qquad \text{(eqn. 4 - 15)}$$

$$P \simeq \Delta H . S_y \qquad \text{(eqn. 4 - 16)}$$

where: P = precipitation.
R = runoff.
ET = evapotranspiration.
ΔH = change in groundwater level.
S_y = specific yield.

$\Delta S.M.$ = change in soil moisture.

ΔS_w = change in surface-water storage (surface detention).

In Figure 33, the correlation between precipitation and the hydrograph of well NB1A, during the summer groundwater recession period, June 1 to October 21, 1968, shows that evapotranspiration and soil-moisture deficiencies are high and recharge is practically negligible. On September 28, 1968, the small response to the 2.25 inches of precipitation reflects the large soil moisture deficiency due to previous drought. The interval between October 21 and October 30, 1968, was a favourable period during the autumn recharge cycle, and groundwater levels rose 5.37 feet in eight days, due to a total of 0.49 feet of precipitation. It is assumed that the "Lisse" effect is negligible because the 5.37 foot rise declined by only the normal recession rate to November 14. The "Lisse" effect is a rise of groundwater level due to the increased pressure of air entrapped in the vadose zone between the percolating water and the water table. For the same reason it is assumed that no air is entrapped in the aquifer pore spaces by rising groundwater (Rassmussen and Andreasen, 1959). Based on equation (4 - 16), the specific yield of the Upper Sandstone aquifer at well NB1A, is 0.091 for this period. This estimate together with the estimated specific yields of six other wells are listed in Table 4.

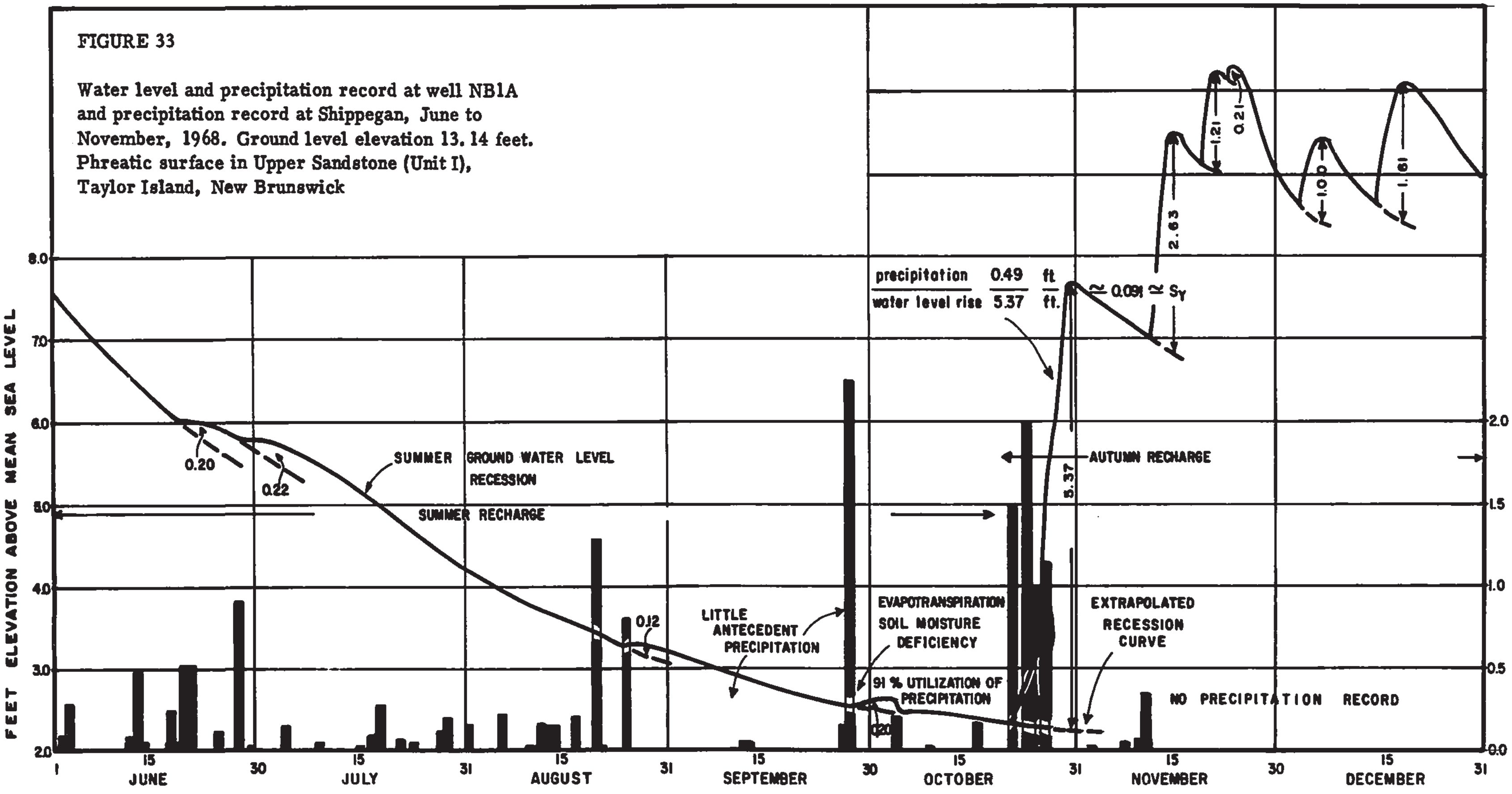


FIGURE 33

Water level and precipitation record at well NB1A and precipitation record at Shippegan, June to November, 1968. Ground level elevation 13.14 feet. Phreatic surface in Upper Sandstone (Unit I), Taylor Island, New Brunswick

TABLE 4

CALCULATED SPECIFIC YIELDS OF UPPER SANDSTONE (UNIT I)

Based on groundwater level response to precipitation during autumn recharge period of minimal evapotranspiration and soil-moisture deficiency. Surface runoff and detention are negligible.

Recharge and Precipitation Period	Well or Water Table Piezometer W.P.	Precipitation in Feet	Ground Water Level Rise in Feet	Specific Yield Sy
1968 Oct. 21 - Oct. 30	9 W	0.49	3.28	0.149
	NB 1A W	0.49	5.37	0.091
	NB 2A W	0.49	3.90	0.125
	61B W	0.49	4.98	0.098
	63C W	0.49	4.67	0.105
	64A W	0.49	3.38	0.145
	67B W	0.49	5.16	0.095
				mean Sy 0.115
1969 Nov. 3 - Nov. 15	4WA W	0.406	3.92	0.103
Nov. 3 - Nov. 14	NB 2C P	0.346	4.16	0.088
Nov. 3 - Nov. 14	61B W	0.406	4.23	0.096
Nov. 3 - Nov. 14	63C W	0.346	2.81	0.123
Nov. 3 - Nov. 14	64A W	0.346	2.78	0.125
Nov. 3 - Nov. 14	67B W	0.346	3.91	0.089
Nov. 3 - Nov. 14	83C P	0.346	3.43	0.101
Nov. 3 - Nov. 14	85D P	0.346	3.42	0.101
		mean rise	3.58	mean Sy 0.103
			grand mean Sy	0.108
			standard deviation =	0.02

A second similar favourable recharge period occurred between November 3 and November 7, 1969 (Figure 34). The precipitation, cumulative rise of groundwater levels and estimated specific yields for eight wells and piezometers for this period are listed in Table 4. Using this data for the 1968 and 1969 fall recharge periods, the mean specific yields of the Upper Sandstone aquifer are 0.115 and 0.103 respectively, giving a grand mean of 0.108. These numbers may be compared to the results of eighteen laboratory porosity tests made on Upper Sandstone specimens from ten locations. The mean porosity estimate is 0.129 (Table 2). Variability of the porosity determinations is much larger than that of the specific yield determinations, the respective best-estimate of population standard deviations being 0.08 and 0.02 respectively. The larger variance of porosity determined in laboratory analysis is undoubtedly due to the small sample size of the rock specimen compared to the large field sample size of the aquifer tested by water level response in specific yield determinations.

Student's t-distribution analysis based on the assumption that the two populations, that of porosity and that of specific yield, have identical standard deviations and means, gives results which are not significant at the 5 percent level of confidence, for the variates listed in Tables 2 and 4 (Alder and Roessler, 1964). The difference of 0.02 between the porosity and specific yield sample means

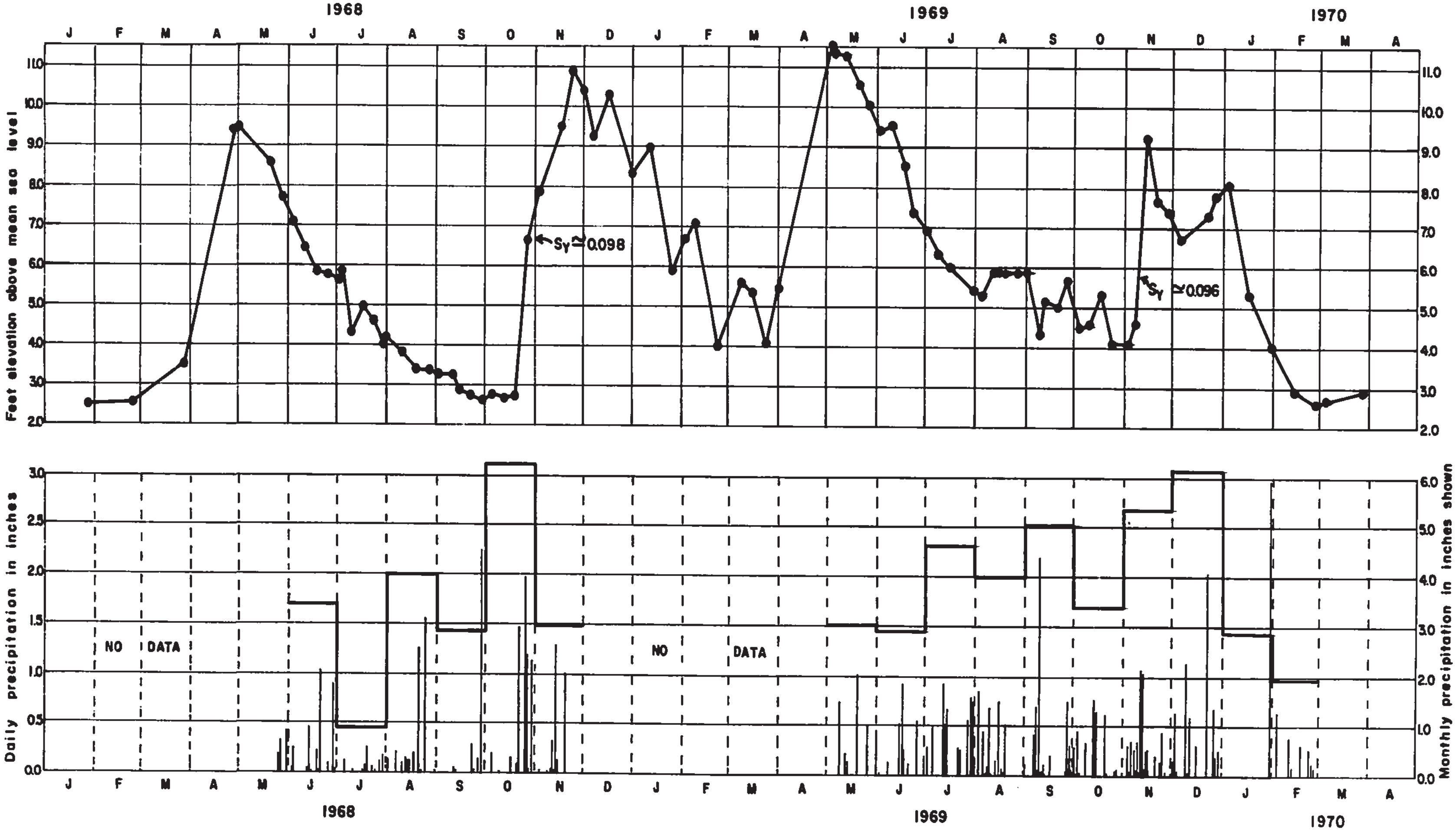


FIGURE 34

Water level record at well 61B and precipitation record at Shippegan, June, 1968 to May, 1970. Ground level elevation 13.50 feet. Phreatic surface in Upper Sandstone (Unit I), Taylor Island, New Brunswick appears to be a reasonable value for the specific retention, Sr, of the aquifer for this sort of material (Cohen, 1963).

4.7 Recharge Cycle

The determination of specific yields of the Upper Sandstone aquifer permits the quantitative determination of recharge from the water level rise on groundwater hydrographs measured from an extrapolated recession curve (Figure 33). Of particular importance is the cyclic nature of recharge. Recharge far exceeds discharge during October, November, December, March and April, whereas during the remaining months the converse is true. During the 60-day period October 21 to December 19, 1968, 13.1 inches or 29 percent of total annual precipitation was recharged into the Upper Sandstone aquifer at well NB1A (Figure 33). In contrast, during the 143-day period from June 1 to October 21, 1968, summer recharge at well NB1A amounted to 0.59 inches or less than 1.5 percent of total annual precipitation. The recession of groundwater levels during this time is due to the sum of evapotranspiration, groundwater discharge, and soil moisture retention being far in excess of recharge. Precipitation over this period was 12.8 inches or 28 percent of total annual precipitation.

No accurate determination of total annual recharge has been made for any budget year; however approximate recharge based on specific yields and groundwater hydrographs indicate that recharge is approximately 20 inches per year or about 50 percent of total annual precipitation (Figure 34).

4.8 Evaluation of Upper Sandstone Aquifer Response to Pumping with a Digital Model

The Pinder (1965) digital model for aquifer evaluation simulates the response of a confined or unconfined aquifer to pumping from one or more wells. The aquifer may be irregular in shape, non-homogeneous, and have recharge from lakes or streams through irregularly shaped boundaries.

The non-steady flow of water in a non-homogeneous porous aquifer can be written using Einstein's convention as follows (Pinder and Bredehoeft, 1968):

$$\frac{\partial}{\partial x_i}\left(T_{ij}\frac{\partial h}{\partial x_j}\right) = S\frac{\partial h}{\partial t} + \omega(x,y,t) \qquad \text{(eqn. 4 - 17)}$$

where: T_{ij} = the transmissibility tensor.

h = hydraulic head (L).

S = storage coefficient (ratio).

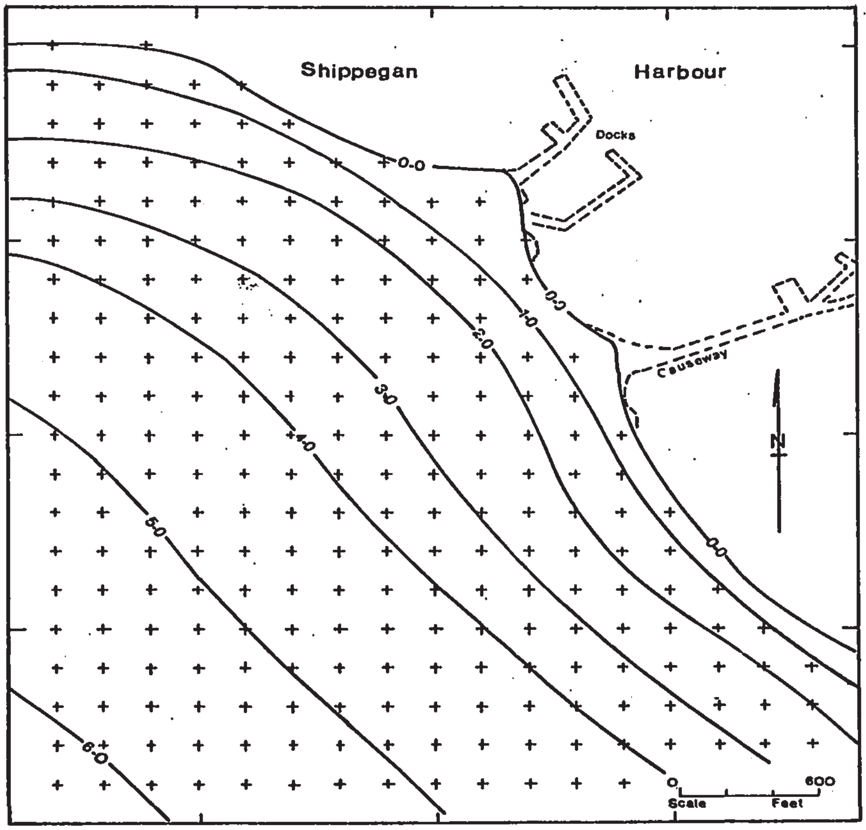
t = time.

ω = volume flux per unit area into or out of the system, the net effect of recharge and discharge from the aquifer due to other wells, leakage, or other causes.

The digital model solves a series of N, linear parabolic partial differential equations by means of a finite-difference technique. The equations are based on equation 4 - 17, and N is the number of nodes in the data matrix. A rectangular grid system with the field values of transmissibility (or permeability and aquifer thickness) and storage coefficient at each grid intersection are used to generate two matrices. A third matrix consists of the pumping rate at each grid intersection or node where a well is located and the permeabilities of stream or lake bottoms, where they occur. Other data such as the initial head in the aquifer is recorded. Printout includes the hydraulic head values resulting from drawdown, for each node influenced by pumping at the specified time since pumping started.

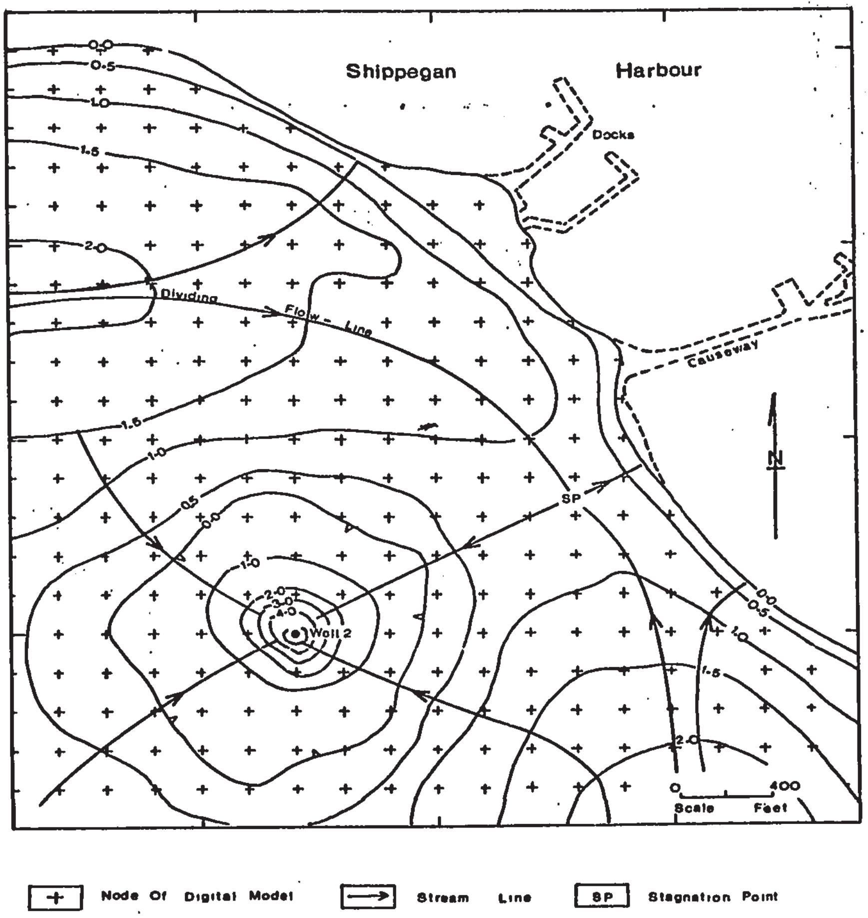
Figure 35 is a contoured map of assumed initial fresh-water heads in the Upper Sandstone aquifer within the town of Shippegan. The response to pumping at a rate of 1,495 imperial gallons per minute for 237 days at municipal well site 2 given by the Pinder digital model is shown by the cone of depression in Figure 36. It is apparent from the position of the limiting flow line and stagnation point (S.P.), which is located about 400 feet from Shippegan Harbour, that well 2 is in imminent danger of being contaminated by sea-water from Shippegan Harbour. Figure 36 may be compared to Figures 4 and 49 for geographic reference.

Figure 35: Contoured initial fresh-water heads in the Upper Sandstone aquifer (Unit I) in feet elevation above mean sea level, Shippegan, New Brunswick



Contour interval 10 feet

Figure 36: Modelled response of Upper Sandstone aquifer (Unit I) after steady pumping of municipal well 2 for 237 days at a rate of 1,495 imperial gallons per minute, Shippegan, New Brunswick



Fresh-water heads are contoured in feet above mean sea level. Contour interval 0.5 feet

CHAPTER V

5. TIDAL GROUNDWATER FLUCTUATIONS AS A BASIS FOR ESTIMATING AQUIFER CHARACTERISTICS

5.1 General

Fluctuations of water levels in wells and piezometers on Taylor Island, in response to cyclic changes of tide-water stage, can be measured to distances as great as forty-six hundred feet inland from the sea. The ratio of net rise or fall of groundwater range, s_r, over an observed period, to the net rise or fall of tidal water range, $2s_o$, gives the apparent tidal efficiency, TE_{App}. The time lag, t_1, from the inception of a given point on a train of tidal waves increases with distance, X, inland. If a confined aquifer is located directly under the sea, at the point of inception of the tidal wave train, where $t_1 = 0$, and $x = 0$, the change in load due to tidal fluctuations, according to the principle of effective stress, (Taylor, 1948, p. 222), is carried in part by the aquifer soil skeleton and in part by the confined intergranular water. Since the effective stress within the confined aquifer will be less than the total stress increment due to the tidal water loads, the amplitude of the groundwater fluctuation in a well penetrating the aquifer will be less than that of the tidal fluctuation. The ratio of these amplitudes is defined as true tidal efficiency.

TE_{true} (Jacob, 1950, p. 331).

5.2 Ferris Method of Tidal Analysis

Ferris (1952) described the theory and method of tidal analysis as a basis for estimating aquifer characteristics. Ferris assumed a homogeneous, fully saturated aquifer of uniform thickness, which extends infinitely inland from the sea, as a semisolid. Further, flow is considered to be unidimensional and the aquifer is fully penetrated by the surface water body that propagates the cyclic fluctuations at the sub-outcrop of the formation. The method is applicable to artesian aquifers in which the water is assumed to be released immediately with a decline of pressure at a rate proportional to that decline. However, the analysis is satisfactory for water-table aquifers where (1) the observation well is far enough from the sub-outcrop that it is unaffected by vertical components of flow and (2) the range in cyclic fluctuations at the observation well is only a small fraction of the saturated thickness of the formation.

The differential equation for head change within an aquifer in response to tidal fluctuations for the case of unidimensional flow is given as follows by Ferris (1952, p. 286).

$$\frac{\partial^2 s}{\partial x^2} = \frac{S}{T} \frac{\partial s}{\partial t} \qquad \text{(eqn. 5 - 1)}$$

where: s = net rise or fall of groundwater stage with reference to mean stage over an observed period.

x = distance from sub-outcrop to observation well.

t = time elapsed from convenient reference point within any tidal wave train cycle.

S = coefficient of storage (ratio).

T = coefficient of transmissibility.

$\frac{T}{S}$ = diffusivity.

With boundary conditions

$$x = 0, \quad s = s_0 \sin Wt$$
$$x \longrightarrow \infty, \quad s \longrightarrow 0$$

where: s_0 = the amplitude or half range of the fluctuation of the surface body.

W = angular velocity.

t_0 = tidal period.

$$W = \frac{2\pi}{t_0} \qquad \text{(eqn. 5 - 2)}$$

The solution of the differential equation is given by Jacob (1950, p. 365) as follows:

$$s = s_0 \exp.\left[-x\sqrt{\pi S/t_0 T}\right] \sin\left(\frac{2\pi t}{t_0} - x\sqrt{\pi S/t_0 T}\right) \qquad \text{(eqn. 5 - 3)}$$

Equation (5 - 3) describes a wave motion whose amplitude, or half-range, s_0 , rapidly decreases with a distance X by a factor $s_0 \exp.\left[-x\sqrt{\pi S/t_0 T}\right]$ (eqn. 5 - 4)

From equation (5 - 3) it follows that the time lag required for a particular crest or trough of a wave to travel a distance X inland from sub-outcrop is given by:

$$Lag = t_1 = x\sqrt{\frac{t_o S}{4\pi T}} = x\sqrt{\frac{t_o S_s}{4\pi K}} \qquad \text{(eqn. 5 - 5)}$$

Apparent tidal efficiency, TE_{App}, due to transmission of head changes at sub-outcrop is determined by the ratio of range of groundwater fluctuations, s_r , of an observation well at distance X from sub-outcrop to the range of a fluctuating surface water body $2s_o$, and is given by Ferris (1952) as:

$$TE_{App} = \frac{s_r}{2s_o} = \exp.\left[-x\sqrt{\frac{\pi S}{t_o T}}\right] \qquad \text{(eqn. 5 - 6)}$$

A plot of log TE_{App} versus X will yield a straight line declining from $(x = 0,\ TE_{App} = 1)$ to $(X \longrightarrow \infty, TE_{App} \longrightarrow 0)$ for a given value of $\frac{S}{T}$.

It follows that:

$$\frac{S}{T} = \frac{t_o (\log_e TE_{App})^2}{\pi x^2} \qquad \text{(eqn. 5 - 7)}$$

By combining equations (5 - 6)and (5 - 7)

$$TE_{App} = - \exp.\left[\frac{2\pi t_1}{t_o}\right] \qquad \text{(eqn. 5 - 8)}$$

Equation (5 - 6) can be expressed in U.S. gallons per-day-per-foot units as follows:
(Ferris, 1952)

$$2.1\sqrt{\frac{S}{t_oT}} = \frac{-\log_{10}(\Delta r/2\Delta_o)}{X} \qquad \text{(eqn. 5 - 9)}$$

A plot of the logarithm of TE_{App} or $\frac{\Delta r}{2\Delta_o}$ versus the distance of each observation well from the sea-shore, will yield a straight line distribution of points if the aquifer is unconfined. The slope of this line is the right-hand side of the equation (5 - 9) as shown in Figures 37 and 38. If the logarithm of TE_{App} is taken over one log cycle, equation (5 - 9) becomes:

$$2.1\sqrt{\frac{S}{t_oT}} = -\frac{1}{\Delta\overline{X}} \qquad \text{(eqn. 5 - 10)}$$

where: $\Delta\overline{X}$ = the corresponding distance in feet over the logarithm cycle.
The equation in imperial gallons-per-day-per-foot units reduces to:

$$\frac{T}{S} = \frac{3.67\,(\Delta\overline{X})^2}{t_o} = \frac{K}{S_s} \qquad \text{(eqn. 5 - 11)}$$

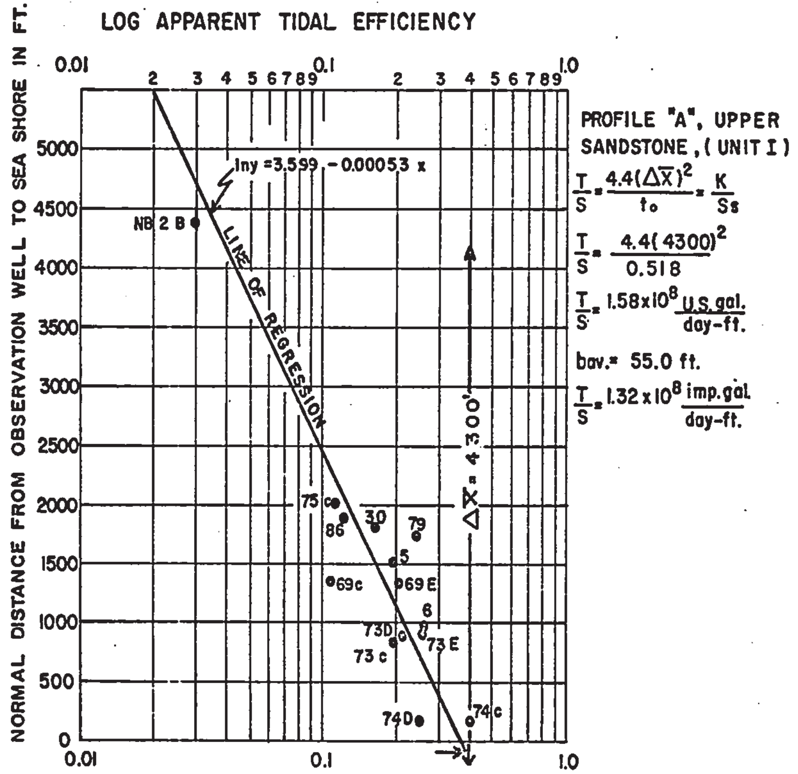
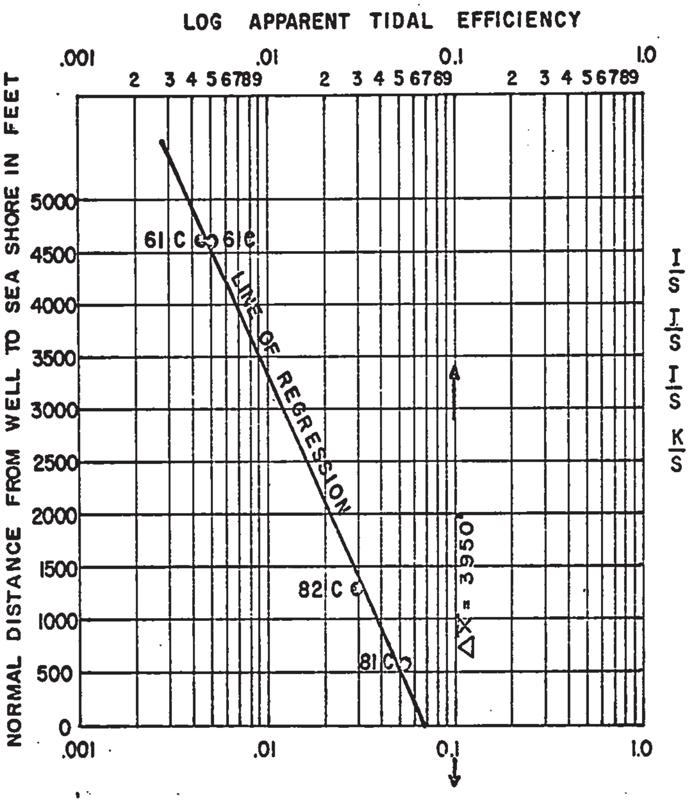


FIGURE 37:

Plot of the normal distance of observation wells to the sea shore against the log of apparent tidal efficiency



PROFILE "C" UPPER SANDSTONE (UNIT I)

$b_{AV} = 78$ ft.

$$\frac{T}{S} = \frac{4.4(\Delta \overline{X})^2}{t_0}$$

$$\frac{T}{S} = 1.33 \times 10^8 \, \frac{\text{U.S. gal.}}{\text{day-ft.}}$$

$$\frac{T}{S} = 1.11 \times 10^8 \, \frac{\text{imp. gal.}}{\text{day-ft.}}$$

$$\frac{K}{S} = 1.43 \times 10^6 \, \frac{\text{imp.gal.}}{\text{day-ft.}^2}$$

FIGURE 38:

Plot of the normal distance of observation wells to the sea shore against the log of apparent tidal efficiency where: S = storage coefficient of the aquifer.

S_s = specific storage, feet^{-1}.

K = coefficient of permeability in imperial gallons-per day-per square foot.

If the aquifer response is due to loading at sub-outcrop above a confined aquifer, rather than head changes due to direct transmission at sub-outcrop, the amplitude factor of equation (5 - 4) should be multiplied by $[\alpha/(\alpha+\theta\beta)]$ which is true tidal efficiency. TE_{true} (Ferris, 1952; Jacob, 1950, p. 356).

$$TE_{true} = \left[\alpha/(\alpha + \theta\beta)\right] \quad \text{(eqn. 5 - 12)}$$

where: α = vertical compressibility of the aquifer in ft.^{2}/lb.

β = compressibility of water in ft.^{2}/lb.

θ = porosity of the aquifer (ratio).

The value of α may vary considerably from one aquifer to another aquifer; the best estimate of its value is determined from pump-test analyses where the storage coefficient S, is expressed as:

(De Wiest, 1965, p. 185)

$$S = S_s \cdot b = \gamma b\left[\alpha + \theta\beta\right] \quad \text{(eqn. 5 - 13)}$$

where: S_s = specific storage, feet^{-1}.

γ = specific weight of water, lb_f. per ft.^{3}.

b = aquifer thickness, feet.

By combining equations (5 - 12) and (5 - 13), is given as: (DeWiest, 1965)

$$S = \frac{\theta \beta b \gamma}{1 - TE_{true}} \qquad \text{(eqn. 5 - 14)}$$

For confined aquifers, the sum of true tidal efficiency and barometric efficiency (BE) equals one. (Jacob, 1950)

$$TE_{true} + BE = 1 \qquad \text{(eqn. 5 - 15)}$$

and hence $TE_{true} < 1.0$ at $X = 0$. For aquifers which are unconfined or which respond to transmission of head change at sub-outcrop, $TE_{true} = 1.0$. In such aquifers there is no tidal loading and sea-water has free access at sub-outcrop to the aquifer. The value of TE_{true} may be determined from pump test data and geological interpretation by means of equations (5 - 12) and (5 - 13) as shown in Table 7.

The apparent tidal efficiency of a confined aquifer from equations (5 - 6) and (5 - 12) is:

$$TE_{App} = TE_{true} \cdot \exp\left[-x\sqrt{\frac{\pi S}{t_o T}}\right] \qquad \text{(eqn. 5 - 16)}$$

$$TE_{App} = TE_{true} \cdot \exp\left[-x\sqrt{\frac{\pi S_s}{t_o K}}\right] \qquad \text{(eqn. 5 - 17)}$$

For $X = 0$, $TE_{App} = TE_{true} < 1.0$.

By substituting equation (5 - 5) into equation (5 - 16), (Carr and Van der Kamp, 1969).

$$TE_{true} = TE_{App} . \exp\left[2\pi t_1 / t_0\right] \quad \text{(eqn. 5 - 18)}$$

Equations 5 - 14, 5 - 16, and 5 - 18, show that measurements of time lag, t_1, and apparent tidal efficiency permit the calculation of TE_{true}, specific storage, and permeability (Carr and Van der Kamp, 1969, p. 1023 - 1024).

By rearranging equation (5 - 5) (Ferris, 1952)

$$\frac{T}{S} = \frac{x^2 t_0}{4\pi t_1^2} = \frac{K}{S_s} \quad \text{(eqn. 5 - 19)}$$

For T in imperial gallons-per-day-per foot, t_0 and t_1 in days, equation (5 - 18) becomes:

$$\frac{T}{S} = \frac{0.55\, t_0 (\overline{\Delta x})^2}{t_1^2} = \frac{K}{S_s} \quad \text{(eqn. 5 - 20)}$$

An arithmetic plot of the distance of observation wells from the sea shore and the corresponding values of time, t_1, gives a straight line distribution of points, the slope of which is $(\overline{\Delta x})^2/t_1$ The intersection of the straight regression line at $t_1 = 0$, with the distance axis, gives the distance to sub-outcrop from the sea shore (Figure 41).

5.3 Discussion of Tidal Analysis Results

An example of the variations of observed apparent tidal efficiencies and time lags for piezometer 74C is shown in Figure 40 while the mean observed apparent tidal efficiency is given in Table 5. Tidal fluctuations measured by a

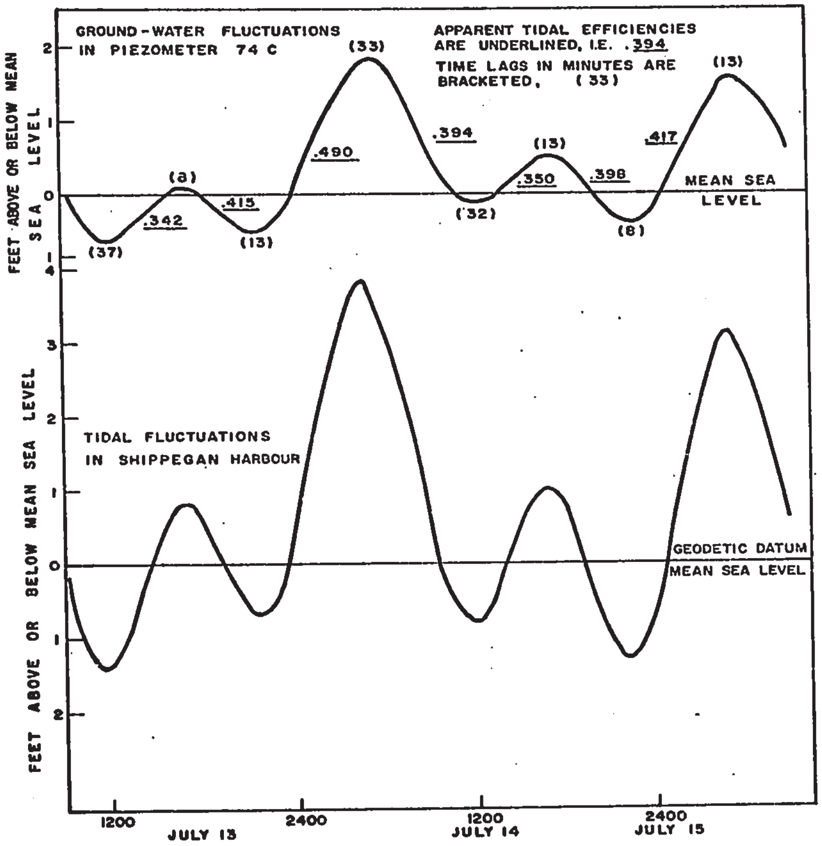


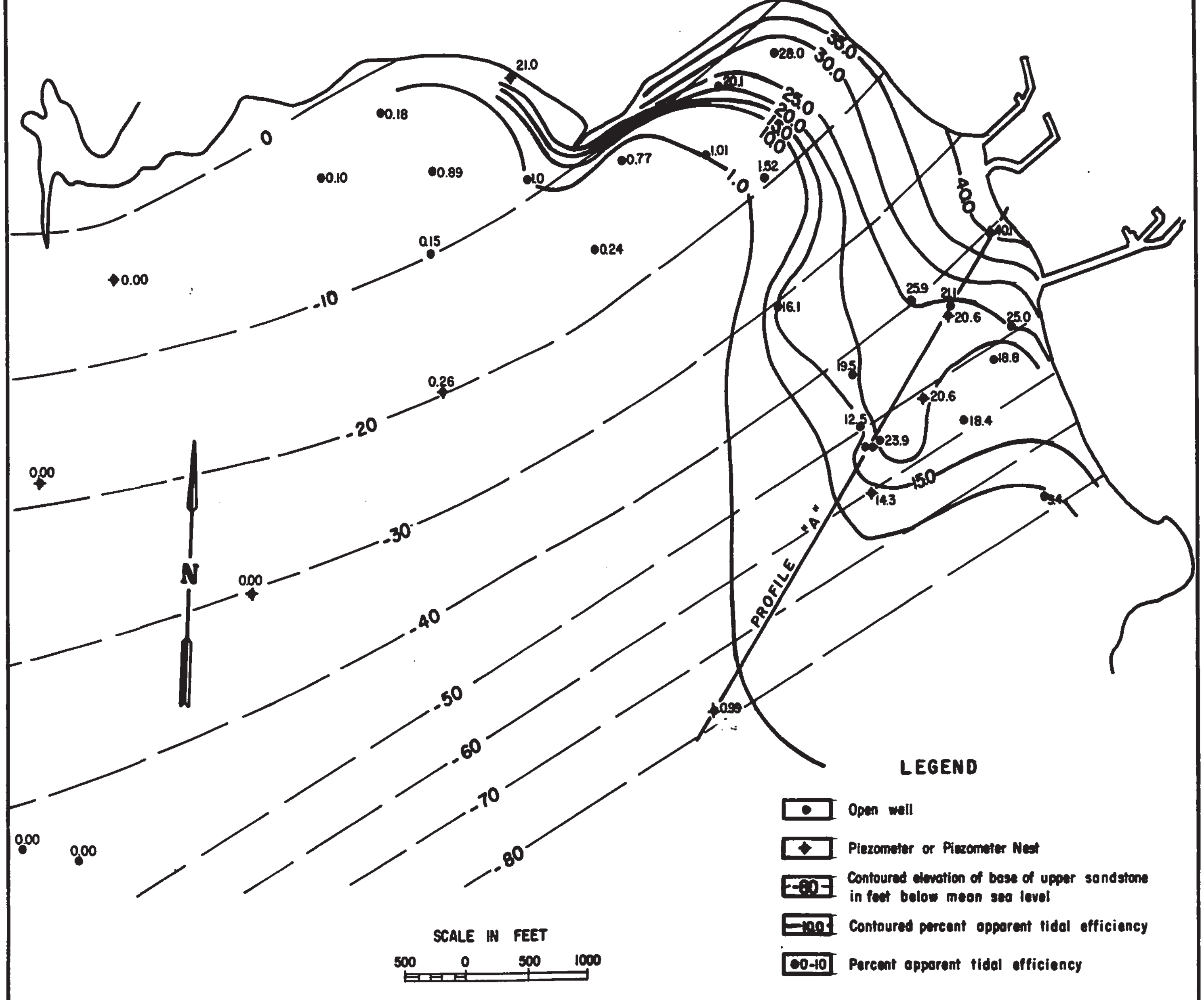
Figure 39

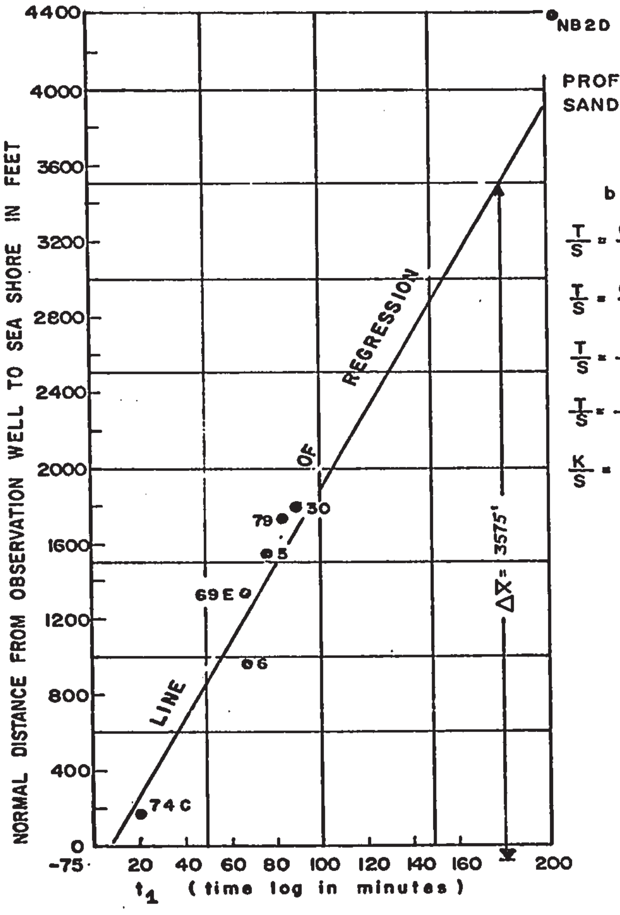
Tidal fluctuations in Shippegan harbour and corresponding groundwater level fluctuations in piezometer 74C, Upper Sandstone aquifer (Unit I) tidal gage on Shippegan Harbour (Figure 39) show a mixed, mainly semi-diurnal tide, with two complete tidal oscillations daily, unequal in height, and an average period of about 745 minutes (Table 5). Values of the observed groundwater level response in the Upper Sandstone aquifer measured with a type F Stevens Recorders and Keck water-level sensing devices which are converted to apparent tidal efficiencies are shown in Figure 40. The apparent tidal efficiency contours demonstrate that the tidal-wave train extends furthest inland along profile "A" (Figure 4). This effect is largely due to the attitude and thickness of the Upper Sandstone aquifer which is present under profile "A" but which thins rapidly in the northwestern section of the area shown in Figure 10.

Diffusivities were determined for profiles "A" and "C", Figures 37 and 38, according to equation 5 - 10, from an arithmetic plot of time lag versus distance of observation wells from the sea shore. The respective values of 1.32×10^8 and 1.11×10^8 imperial gallons-per day-per foot are of the same order of magnitude as the mean diffusivity values determined by pump-test analysis (Table 6). Seven open wells and a piezometer located on or near profile "A" (Table 8), were selected for analysis using the method of linear relationship of time-lag as a function of distance from sea shore, as shown in Figure 41. The regression line through data points gives an off-shore distance to sub-outcrop of 75 feet, at which distance $t_1 = 0$.

FIGURE 40

APPARENT TIDAL EFFICIENCIES IN PERCENT, AND ELEVATIONS OF UPPER SANDSTONE (UNIT I), SHIPPEGAN, NEW BRUNSWICK





PROFILE "A", UPPER SANDSTONE (UNIT I)

b = 55 ft.

$$\frac{T}{S} = \frac{0.60\ \Delta\overline{X}^2 t_0}{t_1^2}$$

$$\frac{T}{S} = \frac{0.60 \times (3500)^2 \times 0.518}{(3/24)^2}$$

$$\frac{T}{S} = 3{\cdot}8 \times 10^8\ \frac{\text{U.S. gal.}}{\text{day-ft.}}$$

$$\frac{T}{S} = 3{\cdot}2 \times 10^8\ \frac{\text{imp.-gal.}}{\text{day-ft.}}$$

$$\frac{K}{S} = 5{\cdot}8 \times 10^6\ \frac{\text{imp.-gal.}}{\text{day-ft.}^2}$$

Figure 41: Plot of tidal time lag, t_1, against the normal distance from observation well to the sea shore in feet.

Eight pump test analyses in wells 2 and 33 near profile "A" (Table 3) gave a mean value of permeability of 9.08×10^3 imperial gallons-per day-per square foot, the maximum and minimum values being 1.36×10^4 and 5.1×10^3 respectively. In Figure 19, a Theis non-equilibrium distance-drawdown type-curve fit of data points from observation wells around pumping well 2, gives a permeability of 8.5×10^3, a storage coefficient of 9.4×10^{-4}, a specific storage of 1.65×10^{-5}, and a diffusivity of 5.2×10^8. The radius of the cone of depression extends to 1.5×10^3 feet after 10 minutes of pumping. Calculated values of the Upper Sandstone aquifer compressibility, α, is 8.4×10^{-4} square feet per pound which in turn gives a true tidal efficiency of 1.0 (Table 7). The magnitude of TE_{true}, indicates that tidal fluctuations in the Upper Sandstone aquifer may be regarded as due to transmission of head changes at sub-outcrop in Shippegan Harbour. Tidal loading which causes an increase of effective stress, pore water pressures and an artesian response, does not appear to take place.

The values of the Upper Sandstone aquifer characteristics determined by equation (5 - 18) and equation (5 - 19) with the specific storage value given above, are listed in Tables 6 and 7. Coefficients used with these equations include a mean value of porosity of 0.13, a groundwater compressibility at 7° C of 2.32×10^{-8} square feet per pound, and a specific weight of water of 62.4 pounds per cubic foot.

TABLE 5

VARIATIONS OF OBSERVED APPARENT TIDAL EFFICIENCIES AND TIME LAGS OF PIEZOMETER 74C, JULY 13 TO 15, 1969

	TIDAL GAGE			PIEZOMETER				
Date 1969	Time in Hours & Minutes of Tidal Peak (P) or Trough (T)		Tidal Range Difference in Feet	Time in Hours & Minutes of Piezometer Trough or Peak		Piezometer Stage Difference in Feet	Observed Apparent Tidal Efficiency	Time Lag In Minutes
July								
13	1100	T	2.25	11:37	T	0.77	0.342	37
13	1644	P	1.52	16:52	P	0.63	0.415	8
13	2124	T	4.82	21:37	T	2.36	0.490	13
14	449	P	4.96	5:22	P	1.95	0.394	33
14	1209	T	1.83	12:41	T	0.64	0.350	32
14	1639	P	2.31	16:52	P	0.92	0.398	13
14	2214	T	4.63	22:22	T	1.93	0.417	8
15	4.54	P		5:07	P			13
Mean Semidiurnal Tidal period = 750 minutes							Mean = 0.401	Mean = 19.1

TABLE 6

VALUES OF AQUIFER CHARACTERISTICS OF UPPER SANDSTONE DETERMINED BY TIDAL TIME LAG WITH SPECIFIC STORAGE DETERMINED FROM PUMP TEST ANALYSES

Open Well, O or Piezometer, P		X, Distance From Sub-outcrop, Ft.	t_1 Time Lag Minutes	Apparent Velocity Feet Per Minute	T.E. App.	$\frac{S}{T}=\frac{S_s}{K}=\frac{4\pi t_1^2}{t_0 X^2}$ Minutes per Sq. Ft.	Ss, Specific Storage Ft.$^{-1}$	K, Permeability Ft. Per Minute	K Ft. Per Day	K Imp. Gpd. Per Sq. Ft.	$\frac{T}{S}=\frac{K}{S_s}$ Imp. Gpd. Per Ft.
74C	P	255	19	13.4	0.401	9.35×10^{-5}	1.6×10^{-5}	1.7×10^{-1}	245	1.53×10^{3}	9.5×10^{7}
6	0	1035	83	12.5	0.259	1.08×10^{-5}	1.6×10^{-5}	1.48	2140	1.33×10^{4}	8.3×10^{8}
69E	P	1425	67	21.2	0.206	3.72×10^{-5}	1.6×10^{-5}	4.30×10^{-1}	620	3.86×10^{5}	2.4×10^{8}
5	0	1635	77	21.2	0.195	3.72×10^{-5}	1.6×10^{-5}	4.30×10^{-1}	620	4.17×10^{3}	2.4×10^{8}
79	0	1815	83	21.8	0.239	3.51×10^{-5}	1.6×10^{-5}	4.70×10^{-1}	670	3.56×10^{3}	2.6×10^{8}
30	0	1875	92	20.4	0.161	4.04×10^{-5}	1.6×10^{-5}	3.96×10^{-1}	570	4.05×10^{3}	2.5×10^{8}
NB2D	P	4465	205	21.8	0.295	3.53×10^{-5}	1.6×10^{-5}	4.50×10^{-1}	650	4.90×10^{3}	2.5×10^{8}
				Mean 18.9						Mean 4.90×10^{3}	Mean 3.1×10^{8}

TABLE 7

VALUES OF AQUIFER CHARACTERISTICS OF UPPER SANDSTONE DETERMINED BY APPARENT TIDAL EFFICIENCIES WITH SPECIFIC STORAGE DETERMINED FROM PUMP TEST ANALYSES

Open Well, O or Piezometer, P		X, Distance From Sub-outcrop in Ft.	t_1, Time Lag Minutes	Apparent Velocity Feet Per Minute	T.E. App.	$\frac{S}{T}=\frac{S_s}{K}=t_0\frac{(\ln T.E._{app})^2}{\pi x^2}$ Min. Per Sq. Ft.	Ss, Specific Storage Ft.$^{-1}$	K, Permeability Ft. Per. Min.	K, Ft. Per Day	K, Imp. Gpd. Per Sq. Ft.	$\frac{T}{S}=\frac{K}{S_s}$ Imp. Gpd. Per Ft.
74C	P	255	19	13.4	0.401	3.07×10^{-3}	1.6×10^{-5}	5.2×10^{-3}	7.5) to close		
6	O	1035	83	12.5	0.259	9.25×10^{-3}	1.6×10^{-5}	1.73×10^{-3}	2.5) to sub-outcrop		
69E	P	1425	67	21.2	0.206	3.95×10^{-5}	1.6×10^{-5}	4.05×10^{-1}	5.85×10^{2}	3.64×10^{3}	2.28×10^{8}
5	O	1635	77	21.2	0.195	3.70×10^{-5}	1.6×10^{-5}	4.33×10^{-1}	6.24×10^{2}	3.89×10^{3}	2.44×10^{8}
79	O	1815	83	21.8	0.239	1.34×10^{-6}	1.6×10^{-5}	1.19	17.10×10^{2}	1.07×10^{4}	6.7×10^{7}
30	O	1875	92	20.4	0.161	4.60×10^{-5}	1.6×10^{-5}	3.49×10^{-1}	5.03×10^{2}	3.14×10^{3}	1.96×10^{8}
NB2D	P	4465	205	21.8	0.295	3.04×10^{-6}	1.6×10^{-5}	5.27×10^{-1}	7.60×10^{2}	4.73×10^{3}	2.96×10^{8}
										Mean 5.22×10^{3}	Mean 2.06×10^{8}

S determined from Theis non-equilibrium artesian distance-drawdown type curve (Figure 20), August 16, 1969

Diffusivity $=\frac{T}{S}=\frac{K}{S_s}= 5.15 \times 10^{8}$

Storage Coefficient $= S = 9.4 \times 10^{-4} = \gamma b(\alpha+\theta\beta) = 62.4 \quad (\alpha + 0.13 \times 2.13 \times 10^{-8})$

Aquifer Compressibility $= \alpha = 8.4 \times 10^{-6}$ ft.^{2} per lb$_f$.

$TE_{true} = \frac{\alpha}{\alpha+\theta\beta} = 1.0$, therefore tidal response is due to head change at sub-outcrop rather than loading of a confined aquifer

$TE_{true} + BE = 1.0, \ BE = 0.0$

Specific Storage $= S_s = \frac{S}{b} = \frac{9.2 \times 10^{-4}}{57} = 1.6 \times 10^{-5}$ ft.$^{-1}$

Mean values of permeability determined by time lags and apparent tidal efficiencies are 4.90 x 10^3 and 5.22 x 10^3 respectively, compared to the mean value of seven pump tests given of 9.08 x 10^3 imperial gallons per day per square foot. Mean diffusivity values determined by time lags and apparent tidal efficiencies are 3.1 x 10^8 compared to the pump test value given above of 5.2 x 10^8 imperial gallons per day per foot. All results are of the correct order of magnitude. Discrepancies in permeability values determined by the tidal method of analysis and pump test analysis are probably related to the value of the storage coefficient employed.

Analysis of the Upper Sandstone aquifer by the Carr and Van der Kamp (1969) method for confined aquifers gives permeability values and specific storage values which are smaller by two orders of magnitude than those given above. The successful application of this variant of the Ferris (1951) method of tidal analysis is probably dependent upon the calculation of α and TE_{true} from pump test analysis and an estimate of the distance from the sea shore to sub-outcrop.

CHAPTER VI

6. NATURAL GROUNDWATER FLOW REGIME OF TAYLOR ISLAND

6.1 The Flow System

The groundwater heads in open wells and shallow piezometers at any given time define the phreatic surface at those points. Contours of the phreatic surface at Taylor Island (Figures 42 and 43) show a central groundwater mound or ridge which extends from Gull Lake, northwestward along the topographic axis of Taylor Island. Groundwater heads fall away coastward in all directions from the mound in conformity to the gentle decline of the land surface. Flow directions are shown as streamlines normal to the groundwater head contours. During the high stage periods of spring or autumn recharge, the central portion of the groundwater mound near Gull Lake rises to elevations of over 10 feet, whereas near the end of the summer or winter groundwater recession cycle, the central portion of the groundwater mound falls to elevations as low as 4.5 feet. Pumping of coastal well fields is especially hazardous with regard to sea-water intrusion during the low stage periods, when the fresh-water heads in the Upper Sandstone aquifer are minimal.

On the long axis of the central groundwater mound, the groundwater divide is situated closer to Basse Bay than

Figure 42: Phreatic surface, Taylor Island, New Brunswick, groundwater heads in feet above mean sea level during high stage, June 23, 1969
contour interval = 1 foot

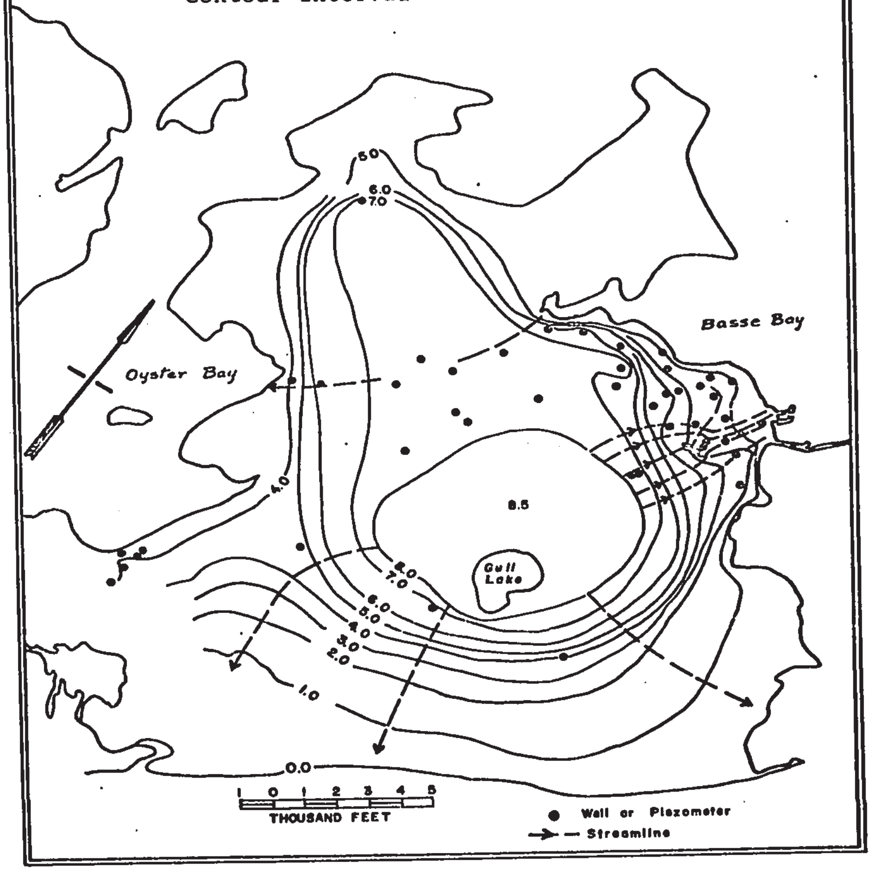
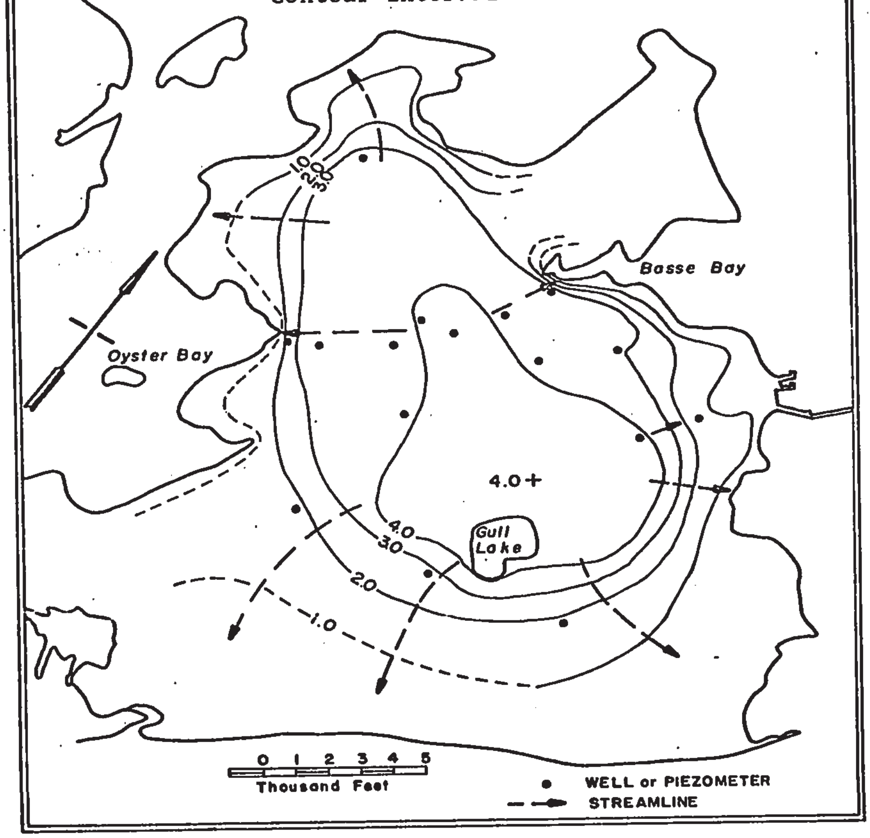


FIGURE 43

Phreatic surface, Taylor Island, New Brunswick, groundwater heads in feet above mean sea level during low stage, February 27, 1970.
Contour interval = 1 foot



Oyster Bay as shown in Figures 44 and 45. Groundwater heads in profile "B" indicate that the divide shifts with depth toward Basse Bay, whereas heads in profile "D" indicate a shift of the divide with depth toward Oyster Bay. The controlling factors in the assymetric position of the divide on Taylor Island is the attitude of the base of the Upper Sandstone aquifer, which dips southerly and away from Basse Bay. The edge of the Upper Sandstone unit at the seashore on Basse Bay thinned by erosion severely restricts the discharge of groundwater into Basse Bay, and causes the bulk of flow to discharge in the opposite direction.

The permeability ratio between the Middle Claystone and Lower Sandstone units, based on the application of Darcy's equation and continuity over regions ABED and BCFE (Figure 44), is in the order of 1.0 to 1.6 x 10^5. The permeability ratio between the Middle Claystone and Upper Sandstone determined by slug tests and pump tests are 1.0 to 8.4 x 10^7 respectively (Figure 31). Leakage through the Middle Claystone unit is slow. The permeability determined by the Hvorslev (1951) method is 3.48 x 10^{-8} cm. per second (under a unit gradient of one foot per foot), or 6.24 x 10^{-4} imperial gallons per day per square foot at piezometer 85B. Consequently the transfer of large quantities of water from the Upper Sandstone aquifer through the Middle Claystone aquiclude to the Middle Sandstone or Lower Sandstone aquifers (Figure 42) is a function of both surface area of the aquiclude and time. It is apparent from the permeabilities cited that fracture flow involving small head losses in the Middle Claystone unit is not an important flow process.

As a consequence of the large permeability contrast between the sandstone and claystone units, flow vectors within the Upper and Middle Sandstone aquifers are nearly horizontal and flow vectors within the Middle Claystone aquiclude are nearly vertical (Figs. 4 & 44) According to the relative values of permeability cited and the piezometric gradients shown in Figure 44, the volume of discharge per unit time Q , calculated by Darcy's equation, must be several orders of magnitude greater through the Upper Sandstone aquifer than through the Middle Claystone aquiclude. From the above it is concluded that most of the annual recharge on Taylor Island, which is derived directly from local precipitation, is transferred directly through the Upper Sandstone aquifer to the coastal discharge areas. Conversely, the proportion of recharge which flows from the Upper Sandstone and through the Middle Claystone must be an extremely small part of total annual recharge to the Upper Sandstone.

6.2 Ghyben-Herzberg Lens and the Transition Zone

In profile "B", (Figures 4 and 44), brackish water containing 86 ppm chloride, at a depth of 218 feet in well NB1A, July 3, 1969, indicates that the position of the mean isochlor (8,500 ppm) in the transition zone at the base of

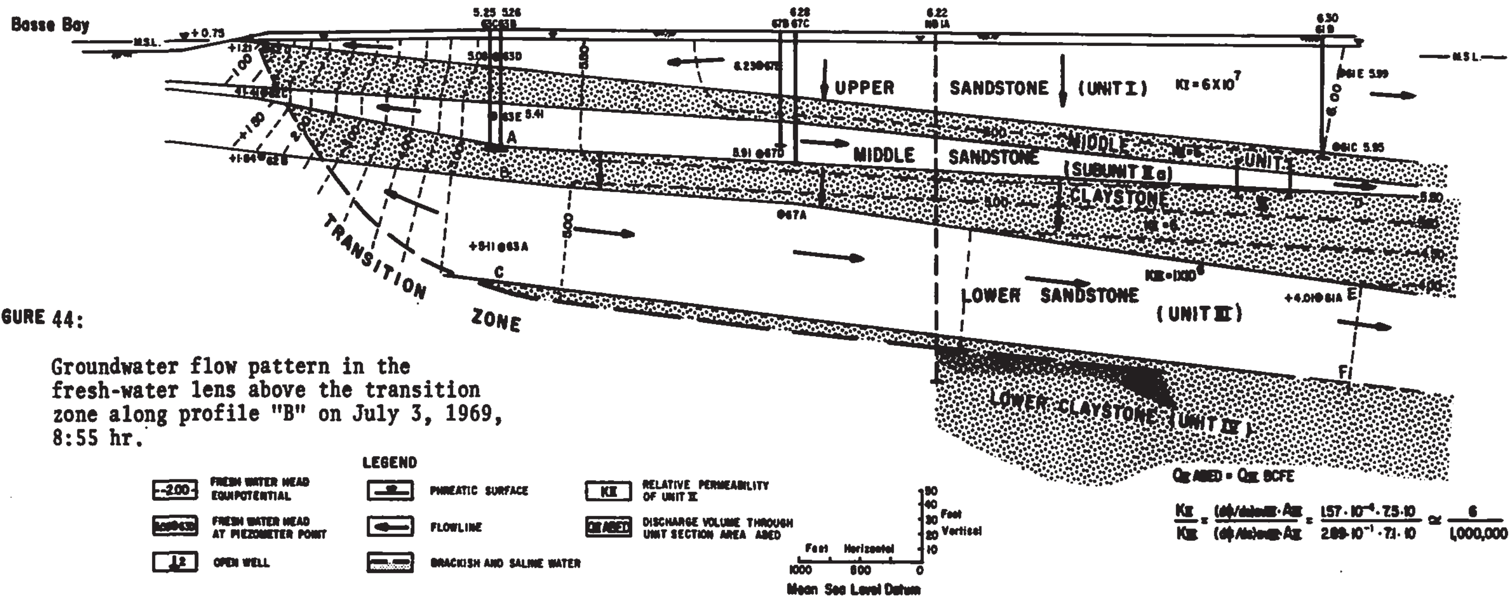


FIGURE 44:

Groundwater flow pattern in the fresh-water lens above the transition zone along profile "B" on July 3, 1969, 8:55 hr.

the bi-convex fresh water lens is probably located at a depth of about 270 feet below mean sea level, as would be expected from the Ghyben-Herzberg equation (Davis and De Wiest, 1966). In profile "D", (Figures 30, 45 and 46) the transition zone at the base of the bi-convex fresh water lens or Ghyben-Herzberg lens was not reached as all boreholes produced only fresh water samples. The exact position and thickness of the transition zone can only be determined by future drilling of deeper wells.

Chloride values at a depth of 218 feet in well NB1A changed only from 85 to 91 ppm, between May 15 and August 14, 1969; the position of the 30 ppm isochlor (chosen to mark the border of the transition zone) changed from a depth of 340 feet below ground level to a depth of 205 feet below ground level. This movement of the transition zone, over a vertical range of at least 35 feet, indicates that long term changes in the position, and possibly thickness of the transition zone take place in adjusting to the hydrostatic balance.

Wentworth (1942) has concluded that because the ratio between storage in the Ghyben-Herzberg bi-convex fresh water lens above mean sea level (top storage) and below mean sea level (bottom storage) is one to forty units, all changes in bottom storage must lag considerably behind changes in top storage. For storage changes involving large volumes this time lag must amount to months or even years. The time lag is due to the time required for recharge from top storage

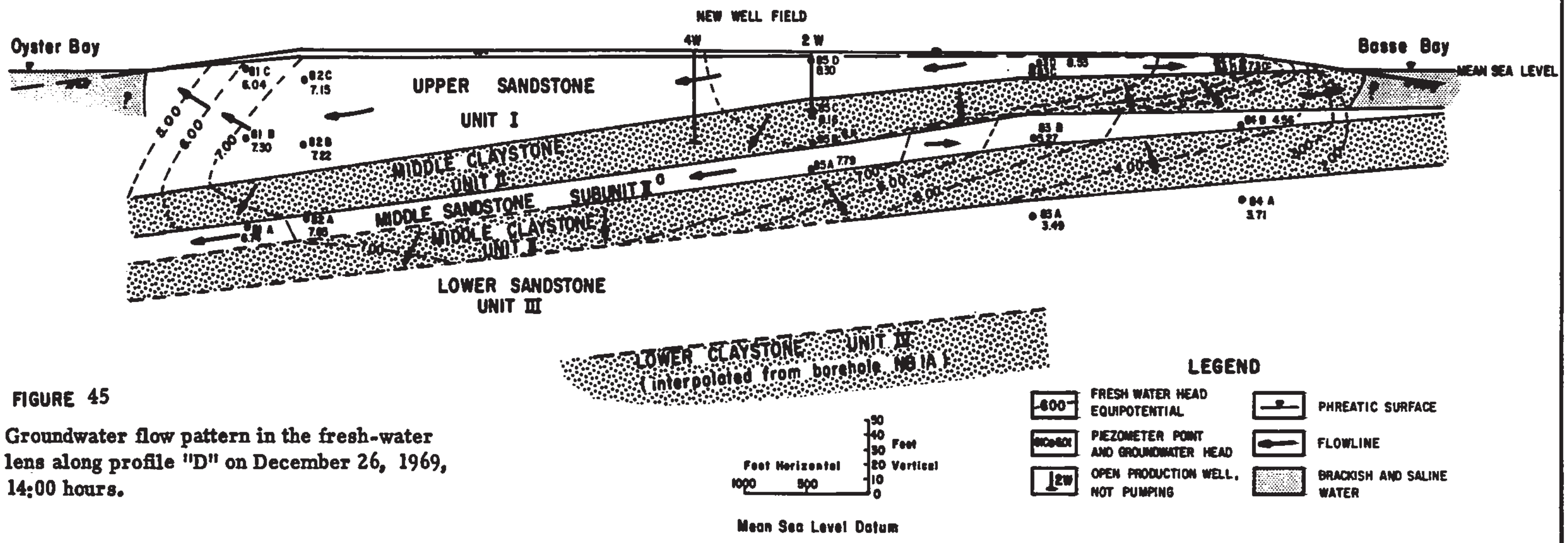


FIGURE 45

Groundwater flow pattern in the fresh-water lens along profile "D" on December 26, 1969, 14:00 hours.

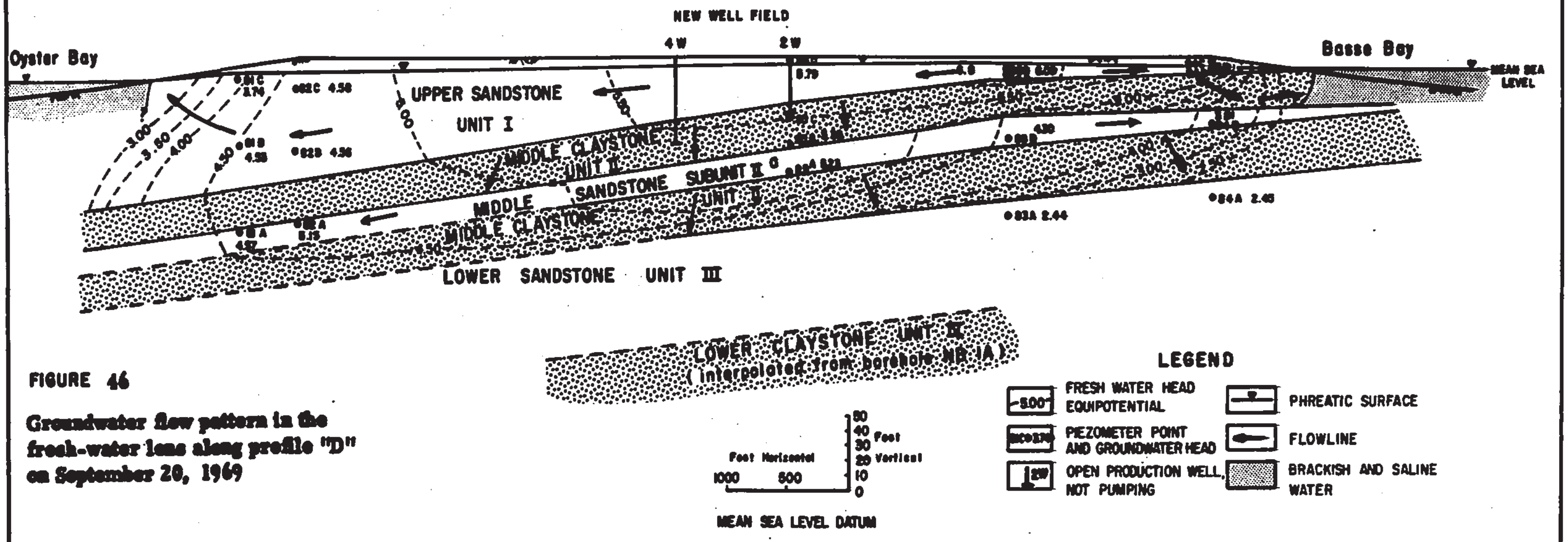


FIGURE 46

Groundwater flow pattern in the fresh-water lens along profile "D" on September 20, 1969

to enter into bottom storage to correct for excess fresh water heads which exist, and for bottom storage water to move upward under the buoyant hydrostatic pressure of sea water during periods of deficient fresh water heads. In a multilayered aquifer-aquiclude system, such as at Taylor Island, large permeability contrasts between the sandstone and claystone units would tend to increase the time lag, and short-term fluctuations of top storage are not reflected by short-term changes in bottom storage.

Brackish water 140 ppm cloride at a depth of 260 feet in well NB2A, December 20, 1967, indicated that an 8,500 ppm isochlor is probably located at a depth of about 340 feet below mean sea level, according to the Ghyben-Herzberg equation. The presence of brackish water at this depth in 1967 was indicated by the reduction of resistivity values in the electric log of this well, as shown in Figure 9. Sampling at depths between 200 and 280 feet during August, 1968, and between May and August, 1969, failed to reveal the presence of brackish water (Figures 45 and 46). Hence the position of the upper part of the transition zone appears to fluctuate by at least 80 feet at well NB2A. The error in the Ghyben-Herzberg estimate of the position of the hypothetical fresh salt water interface or the mean isochlor, due to dynamic flow as discussed by Davis and De Wiest (1966, p. 240) should be minimal at this depth, where flow gradients are undoubtedly small.

The presence of a bi-convex Ghyben-Herzberg fresh water lens in apparent long-term hydrostatic balance with sea water indicates that hydraulic continuity prevails throughout the media despite the presence of relatively impermeable claystone aquicludes. Because of the nearly impermeable claystone aquicludes and small horizontal gradients which exist in the lower portion of the bi-convex lens, the proportion of total annual recharge in the flow regime which circulates here must be extremely minimal. For this reason, pumping of fresh water from artesian aquifers in the lower portion of the bi-convex lens is likely to cause sea-water intrusion immediately following the removal of fresh water from storage.

The decline of groundwater heads with depth under the interior recharge area of Taylor Island, the flow of groundwater in profiles "B" and "D" toward the mainland and the position of brackish water described above, together indicate that no regional flow from the mainland participates in the groundwater flow regime of Taylor Island.

At Basse Bay discharge of water from the Ghyben-Herzberg lens takes place almost entirely by flow into the sea below the high tide level, through the transition zone as shown in Figure 44. The chloride distribution within this coastal discharge area is given in Table 8 for open well 62B (piezometer 62B of Figure 44). Seepage springs are rare. One small spring, located at the strand line, immediately above high-tide level, 900 feet west of piezometer 62B (Figures 4 and 5) discharged water of 39 ppm chloride at high tide and 33 ppm at low tide on June 13, 1969. Samples of water taken from dug holes in the exposed flats at low tide on Basse Bay gave chloride contents ranging from 4,950 to 16,200 ppm. Slumping of the sand surrounding the holes, piping of water into the holes, and the low degree of compaction of the sand is evidence that excessive pore-water pressures due to discharge are present below the mean tide level.

TABLE 8

CHLORIDE IN PARTS PER MILLION AS A FUNCTION OF DEPTH FROM OPEN WELL 62B, AUGUST 15, 1968

Sample Depth in Feet	Elevation	Chloride ppm
7.85	0.10 water table	
10	- 2	99
20	-12	99
40	-32	240
50	-42	226
60	-52	234
70	-62	263
80	-72	232
100	-92	351

6.3 Sea-Water Intrusion Wedge at Shippegan

The sea-water intrusion wedge within the town of Shippegan is approximately a "V"-shaped transition zone, the base of which extends along the sea-shore at Shippegan Harbour and the apex of which penetrates inland about 1,800 feet (Figures 49 and 50). In section the diffusion zone of the intrusion wedge is defined by isochlors which are inclined landward and which terminate at the base of the Upper Sandstone aquifer (Figures 51 and 53). The mathematical model of a "V"-shaped area of recharge water whose apex is located at the pumping well (Figure 18C), fits the field model of the sea-water intrusion wedge at Shippegan. The furthest point of inland penetration of the apex of the "V"-shaped intrusion wedge is centred on municipal production wells 2 and 3 (Figure 4).

In June, 1964 intruding brackish water first reached production well 2. Between August, 1967 and August, 1969 the forward toe of the transition zone, on the apex of the intrusion wedge, appears to have been situated at a maximum distance of about two hundred feet north of production well 2 (Figures 49 and 51). Despite the fact that the groundwater flow pattern within the transition zone has been predominantly seaward (Figures 47 and 49) and only briefly landward (Figures 48 and 50) the configuration of the intrusion wedge and the position of the transition zone has been remarkably constant during the nine-month period of observation by the author.

In Figure 47, flow patterns based on groundwater heads in wells and piezometers in the Upper Sandstone aquifer show that flow through the transition zone to the sea occurred on June 23, 1969, during a period of high-stage groundwater levels. During a period of low-stage groundwater levels, on August 14 and 15, 1967, (Figure 34) gradients were landward in the transition zone and flow from Shippegan Harbour toward production wells 2 and 3 took place (Figures 48 and 50). Steep gradients near Basse Bay, shown in Figures 49 and 50, are due to the reduced thickness of the Upper Sandstone aquifer as shown in Figure 42, profile "B". The reversal of gradient and flow direction in the sea-water intrusion wedge is related to: (1) the fresh groundwater head in the central portion of Taylor Island and hence the gradient and velocity, Vo, of natural discharge to the sea, and (2) the discharge rate of pumping wells 2 and 3 as well as other small production wells in the intrusion wedge bordering Shippegan Harbour.

The reversal of gradient and flow directions defined by fresh-water heads in the transition zone of the Upper Sandstone aquifer, profile "A", is illustrated in Figures 47 and 48. On August 14, 1968 gradients and flow directions were entirely toward production wells 2 and 3, from Shippegan Harbour, as shown in Figure 48. On August 7, 1968 the chloride content of the production wells was 140 ppm, and by August 26, 1968 the chloride content reached 593 ppm. A

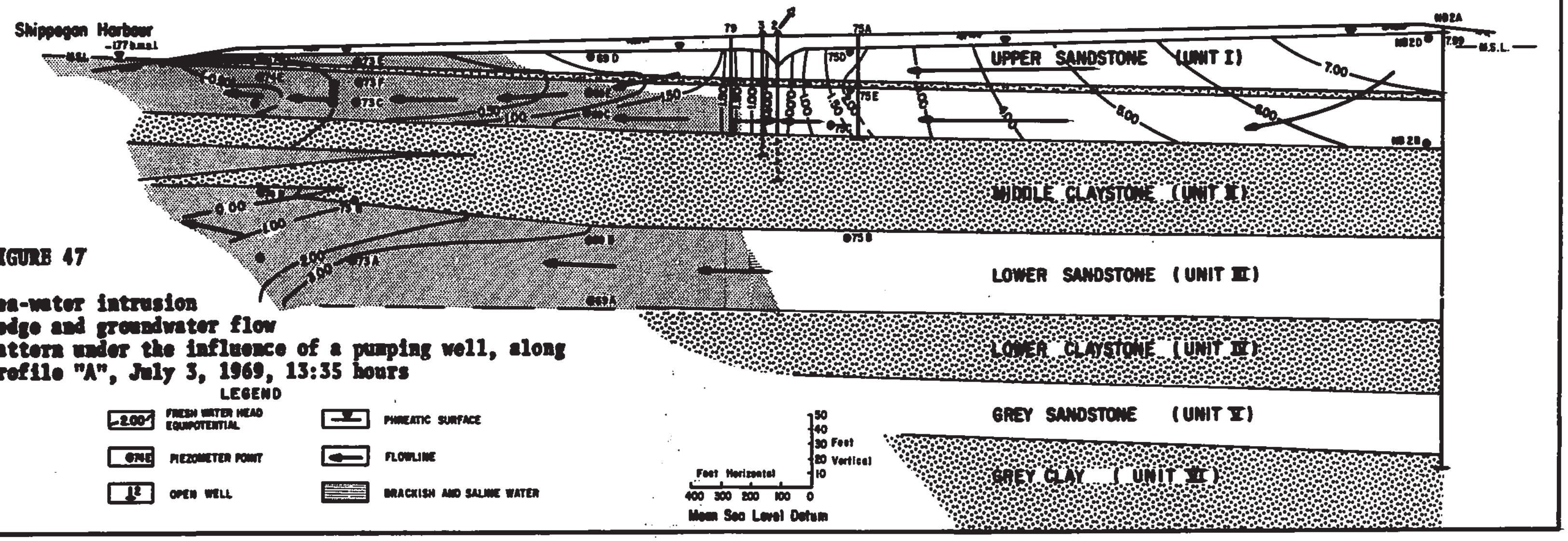


FIGURE 47

Sea-water intrusion
wedge and groundwater flow
pattern under the influence of a pumping well, along
profile "A", July 3, 1969, 13:35 hours

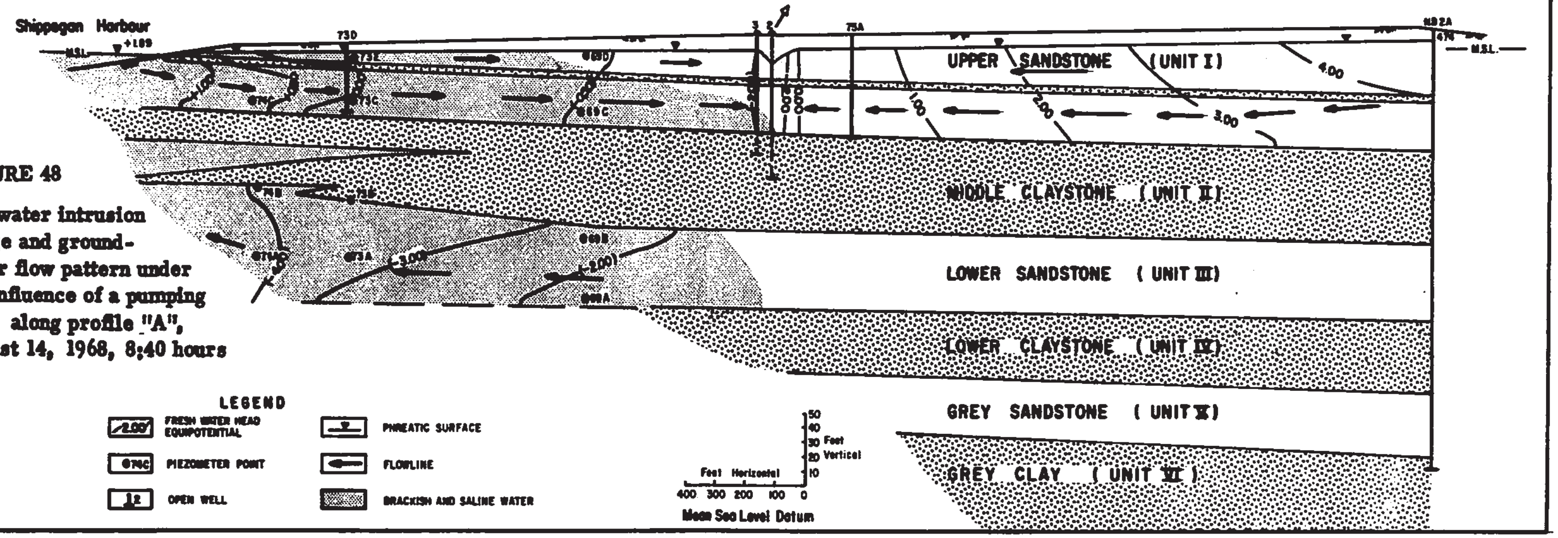


FIGURE 48

Sea-water intrusion wedge and ground-water flow pattern under the influence of a pumping well, along profile "A", August 14, 1968, 8:40 hours

Figure 49: Flow net based on groundwater heads above mean sea level in the Upper Sandstone aquifer (Unit I), Shippegan, Taylor Island, New Brunswick. June 23, 1969, 9:00 to 10:00 hrs.

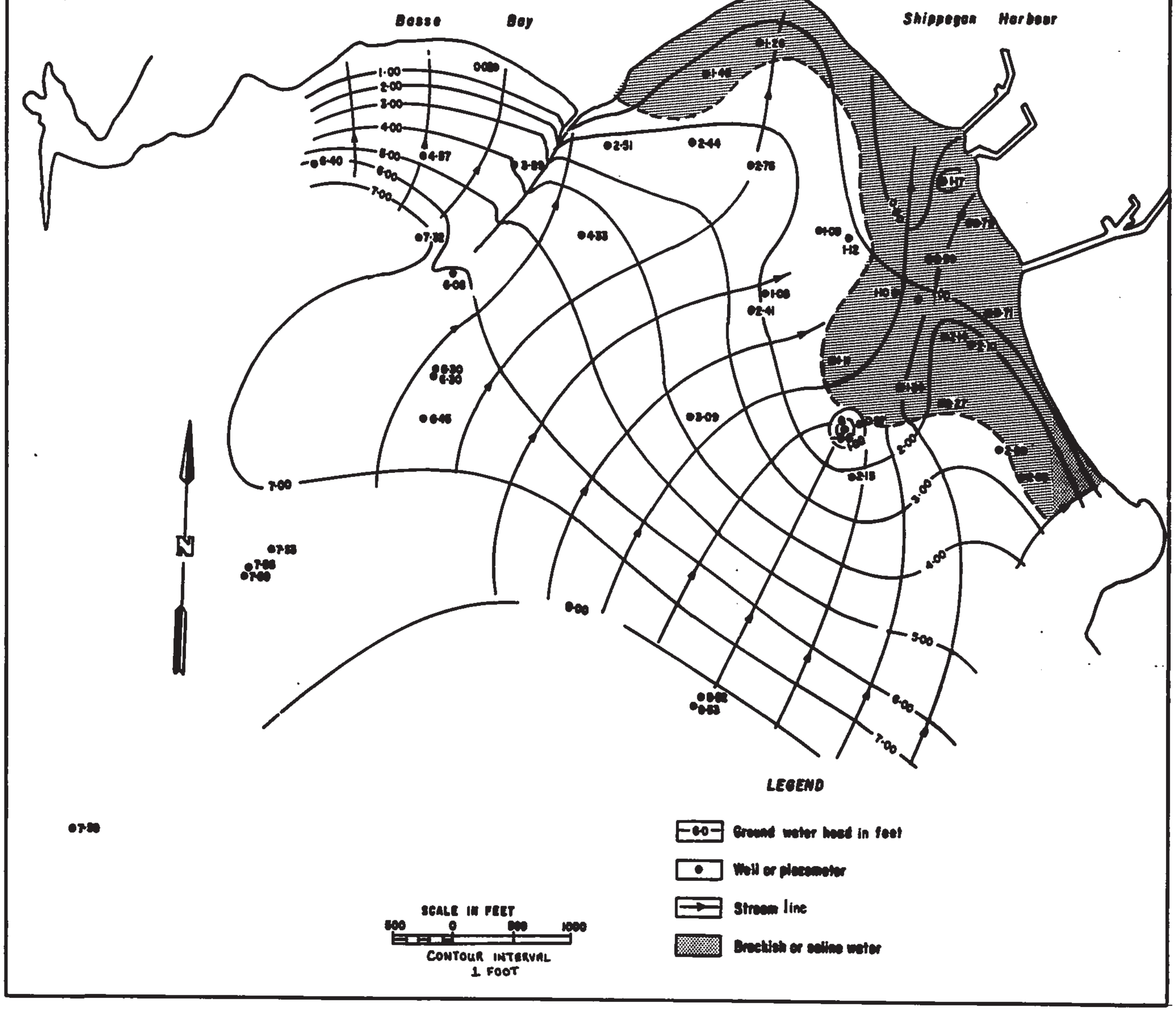
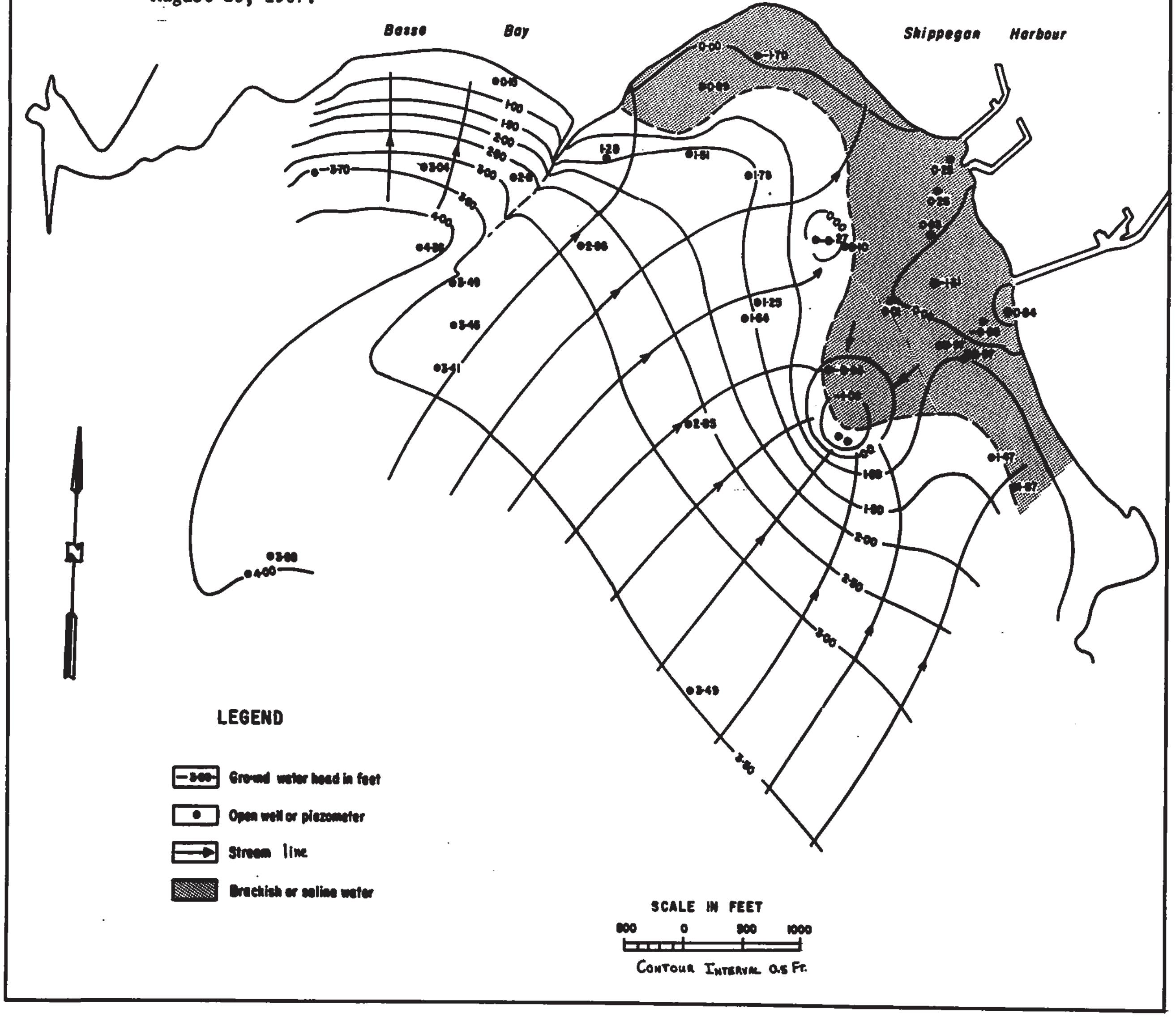


Figure 50: Flow net based on groundwater heads above mean sea level in the Upper Sandstone aquifer (Unit I), Shippegan, Taylor Island, New Brunswick.
August 15, 1967.



groundwater hydrograph of well NB1A, Figure 33, shows that during this period fresh-water heads on Taylor Island were minimal. By early December, 1968, after a month of reduced pumping and following a period of autumn recharge, the wells produced fresh water. The normal flow pattern during high groundwater stage within the Upper Sandstone in profile "A" is shown in Figures 47 and 51. Flow and gradients are entirely in a seaward direction, except for the flow between production well No. 2 and a flow divide located near well 79 (Figure 51). This flow divide is equivalent to the flow divide shown at the stagnation point (S.P.) in Figure 18a. With a seasonal decline of the fresh groundwater heads, during periods when discharge from the aquifer exceeds recharge, and when extensive pumping of well 2 takes place, this flow divide migrates toward Shippegan Harbour. Fresh-water heads decline in the transition zone, and the reversal of gradient and flow to production well 2 from the seashore occurs as shown in Figure 18c. The distribution of isochlors in the transition zone shown in Figure 51, on July 4, 1969 may be compared to the fresh-water head equipotentials shown in Figure 47, on July 3, 1969. Although production well 2 continued to produce fresh water until August 18, 1969 the relationship of the toe of the transition zone to the flow divide shows that migration of the flow divide a few hundred feet toward Shippegan Harbour would bring contaminated water to the well.

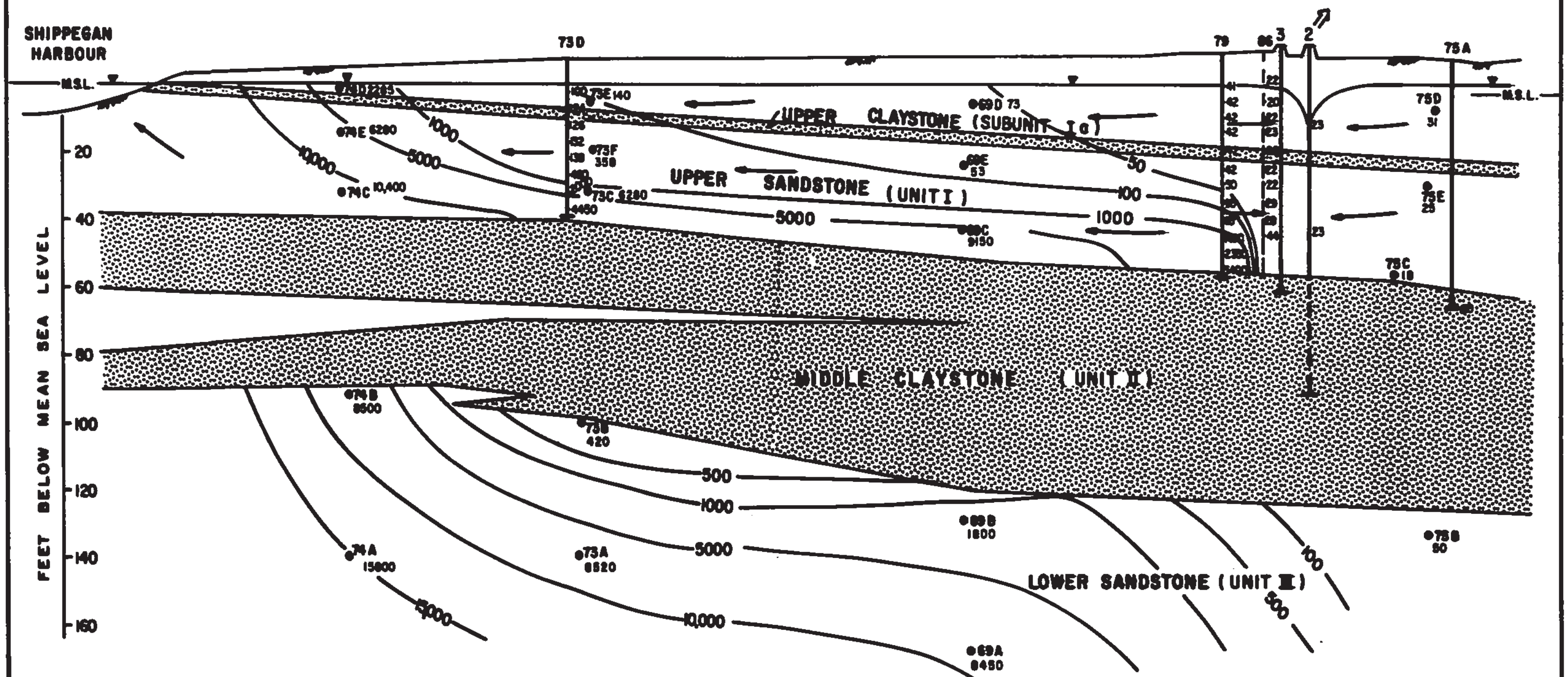


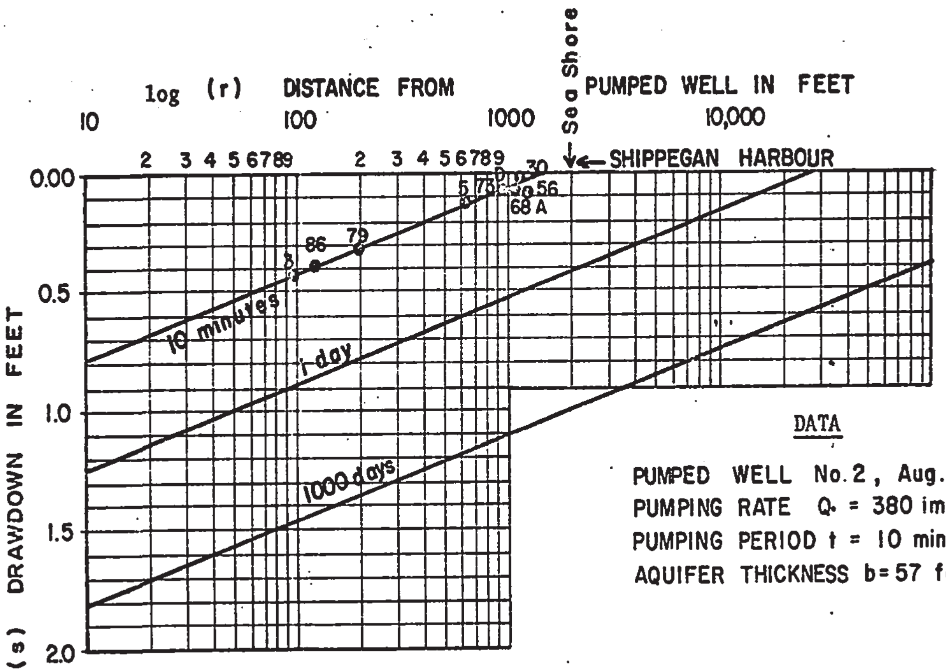
Figure 51: Sea-water intrusion wedge and transition zone defined by isochlors along profile "A" on July 4, 1969.

A distance-drawdown diagram based on a pump test on well 2, August 16, 1969 shown in Figure 52, illustrates how the flow divide of the cone of depression would extend to the recharge boundary at Shippegan Harbour within one day in a fresh-water system, if natural discharge from the interior of Taylor Island toward Shippegan Harbour was not present.

Sea water intrusion in the Lower Sandstone (Unit III) aquifer is considered to be due to the hydrostatic adjustment of heads in this aquifer in response to fresh-water heads reduced to mean sea level in the Upper Sandstone (Unit I) aquifer, according to the Ghyben-Herzberg principle (Davis and De Wiest, 1966), as well as intermittent production of saline water from wells 19, 27, and 77 (Figure 4). Anomalous below sea level heads in the Lower Sandstone aquifer shown in Figure 48 are believed to be principally due to production of saline water from well 19.

Field evidence does not indicate that coning of saline or brackish water has occurred from the Lower Sandstone aquifer due to production wells 2 and 3.

The configuration of the transition zone is also given by distribution of isochlors in profiles drawn along 15th Street and 16th Street, Shippegan, shown in Figures 4, 53 and 54. Bear and Dagan (1962, p. 12) define the length of the sea water intrusion wedge, L, measured along the base

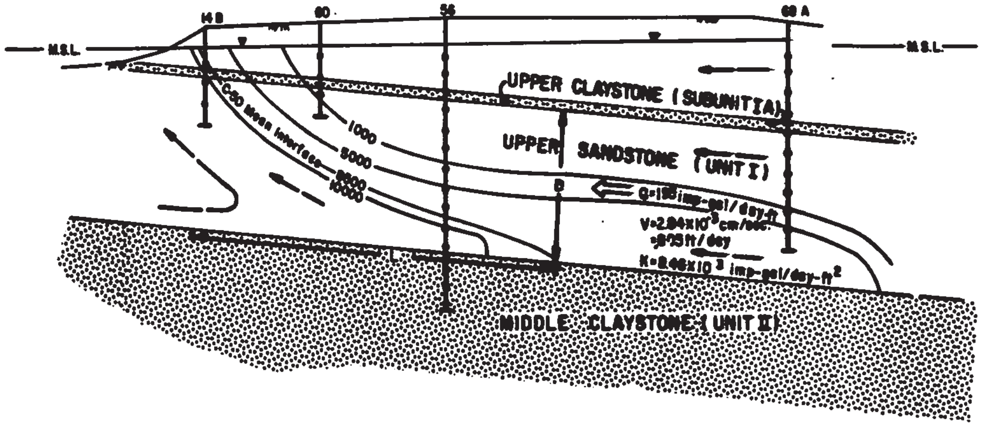


DATA

PUMPED WELL No. 2, Aug. 16, 1969
PUMPING RATE Q = 380 imp.-gal./min.
PUMPING PERIOD t = 10 minutes
AQUIFER THICKNESS b = 57 feet

FIGURE 52: Distance-drawdown graph of response to pumped well 2, and projected distance-drawdowns after 1 day and 1,000 days of steady pumping

FIGURE 53:
PROFILE OF ISOCHLORS AND GROUND-WATER FLOW PATTERN
16-TH. ST., SHIPPEGAN, N.B., JULY 24, 1969.



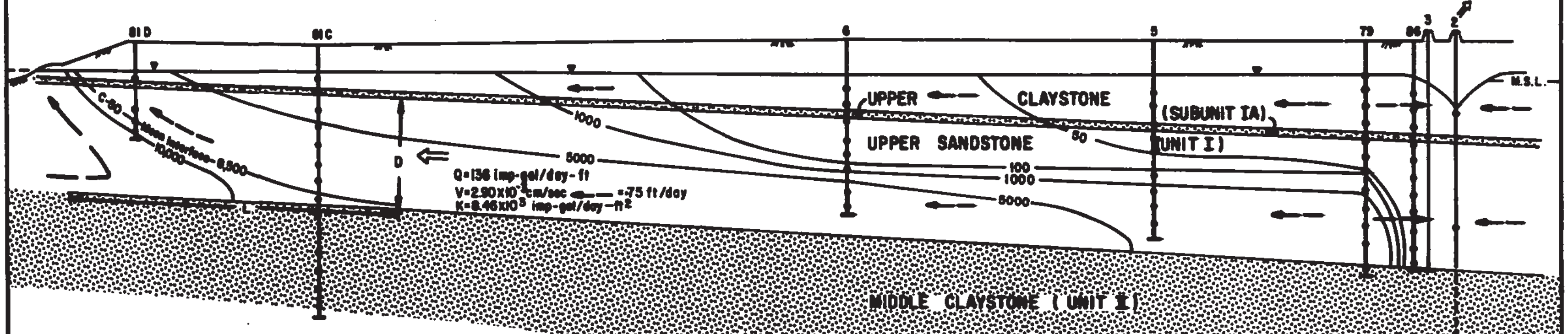
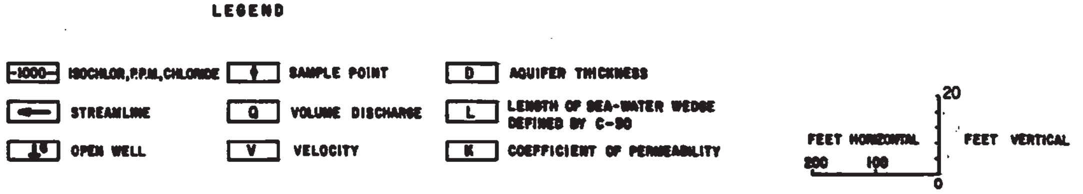


FIGURE 54:
PROFILE OF ISOCHLORS AND GROUND-WATER FLOW PATTERN
15-TH. ST., SHIPPEGAN, N.B., JULY 24, 1969.



of a confined aquifer from the idealized discharge point on the sea floor to the toe of the wedge, according to the following equation:

$$L = \frac{K' D^2}{2 Q} \qquad \text{(eqn. 6 - 1)}$$

where: $K' = \frac{K(\rho_s - \rho_f)}{\rho_s}$

and: K = permeability or hydraulic conductivity.

Q = total discharge per unit section.

ρ_s = density of sea water.

ρ_f = density of fresh water.

D = thickness of aquifer.

Provided that the Dupuit assumptions are valid, values of $\frac{\pi K' D}{Q} > 6$ yield results with errors less than 3 percent compared to the exact solution.

Specific discharges, Q/D , can be calculated for seaward flow in the transition zone from equation 6 - 1. On July 24, 1969 in sections along 15th and 16th Streets, at the toe of the mean interface, the specific discharges were 132 and 195 imperial gallons-per day-per foot respectively. On July 25, 1969 the specific discharge at the mean interface toe between 15th and 16th streets, on profile "A", determined by fresh-water head gradients, was 240 imperial gallons-per day-per foot and the Darcy velocity was 1.48 feet per day.

6.4 Groundwater Temperatures

Groundwater temperature measurements were taken in nineteen wells by means of a thermistor-Wheatstone bridge assembly (Beck, 1965) constructed and calibrated for M.L. Parsons, Inland Waters Branch, Ottawa. Measurements were made by lowering the thermistor probe in open wells by two-foot and four-foot intervals and allowing a five-minute time interval for temperatures to reach equilibrium at each position. Resistances measured with a null indicator were converted to temperatures in degrees centrigrade with a previous calibrated accuracy of 0.05 degrees centigrade.

The temperature distribution pattern of groundwater shown by isotherms, is influenced by terrestial heat flow, the thermal and hydraulic properties of the medium, and the temperatures of recharging water as a function of both present and historic climatic conditions. The mean air temperature at the Miscou Lighthouse station between 1966 and 1968 was 39.2° F or 4° C. Groundwater temperatures observed are generally about 1.5 to 2.5° C warmer. In the shallow groundwater flow system at Taylor Island, groundwater temperatures are influenced largely by the temperature of recharging water and the magnitude and direction of groundwater flow. Heat is transferred by convection due to groundwater flow, and by conduction due to temperature gradients which exist transiently in the permeable and thermally-conductive layered medium.

Figure 55 is a temperature log of well NB2A taken on July 21, 1968. A general cooling effect is apparent to a depth of about 82 feet, at the base of the Upper Sandstone unit. At this depth the thermal gradient changes from a relatively constant temperature at 5.6° C, to a gradient which increases with depth at a rate of approximately 1° C per 168 feet. The cooling effect is attributed to a downward movement of relatively cool recharged water. The recharged water is relatively cool because recharge occurs mainly during the fall and spring. The influence of summer temperatures seems to be effective to a depth of about 38 feet or the top of unit 1a.

Figure 56 is a hand-contoured section of groundwater temperatures measured in five wells at 2-foot depth intervals along profile "B" (Figure 4) during August, 1968, with groundwater flow directions superimposed. A thermal divide shown by the downward flexure of the 6.0° C isotherm between wells 63A and 67A coincides approximately with a recharge divide based on contours of groundwater heads measured in July, 1969 (Figure 44). Where recharge flow-divides in section occur, thermal troughs with isotherms displaced in the vertical direction should occur. If convection is the dominant means of heat transfer, $\frac{\partial t^\circ}{\partial x}$, along the dividing streamline should be nearly equal to zero, because there is no groundwater flow across the divide.

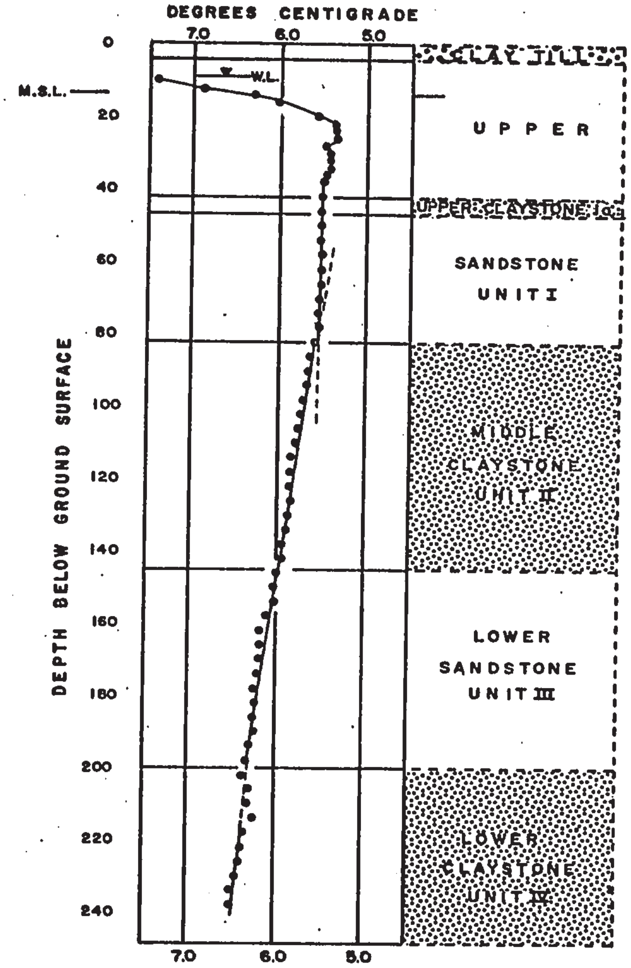


FIGURE 55:

Temperature log in degrees centigrade of well N.B.2A, July 21, 1968.

W.L. = water level   M.S.L. = mean sea level

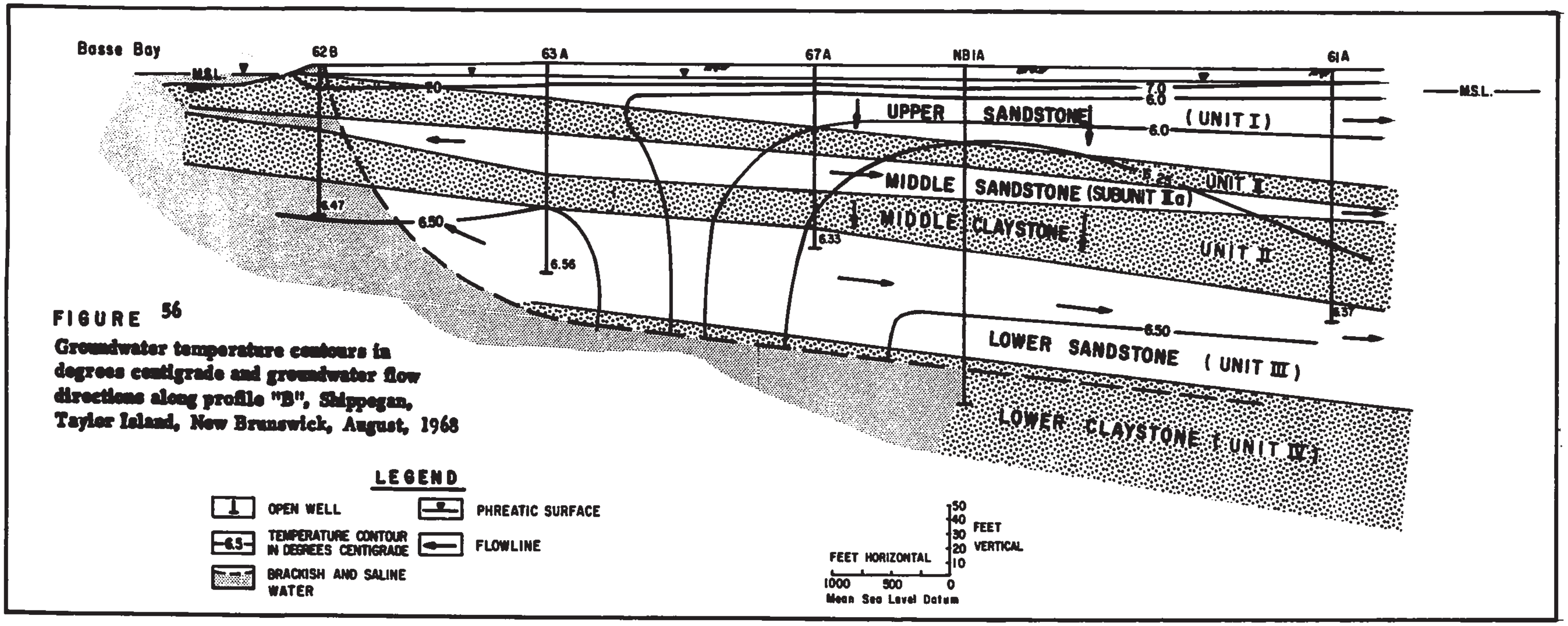


FIGURE 56

Groundwater temperature contours in degrees centigrade and groundwater flow directions along profile "B", Shippegan, Taylor Island, New Brunswick, August, 1968

CHAPTER VII

7. CHEMICAL QUALITY OF WATER

7.1 General

In the hydrologic cycle at Taylor Island, the chemistry of water adjusts to the hydrogeologic environment. A simple classification of water types may be made on the basis of water chemistry related to the different environments. These types include rain water, peat water, fresh groundwater, sea water and mixtures of fresh groundwater and sea water (Table 9).

Representative salinity and chloride contents of sea water in Shippegan Sound are 28.0 and 14.6 parts per thousand respectively (Table 9), compared to samples from the open North Atlantic Ocean with about 36.0 and 19.8 parts per thousand salts and chloride respectively (Sverdrup, Johnson and Fleming, 1942). Of the major anions of sea water, chloride is the dominant one and is least affected by chemical or biological change. For this reason, chloride serves as an index cation by which the dilution of salt-water by fresh groundwater and the base-exchange of cations are determined. Normal fresh groundwater at Taylor Island contains about 15 ppm chloride. A rise of chloride concentrations above 30 ppm marks the beginning of salt-water contamination.

For convenience, brackish water is defined as water with a chloride content between 30 and 500 ppm. Saline water contains more than 500 ppm, since the saline taste of water is recognizable above 500 ppm. The taste, hardness, corrosiveness, and low freezing point of saline waters preclude its use for domestic and many industrial purposes. Rain water and peat water (Table 9) are distinguished from other types of water by their low total dissolved-solids content (t.d.s.). Peat water is readily recognizable by a pH less than 5, an amber-brown colour, and organic taste. These characteristics make peat water undesirable for domestic or industrial use. On Taylor Island the development of a groundwater supply is therefore limited to those areas located between the peat bogs and the sea (Figure 68). Production wells in the Upper Sandstone aquifer may be contaminated by brackish water or peat water if improperly located.

7.2 Sampling Procedure and Chemical Analyses

About twenty-five hundred samples were collected with a tube sampler from wells or piezometers. Chloride content was obtained by titrating with standardized solutions of silver nitrate and potassium chromate indicator. The specific conductance in micromhos was measured with a Beckman Wheatstone bridge apparatus corrected to 25 degrees centigrade. The pH of samples, shown in Figure 68, were determined by means of a Fisher calibrated potentiometer with glass and calomel

TABLE 9

CHEMICAL COMPOSITIONS OF RAIN WATER, PEAT WATER, FRESH GROUNDWATER, AND SEA WATER

Constituent	Rain Water		Peat Water		Fresh Groundwater		Sea Water	
	p.p.m.	e.p.m.	p.p.m.	e.p.m.	p.p.m.	e.p.m.	p.p.m.	e.p.m.
Na	1.7	0.07	6.1	0.27	13.0	0.72	8812	383.3
K	0.5	0.01	0.5	0.01	2.2	0.06	302	7.73
Ca	3.5	0.17	3.0	0.15	39.0	1.90	387	19.31
Mg	1.0	0.08	0.8	0.07	7.9	1.24	1015	83.43
HCO_3	0.6	0.01	2.2	0.04	147.9	2.43	155	2.54
SO_4	1.8	0.04	4.5	0.09	10.3	0.21	2049	42.61
Cl	2.7	0.08	13.8	0.39	15.4	0.43	15300	431.5
NO_3	0.0	0.0	0.0	0.0	0.05	0.00	1.5	0.02
Fl	0.2	0.01	0.05		0.12	0.01	1.35	0.07
t.d.s.	12.0		30.95		235.9		28023	
pH	6.0		4.7		6.8		7.15	
Number of Analyses, n	1		1		26		2	

Average chloride content of 7 samples of sea water, Shippegan Sound, 14,572 p.p.m.
Average chloride content of 5 samples of rain water collected over 5 mos., 3.5 p.p.m.
Average pH of 69 samples of fresh groundwater determined in field, 6.83.
Average pH of 19 samples of peat water determined in field, 4.19.

electrodes. Total analyses listed in Appendix A, were determined by the Moncton Laboratory, Water Quality Division, of the Inland Waters Branch. Only samples having a total cation-anion balance error of less than 4 percent were recorded for graphic presentation.

7.3 Chemistry of Brackish and Saline Water

For the groundwater of Taylor Island, specific conductance, corrected for temperature, is a reliable measure of both total dissolved solids and chloride content of samples with concentrations greater than 100 ppm. The linear relationship of both specific conductance and t.d.s. to chloride observed by Carr (1969), Visher and Mink (1964) and others is due to the mixing of fresh water with sea water. This is illustrated in Figures 57 and 58.

A logarithmic plot of the sum of major cations (Na + K + Ca + Mg), as a function of chloride shows a similar, close fit of sample points about the dilution line between sea water and normal fresh groundwater shown in Figure 59. This graph shows that the transition zone can be regarded as a simple mixture of normal fresh groundwater and intruded sea water with some minor excesses and deficiencies of cations due to cation exchange. The terms "excess" and "deficiency" refer to net departures of the sample ionic concentrations above or below the dilution line measured in equivalents per million. Apparently, no solution or precipitation of ions takes place in the transition zone.

Figure 57: Specific conductance as a function of chloride content of water samples, Taylor Island, New Brunswick

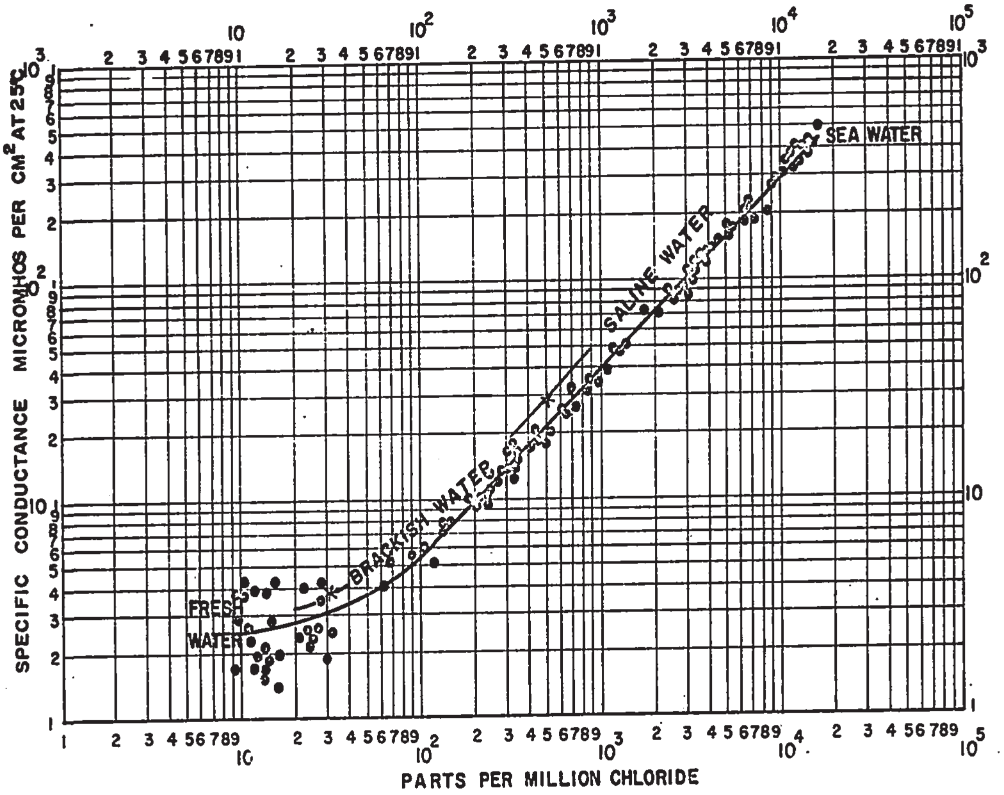


FIGURE 58: Comparison of the total dissolved solids content of water samples as a function of chloride content with that of sea water diluted with fresh groundwater, Taylor Island, New Brunswick

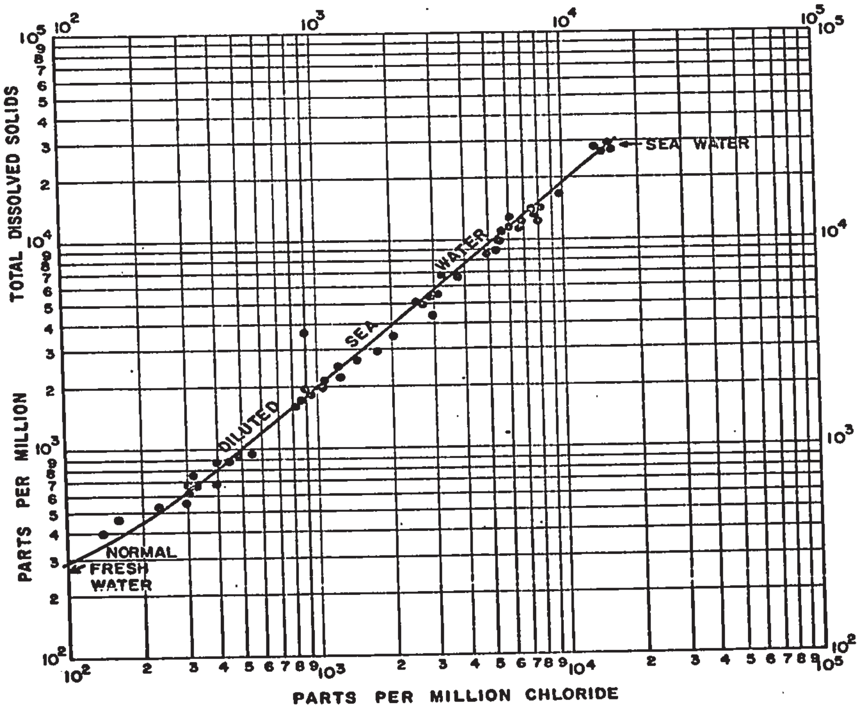


FIGURE 59: Comparison of the major cation content of water samples as a function of chloride content with that of sea water diluted with fresh groundwater, Taylor Island, New Brunswick

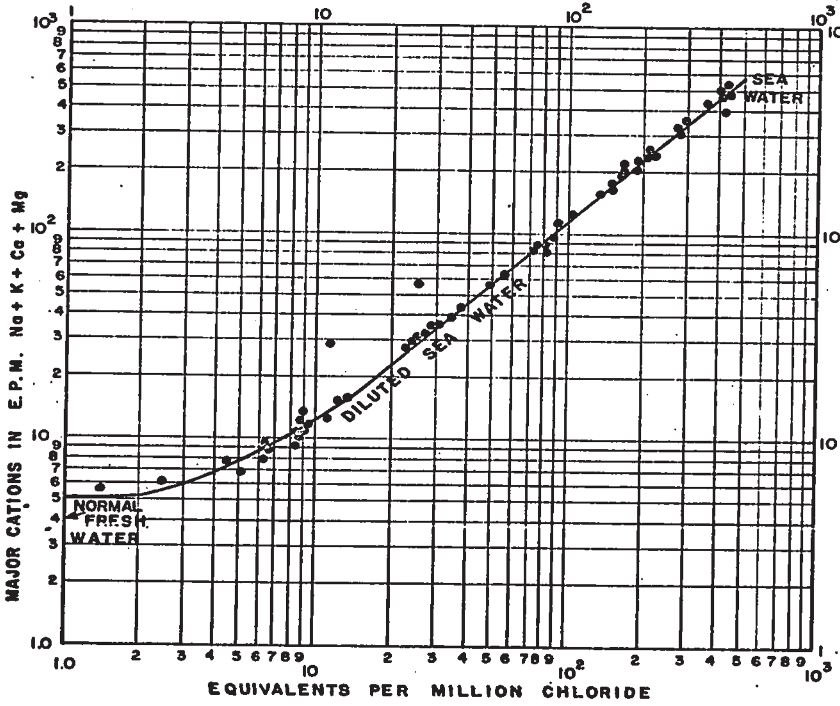


Figure 60 is a graph of the (Ca) plotted vs. (Cl). The net distribution of points above the dilution line indicates that calcium is in excess of that required by the dilution of sea water with fresh groundwater. Conversely, Figure 61 shows that sodium concentrations are generally below the dilution line and hence are deficient. Similarly, Figure 62 illustrates a profound deficiency of potassium. Finally, in Figures 63 and 64, magnesium and sulphate concentrations show no net departure from the dilution line, and hence are neither in excess nor deficient. Since the sample points for the sum of major cations are distributed on or near the dilution line, the deviations involving Ca^{++}, Na^{+}, and K^{+} are due to cation exchange.

Exchangeable cations are those cations in the pore-water of the soil which may exchange positions within the electric diffuse double layer surrounding clay particles, in order to balance and satisfy the negative charge of the clay particles. The intruding sea water contains a much larger concentration of sodium in comparison to calcium and magnesium (Table 9), and hence, at high concentrations, the monovalent sodium cation is preferred over the divalent ions in the exchange sites of the interstitial illite-chlorite clay, of the Upper Sandstone aquifer (Figures 11 and 12). Potassium reacts similarly to sodium particularly if the illite has been previously degraded in the fresh groundwater environment by leaching, in which case potassium ions have been removed from

FIGURE 60: Comparison of the calcium content of water samples as a function of chloride content with that of sea water diluted with fresh groundwater, Taylor Island, New Brunswick

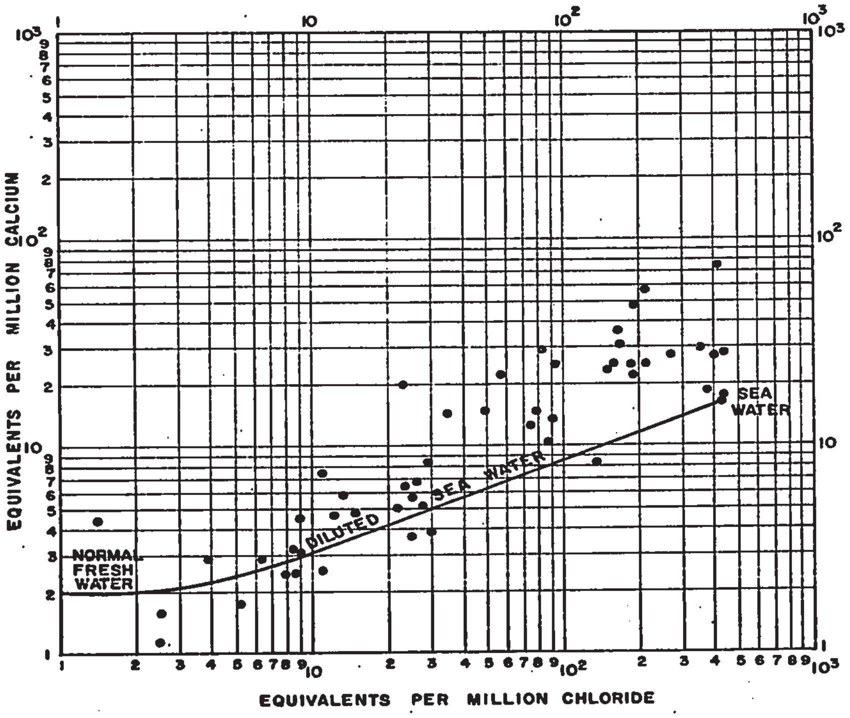


FIGURE 61: Comparison of the sodium content of water samples as a function of chloride content with that of sea water diluted with fresh groundwater, Taylor Island, New Brunswick

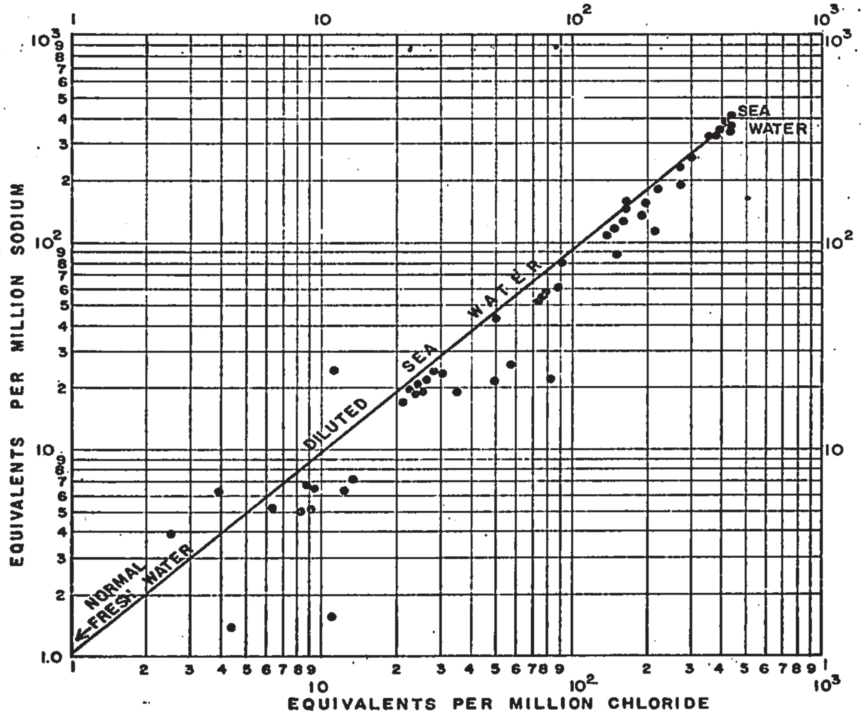


FIGURE 62: Comparison of the potassium content of water samples as a function of chloride content with that of sea water diluted with fresh groundwater, Taylor Island, New Brunswick

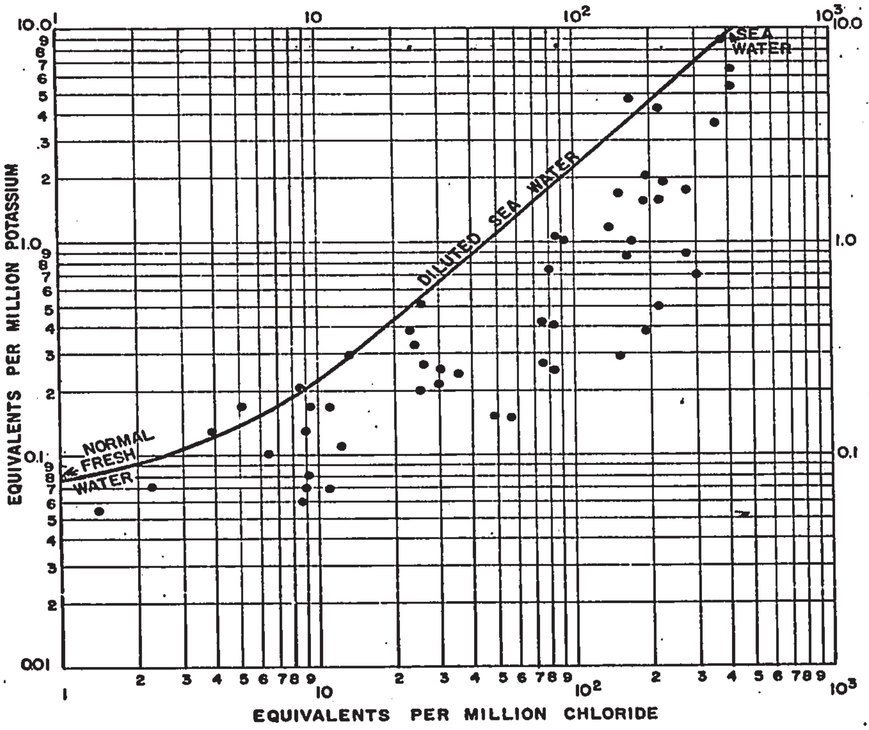


FIGURE 63: Comparison of the magnesium content of water samples as a function of chloride content with that of sea water diluted with fresh groundwater, Taylor Island, New Brunswick

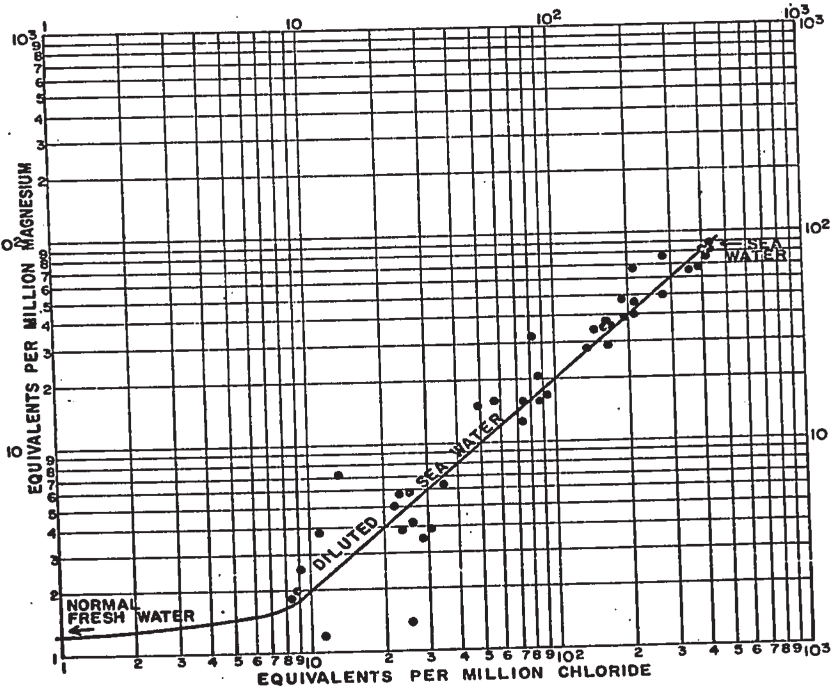
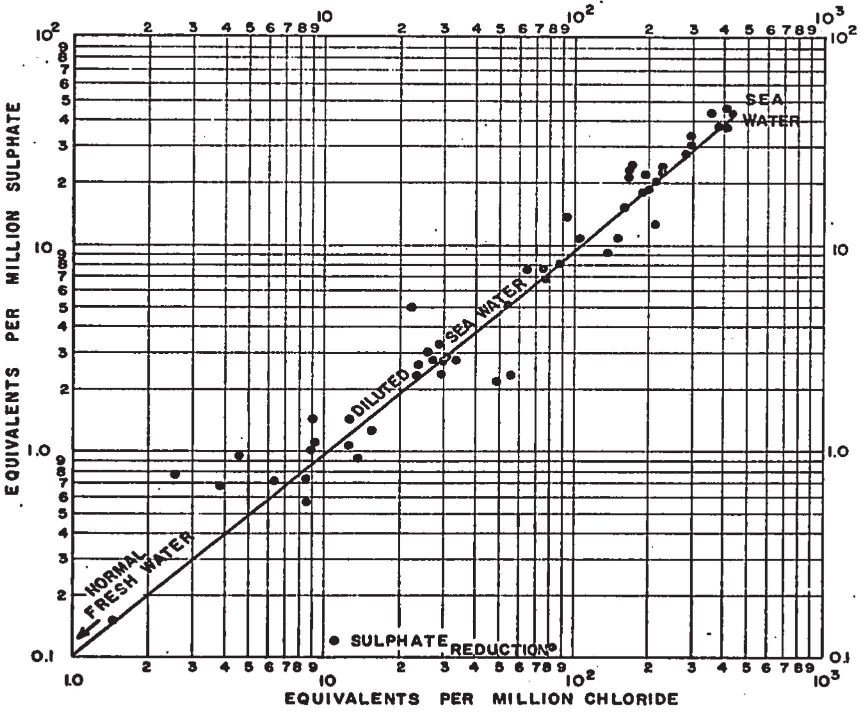


FIGURE 64: Comparison of the sulphate content of water samples as a function of chloride content with that of sea water diluted with fresh groundwater, Taylor Island, New Brunswick



their preferred position between the basal layers of the illite structure. The exchange process can be summarized by the generalized equation:

$$\text{(Ca, Mg) illite - chlorite clay} + \text{Na} + \text{K}$$
$$\rightleftharpoons \text{(Na, K, Mg) illite - chlorite clay} + \text{Ca}$$

(Eqn. 7 - 1)

At chloride concentrations less than 10 epm or 355 ppm, the excess of calcium and deficiency of potassium is not as pronounced as at higher concentrations (Figures 60 and 62).

Vishner and Mink (1964) have observed cation-exchange phenomena in a transition zone at Pearl Harbour in Oahu, Hawaii, and described it by the equation:

$$\text{(Ca, Mg) clay} + 2\ \text{(Na, K)}$$
$$\rightleftharpoons 2\ \text{(Na, K) clay} + \text{(Ca, Mg)}$$

(Eqn. 7 - 2)

Love (1945) has reported average excesses of calcium offset by deficiencies of magnesium and sodium, in the coastal transition zone near Miami, Florida.

A trilinear Piper diagram (Hem, 1959) of all groundwater analyses is given in Figure 65. In this diagram, the major cations (calcium, magnesium, and sodium plus potassium) are plotted as percents of total equivalents per million in the cation triangular field. The major anions (carbonate plus bicarbonate, chloride, and sulphate) are given as percent of total equivalents per million in the anion triangular field.

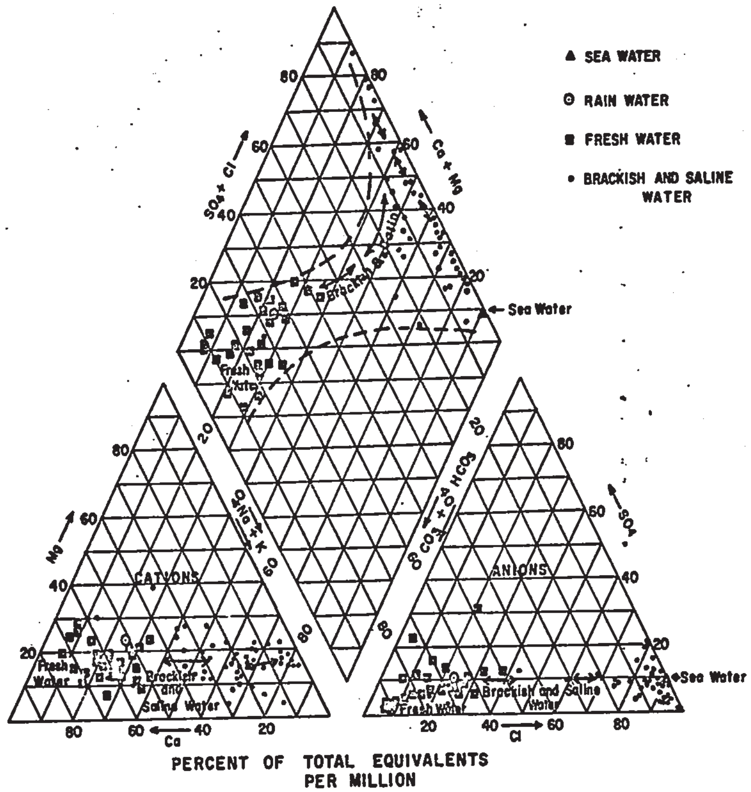
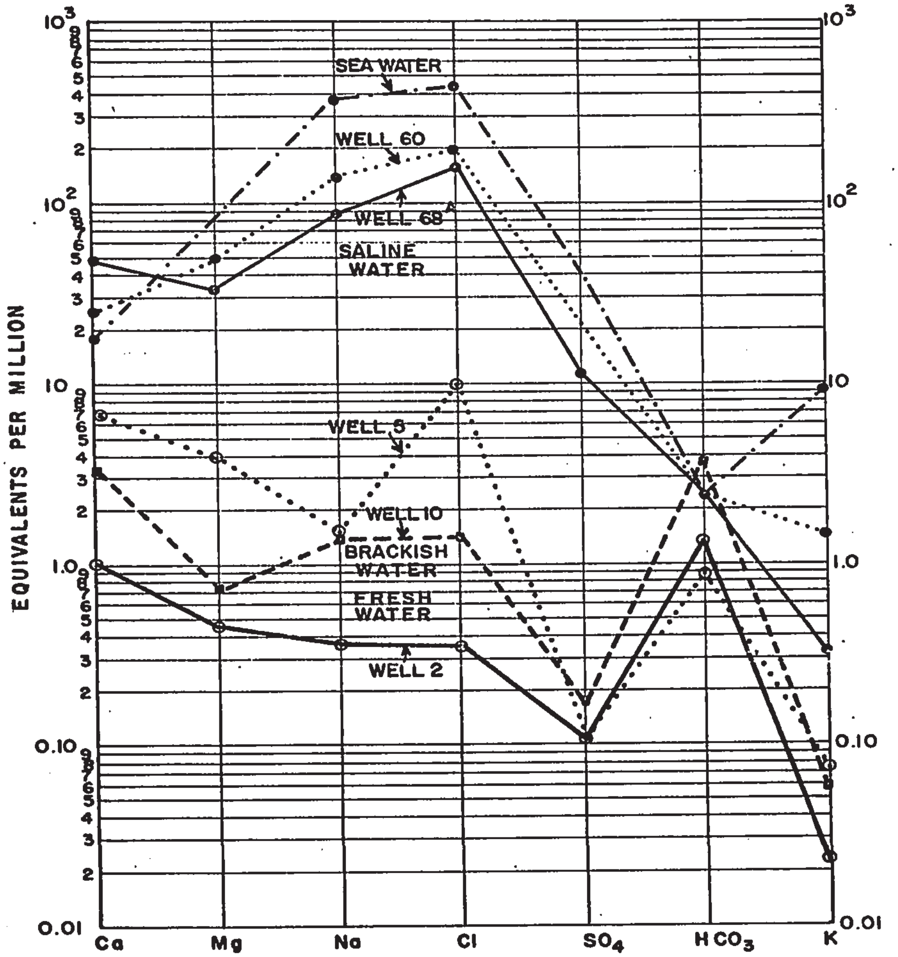


FIGURE 65: PIPER DIAGRAM OF FRESH, BRACKISH, SALINE, SEA AND RAIN WATER SAMPLES, TAYLOR ISLAND, N.B.

The combined concentration of anions and cations is plotted in the diamond-shaped field. In the cation and anion triangles, the dilution of sea water by fresh groundwater to saline and brackish water is shown by the linear distribution of brackish, saline water, and sea-water sample points. The samples show a rapid increase in the proportion of calcium and a decrease in the proportion of sodium plus potassium with dilution of sea water by fresh groundwater and a corresponding decrease in the proportion of chloride and sulphate ions.

Figure 66 is a Schoeller diagram (Hem, 1959), which illustrates the relative concentrations of major ions in epm from selected wells. In this diagram, the slope of a line joining concentration values of any two ions under consideration indicates the ratio of the concentration of the ions in that sample. The difference in slopes of two lines representing two analyses may be compared in order to demonstrate the changes in ionic ratios. The chloride concentration of a sample is used as an index of the degree of dilution of sea water by fresh groundwater. Figure 66 shows that the ratio of calcium to chloride increases with dilution of sea water in samples taken from wells 60, 68A, and 5, whereas the ratio of both sodium and potassium to chloride decreases. Both effects are due to cation-exchange. The decline of sulphate and rise of bicarbonate in the sample taken from well 10, is due to the bacterial reduction of sulphate to hydrogen

FIGURE 66: Schoeller diagrams of major ion concentration of samples of fresh groundwater, brackish groundwater, saline groundwater, and sea water, Shippegan, Taylor Island, New Brunswick



sulphide and bicarbonate in the presence of organic matter. If it is assumed for simplicity that the organic matter oxidized is glucose, the reaction is indicated by the following equation:

$$3\ SO_4 + \underset{\text{glucose}}{C_6 H_{12} O_6} \xrightarrow{\text{bacteria}} 3\ H_2S + 6\ HCO_3 \qquad \text{(Eqn. 7 - 3)}$$

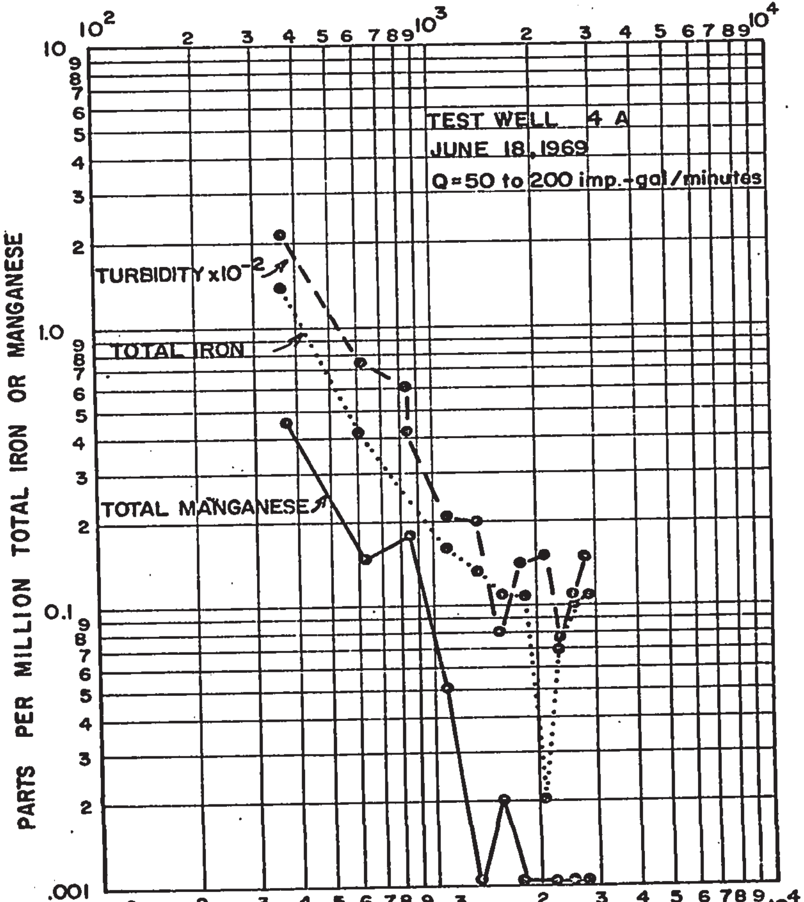
Excepting two samples, Figure 64 indicates that sulphate reduction is not an important process in the transition zone.

7.4 Iron and Manganese

Iron and manganese are geochemically associated, and are reported in chemical analyses (Appendix A) as total concentrations, which includes both dissolved and suspended forms. Recommended concentrations of both iron and manganese for domestic and industrial purposes should not exceed 0.3 ppm. Water with larger concentrations can form a red-brown hydrous-iron oxide and black manganese oxide when aerated.

Iron and manganese together appear to occur largely in a suspended form, since both concentrations are closely related to turbidity, which appears to be due to borehole cuttings. In Figure 67, the decline of turbidity, iron and manganese concentrations with time of development pumping, on test well 4WA, indicates this relationship (New Brunswick Water Authority Analyses). During a 48-hour development pump test on well 1W, by James F. MacLaren Ltd., Consulting Engineers, both iron and manganese continued to exceed 0.3 ppm. Similar pump tests

FIGURE 67: Total iron, manganese, and turbidity concentrations as a function of pumping time on well 4WA, Taylor Island, New Brunswick



on wells 4W and 2W showed a decline of iron and manganese with pumping time, the acceptable limit of 0.3 ppm for both total iron and manganese was reached after 18 and 33 hours of pumping respectively. Correlation of total iron and manganese in ppm for 96 water samples taken from fresh-water wells, shows no linear relationship; the statistical correlation coefficient was close to zero.

7.5 Nitrate

On Taylor Island, nitrate contents of groundwater samples not subject to pollution is generally less than 0.5 ppm (Appendix A). A number of samples from within the town of Shippegan have nitrate contents between 5 and 38 ppm. The sources of this nitrate are from fish processing-plant effluent, septic tanks and other domestic pollution sources.

7.6 Peat Water

Gull Lake and the peat bog which borders it contains a volume of peat water in the order of 3×10^3 acre-feet spread over eight hundred acres. This figure represents a conservative estimate based on the volume of peat reported by Anrep (1923) and the position of the water table. This peat water forms the highest part of the central groundwater mound on Taylor Island (Figure 40) and extends to depths of about twenty-two feet in places. The partly lignified peat moss is separated from the underlying Upper Sandstone aquifer by a foot or two of pebble-clay till. The peat water is characterized by an acidic pH, an unusual poverty of dissolved solids, an objectionable organic taste, and a yellow to brown colour.

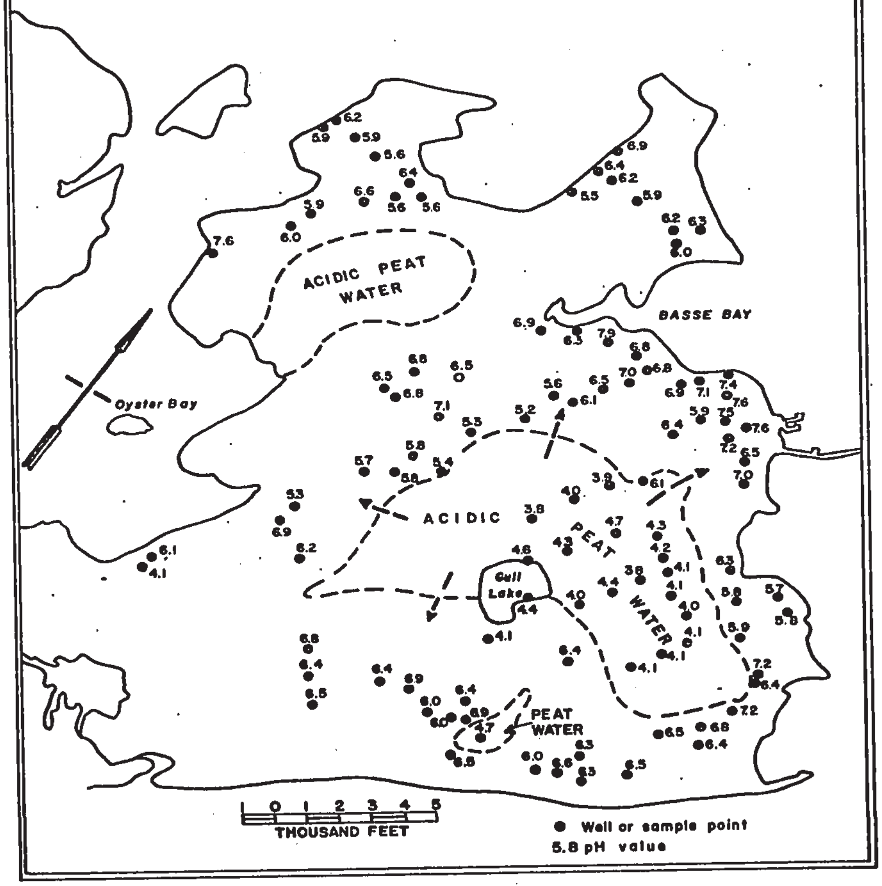
The pH of peat water in the Gull Lake peat bog is more acidic than the pH of fresh groundwater in the Upper Sandstone aquifer adjacent to the bog (Figure 68, Table 9). The average pH of 19 samples of peat-water is 4.2 compared to an average pH of 69 samples of fresh groundwater of 6.8. The acidity of peat water is primarily due to carbonic acid, H_2CO_3, formed from carbon-dioxide which is generated by the decomposition of peat. Peat waters with a pH below 5, indicate that only carbon dioxide is of any quantitative importance in the carbon-dioxide-bicarbonate-carbonate system (Hutchinson 1957, p. 657). Carbonic acid is strongly dissociated as follows:

$$H_2CO_3 \quad \xrightleftharpoons{\text{pH 5 to 8.4}} \quad H^+ + HCO_3^= \qquad \text{(Eqn. 7 - 4)}$$

$$HCO_3 \quad \xrightleftharpoons{\text{pH 8.4 to 14}} \quad H^+ + CO_3^= \qquad \text{(Eqn. 7 - 5)}$$

In this equilibrium the concentration of carbon dioxide in solution determines the pH of peat water. This concentration is dependent not only on the partial pressure of the carbon dioxide gas and its solubility, but also on the formation of bicarbonates which tend to buffer the solution. Comparison of the analyses of peat water and rain water (Table 9, and Ruttner, 1966) shows that absorption of calcium and

FIGURE 68: Field laboratory measurements of pH, Taylor Island, New Brunswick



magnesium ions by colloidal humus occurs in peat bogs. Consequently, alkaline-earth bicarbonate salts are not formed in quantities sufficient to buffer peat water because of a lack of cations. Dissolved organic acids contribute to the pH of peat water and are responsible for the colour and taste.

Discharge from the Gull Lake peat bog to the Upper Sandstone aquifer takes place by leakage through a thin layer of clay till at the base of the peat bog. Groundwater samples taken from the Upper Sandstone in wells bordering in Gull Lake peat bog show pH values greater than 5 (Figure 68). It can be concluded that the peat water loses its acidity, organic taste, and yellow-brown colour upon entering the Upper Sandstone aquifer. The acidity loss is partly due to the presence of sufficient quantities of alkaline-earth metals, and alkalies, in the fresh groundwater marginal to the peat bog. An increase in concentrations of total dissolved solids, bicarbonate, calcium, sodium, magnesium and potassium, and pH, as a function of distance from the bog, supports this hypothesis (Figure 69). A second means by which the pH of peat water could change rapidly to that of fresh groundwater is by cation-exchange between hydrogen ions, alkaline earth metals, alkalies, and interstitial illite-chlorite of the Upper Sandstone aquifer. Ion exchange with the clay minerals could take up large quantities of hydrogen or hydroxonium ions. Both the metal ions absorbed

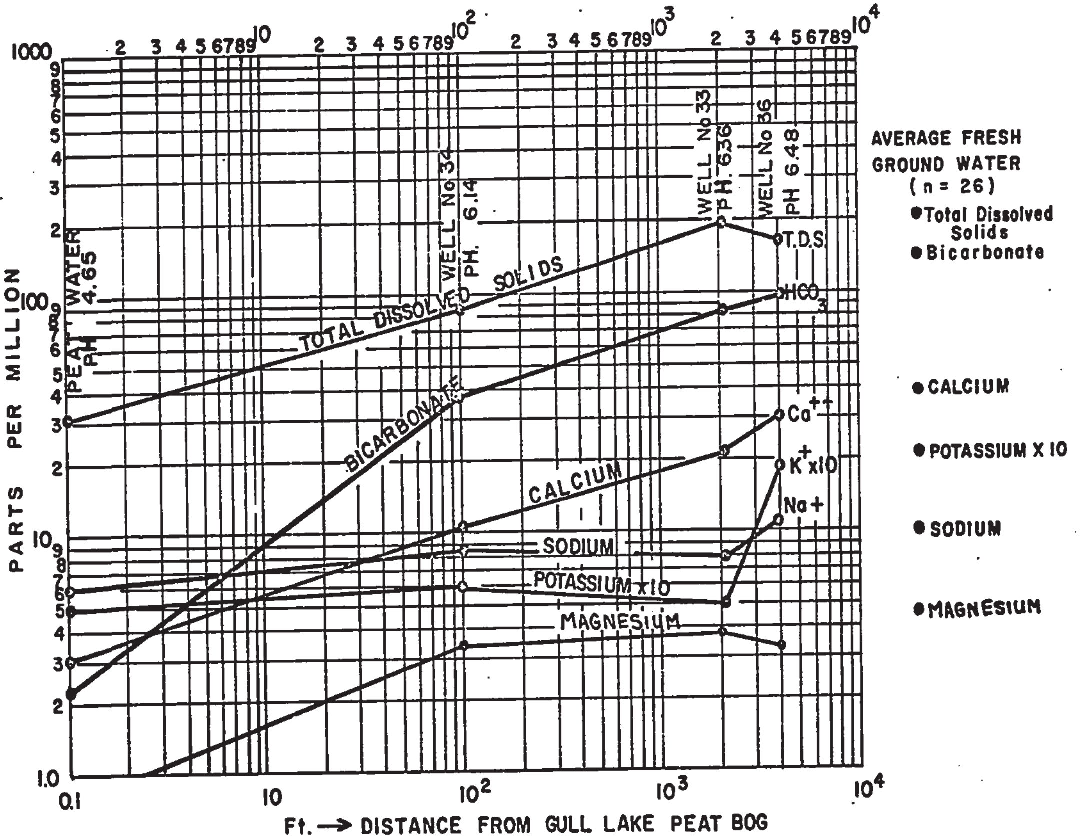


Figure 69: Parts per million total dissolved solids, bicarbonate, calcium, sodium and potassium of peat water and fresh groundwater as a function of distance from the Gull Lake peat bog.

on the clay particle surfaces and the potassium ions absorbed on the illite would be susceptible to replacement by hydrogen ions. This clay buffer system is less well known than that of the carbon dioxide-bicarbonate-carbonate system (Krauskopf, 1967). It can be illustrated as follows:

$$5H + \begin{matrix}80\ (Ca,\ Mg)\\ 30\ (K,\ Na)\end{matrix}\left[\text{illite, chlorite}\right] + 5H_2CO_3$$

$$\rightleftharpoons \begin{matrix}78\ (Ca,\ Mg)\\ 6H\\ 29\ (K,\ Na)\end{matrix}\left[\text{illite, chlorite}\right] + 2\ (Ca,\ Mg). +4\ (HCO_3)_2 + (K,\ Na)\ (HCO_3) \qquad \text{(Eqn. 7 - 6)}$$

The ratios of milliequivalients of cations given above is schematic. The reaction proceeds to the right as the establishment of equilibrium is prevented by the loss of bicarbonate by drainage to the sea (Buchman and Brady, 1964, p. 91). The loss of metallic cations is balanced by the gain of hydrogen ions on the clay micelle.

CHAPTER VIII

8. CONCLUSIONS

8.1 Coastal Well Fields and Taylor Island Problem

Most regions where sea-water intrusion has received considerable attention because of economic importance are regions which are arid and receive minimal recharge and/or are regions where heavy pumping from concentrated irrigation, industrial and domestic demands have caused overdrafts. The water supply problem at Taylor Island is largely a problem of limited supply because of low fresh water heads and small land area. The Ghyben-Herzberg fresh-water lens of Taylor Island is capable of only a limited safe sustained yield, because only a portion of top storage or less than 2.5 percent of fresh groundwater in storage can be utilized consumptively. The pumping of top storage is made difficult due to low freshwater heads and close proximity of wells to the sea shore which in turn are due to the small dimension and low topography of this peninsula. A safe alternative source of municipal water is the Pokemouche River, which is located on the mainland (Figure 4), a distance of twenty miles from Shippegan. Whether this supply should be developed in preference to Taylor Island groundwater is primarily a question of economics and engineering safety. Certainly, the partial drainage of the Gull Lake peat bog through drainage ditches to the sea by the peat moss industry has reduced fresh-water heads on the island and future production of any significant magnitude will reduce these heads further. Any margin of safety will require rigorous engineering design and a limited production capacity.

Assuming that sea-water coning will not occur in a shallow coastal aquifer with a nearly impermeable base, planning of a well field can be facilitated in such areas by the use of a digital computer model. Monitoring of the aquifer response to pumping can be carried out by measuring fresh-water heads and salinities in piezometers which are positioned between the producing well field and the sea coast. In areas where a seasonal decline of water levels brings about a reduced margin of safety from lateral sea-water intrusion, surface storage tanks can be used to supplement reduced pumpage.

Where possible, coastal wells should be developed in shallow unconfined aquifers because the storage coefficient of unconfined aquifers is considerably larger than that of confined aquifers. As a result, for a given coefficient of permeability, time, aquifer thickness and rate of pumping, the radius of a cone of depression in an unconfined aquifer is less than that in a confined aquifer. Moreover, most recharge percolates directly into shallow unconfined aquifers in recharge areas, whereas a declining fraction of this recharge reaches increasingly deeper confined aquifers in a multi-layered aquifer-aquiclude system. Development of the shallowest aquifer also minimizes the possibility of salt-water coning.

8.2 Problem of predicting Sea-Water Intrusion

An exact solution to the position of isochlors in the transition zone under the influence of steady pumping of a coastal well would require a solution to a non-steady flow equation for non-homogeneous fluids. Such a solution requires that continuity of water and salt, and the effects of hydrodynamic dispersion be satisfied. No solution to this problem presently exists, although Bear and Dagan (1963) have attempted an approximate empirical solution based on Hele-Shaw model experiments. Henry (1960) has given an exact solution to the flow pattern and position of isochlors in the transition zone with steady fresh-water flow seaward in a confined aquifer. His solution assumes, for simplicity, that D, the dispersion coefficient is constant.

8.3 Sea-Water Wells

The consumption of fresh water in the fish processing industry can be reduced by the use of sea-water in fluming, plant clean-up, and fishing boat clean-up. A deep coastal salt-water well located offshore is preferable to a sea-water pipe intake system. The coastal well avoids problems such as:

(1) turbidity due to wave action;

(2) pollutants such as bilge oil, toxic bacteria from fish-plant effluent, and fecal colliform bacteria from sewage effluent;

and (3) siltation through and clogging of the pipe intake-duct by sea-weed or bottom muds.

8.4 Aquifer Characteristics and Flow Regime

The mean specific yield of the Upper Sandstone aquifer based on water-level response to precipitation appears to be equal to the mean porosity of the Upper Sandstone aquifer of 0.13 less an assumed specific retention of 0.02. Recharge to the Upper Sandstone aquifer takes place largely during the months of October, November, December, March and April. Total annual recharge is about 20 inches or approximately one-half of total annual precipitation. Natural groundwater flow within the Ghyben-Herzberg bi-convex fresh water lens at Taylor Island is radial from the central high groundwater mound to the sea coast. Because of the extremely high permeability of the Upper Sandstone aquifer and the nearly impermeable claystone aquicludes which lie beneath it, flow vectors within the Upper Sandstone aquifer are nearly horizontal and most of the total annual recharge is transferred directly through the Upper Sandstone aquifer to discharge zones along the sea coast. Groundwater heads indicate that hydraulic continuity prevails throughout the layered aquifer-aquiclude media despite a permeability quotient between the Upper Sandstone aquifer and aquicludes in the order of 10^5 and 10^8.

The proportion of recharge which flows from the Upper Sandstone aquifer through the Middle Claystone aquiclude to lower parts of the bi-convex lens must be an extremely small portion of total annual recharge, and hence short term fluctuations of fresh-water heads in top storage above sea level are not reflected by corresponding short-term changes in the bottom storage below sea level.

The Ferris method of analysis of tidal groundwater fluctuations as a basis for estimating the Upper Sandstone aquifer characteristics gave mean diffusivity values of the same order of magnitude as those determined by pump-test analysis. The mean value of the permeability coefficient of the Upper Sandstone aquifer determined by the time lag method and apparent tidal efficiency method are 4.90×10^3 and 5.22×10^3 respectively compared to the mean value determined by pump tests of 9.08×10^3 imperial gallons per day per square foot.

8.5 Sea-Water Intrusion and Cation Exchange Phenomena at Shippegan, Taylor Island

Flow patterns based on groundwater heads in plan and profile, and isochlor patterns indicate that incipient sea-water intrusion follows a "V" shaped pattern from the fresh-saline water boundary to the pumping well. The apex of the "V" is the pumping well and the extremities of the "V" are flow divides terminated by stagnation points on the recharge boundary. Sea-water intrusion occurs when the dividing flow line produced by the pumping well cone of depression superimposed on the natural flow of fresh water to the sea, reaches the saline recharge boundary. Seaward flow through the transition zone of a sea-water intrusion wedge takes place during periods of high groundwater stage when the dividing flow line is located in close proximity to the pumping well.

Brackish and saline groundwater from the diffusion zone of the sea-water intrusion wedge contain an excess of calcium offset by deficiencies of sodium and potassium. Cation exchange in the interstitial illite-chlorite clay of the Upper Sandstone aquifer accounts for this phenomena.

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APPENDIX A

CHEMICAL ANALYSES OF WATER SAMPLES FROM TAYLOR ISLAND , NEW BRUNSWICK

APPENDIX B

DATA ON WELLS AND PIEZOMETERS, TAYLOR ISLAND, NEW BRUNSWICK

						Analyses in parts per million (p.p.m.)															Alkalinities								Ions in equivalents per million (e.p.m.)								
																													Cations				Anions				
Sample No. Inland Waters Branch	Area	Well or Piezometer (P)	Depth in Feet	Date of Sampling	Aquifer	Ca	Mg	Fe	Mn	Cu	Zn	Na	K	HCO_3	SO_4	Cl	Fl	PO_4	NO_3	Si	Phenol-phthalein as $CaCO_3$	Methyl Orange	Hardness as $CaCO_3$	Total Dissolved Solids	Specific Conductance (mhos x 10^{-6})	pH	Colour in Hazen Units	Turbidity	Na	K	Ca	Mg	HCO_3	SO_4	Cl	Soluble Sodium Percentage	Sodium Adsorption Ratio
974-E-8	Shippegan	69C	52	15/08/68	I	1150.	820.	24.	7.	0.90	13.	2700.	19.0	338.	592.	7600.	1.2	0.00	0.00	7.2	0.0	277.	6241.	13100.	22090.	6.3	25	700.	117.5	0.49	57.4	67.4	5.54	12.3	214.3	48	15
971-E-8	Shippegan	73C	39	15/08/68	I	950.	465.	19.	7.	0.21	6.5	3150.	15.0	160.	864.	6800.	0.90	0.00	0.14	4.6	0.0	131.	4282.	12360.9	20876.	7.5	5	140.	137.0	0.38	47.4	38.2	2.62	17.9	191.8	61	21
956-E-8	Gull Pond Peat Bog Ditch	Ditch Water		6/06/68	peat	3.0	0.8	0.02	0.00	0.04	0.02	6.1	0.5	2.2	4.5	13.8	0.05	0.26	0.00	0.0	0.0	1.8	10.8	30.1	66.1	4.7	225	0.42	0.27	0.01	0.15	0.07	0.04	0.09	0.39	54	0.8
1006-E-8	Shippegan	G	30	21/08/68	I	285.	75.0	0.29	0.20	0.08	0.08	430.	9.3	62.9	132.	1250.	0.50	0.00	0.19	7.6	0.0	51.6	1019.	4037.	2221.	7.0	0	5.9	18.71	0.24	14.22	6.15	1.03	2.75	35.25	48.0	5.4
1005-E-8	Shippegan	60	17	21/08/68	Ia	500.	575.	14.	0.00	0.11	0.11	3150.	62.0	133.	1041.	6800.	0.90	0.00	0.00	8.5	0.0	109.	3612.	12217.	22927.	7.3	0	18.	137.0	1.59	24.95	47.29	2.18	21.67	191.76	65	23
1011-E-8	Shippegan	27	20	21/08/68	I	135.	50.	0.03	0.00	0.01	0.80	500.	10.5	131.	136.	950.	0.20	0.00	0.48	7.0	0.0	108.	543.	18540.	3565.	7.5	0	0.47	21.75	0.27	6.74	4.11	2.15	2.83	26.8	66	9.3
1014-E-8	Shippegan	7	20	21/08/68	I	345.	190.	10.	0.00	0.08	0.10	1260.	10.5	74.6	362.	2700.	0.30	0.00	0.30	8.1	0.0	61.2	1644.	4923.	8886.	7.1	0	17.	54.81	0.27	17.22	15.63	1.22	7.54	76.14	60	12
1008-E-8	Shippegan	10	75	21/08/68	I	48.0	25.4	4.2	1.5	0.44	0.22	115.	8.2	10.5	35.2	300.	0.30	0.00	0.36	9.4	0.0	8.6	224.	553.	1082.	6.0	0	33.	5.00	0.21	2.40	2.06	0.17	0.73	8.46	51	3.3
961-E-8	Shippegan	67D	20	21/08/68	I	32.5	5.2	0.80	0.94	0.01	0.08	13.5	3.8	125.	8.1	20.6	0.09	0.49	0.00	10.4	0.0	103.	103.	171.	273.	6.7	5	1.8	0.59	0.10	1.62	0.43	2.05	0.17	0.58	20	0.4
1015-E-8	Shippegan	42	20	21/08/68	II	23.5	5.2	0.41	0.05	0.06	0.08	12.5	4.5	81.1	6.3	24.0	0.25	0.00	0.12	10.4	0.0	66.5	79.8	135.9	238.	7.5	5	1.1	0.54	0.12	1.17	0.43	1.33	0.13	0.68	24	0.6
1000-E-8	Shippegan	68A	60	20/08/68	II	950.	415.	2.4	1.9	-	0.13	2000.	11.5	141.	500.	5400.	0.75	0.00	0.00	9.2	0.0	116.	4072.	8925.	15716.	7.2	0	18.	87.0	0.29	47.41	34.13	2.31	10.41	152.3	51	12.7
959-E-8	Shippegan Gully	78A	25	5/08/68	I	65.0	15.5	0.50	0.58	0.01	0.02	14.5	4.8	224.	54.3	7.7	0.1	0.00	0.00	12.4	0.0	184.	226.	309.	483.	7.6	20	15.	0.63	0.12	3.24	1.27	3.67	1.13	0.22	12	0.4
1002-E-8	Shippegan	33	50	20/08/68	I	22.2	3.9	0.07	0.08	0.02	0.03	7.6	0.5	81.4	4.5	11.2	0.25	0.00	0.00	10.1	0.0	66.9	71.4	109.	180.	7.6	5	26.	0.33	0.01	1.11	0.32	1.33	0.09	0.32	19	0.4
983-E-8	Shippegan	69D	15	15/08/68	I	22.3	2.3	1.2	0.90	0.04	3.3	13.5	6.0	62.4	31.7	16.0	0.30	0.00	0.00	2.0	0.0	51.2	65.1	134.	208.	7.1	40	0.29	0.59	0.15	1.11	0.19	1.02	0.65	0.45	28	0.7
1004-E-8	Haut Shippegan	64A	50	20/08/68	I	39.5	6.4	4.0	1.00	0.04	0.11	12.5	1.1	128.	9.0	29.0	0.40	0.00	0.00	8.1	0.0	105.	125.	190.	307.	7.6	5	180.	0.54	0.03	1.97	0.53	2.10	0.19	0.82	17	0.5
1012-E-8	Shippegan	44	20	21/08/68	II	16.6	2.1	0.0	0.00	0.01	0.11	8.2	0.6	49.9	7.2	12.9	0.20	0.00	0.00	6.2	0.0	40.9	50.0	84.0	146.	7.0	5	46.	0.36	0.02	0.83	0.17	0.82	0.15	0.36	26	0.5
1007-E-8	Shippegan	24	20	21/08/68	I	170.	42.0	0.07	0.00	0.06	0.17	540.	9.0	127.	114.	1050.	0.40	0.00	0.41	7.0	0.0	104.	597.	1995.	3654.	7.4	0	0.12	23.49	0.23	8.48	3.45	2.08	2.37	29.61	6.6	9.6
996-E-8	Shippegan	68A	20	20/08/68	I	380.	180.	3.0	0.20	0.06	0.06	510.	5.9	113.	106.	1750.	0.20	0.00	0.00	7.7	0.0	92.4	1688.	2999.	5694.	7.3	5	32.	22.19	0.15	18.96	14.80	1.85	2.20	49.35	39	5.4
998-E-8	Shippegan	56	20	20/08/68	Ia	50.0	31.5	7.4	0.20	0.05	0.03	150.	6.8	82.7	52.8	330.	0.80	0.00	0.00	0.00	0.0	67.9	254.	670.	1281.	7.4	5	34.	6.53	0.17	2.50	2.59	1.36	1.10	9.31	54	4.1
982-E-8	Shippegan	74B	38	15/08/68	I	450.	600.	51.	1.3	0.54	4.6	5350.	87.5	229.	1320.	9900.	1.5	0.00	0.00	3.9	0.0	188.	3589.	17883.	28090.	7.6	20	180.	232.7	2.24	22.46	49.34	3.75	27.50	279.2	75	39
978-E-8	Shippegan	69A	178	15/08/68	III	500.	450.	19.6	7.4	0.32	36.0	2900.	34.0	362.	1092.	5800.	0.45	0.00	0.00	4.3	0.0	297.	3098.	11022.	16692.	7.3	15	0.20	126.1	0.87	24.95	37.01	5.93	22.73	163.6	66	23
979-E-8	Shippegan	73A	147	15/08/68	III	650.	430.	18.4	1.0	0.18	5.9	3450.	39.5	163.	2048.	6000.	0.56	0.00	0.00	3.6	0.0	134.	3389.	12728.	18519.	7.2	15	290.	150.0	1.01	32.44	35.36	2.67	42.64	169.2	68	26
981-E-8	Shippegan	69B	137	15/08/68	III	650.	70.0	12.4	4.6	0.12	24.0	640.	20.0	316.	1403.	900.	0.25	0.00	0.00	7.5	0.0	260.	1912.	3687.	4969.	6.9	5	56.	19.14	0.51	32.44	5.76	5.18	29.21	25.38	33	4.4
1003-E-8	Shippegan	60	26	20/08/68	I	500.	600.	10.0	0.00	0.19	0.06	4125.	75.0	133.	1086.	8000.	1.0	0.00	0.10	8.4	0.0	109.	3715.	14671.	23980.	7.2	0	22.	179.4	1.92	24.95	49.34	2.18	22.61	225.60	70	29
994-E-8	Shippegan	56	75	20/08/68	II	1000.	820.	5.0	0.00	0.17	0.03	4375.	34.5	231.	1448.	9900.	1.74	0.00	0.00	8.1	0.0	192.	5867.	17708.	31755.	7.3	5	34.	190.3	0.88	49.9	67.4	3.82	30.15	279.2	62	25
1001-E-8	Shippegan	68A	40	20/08/68	I	440.	190.	3.4	0.16	0.07	0.08	590.	5.9	73.4	114.	2050.	0.50	0.00	0.00	8.7	0.0	60.2	1879.	3439.	6143.	7.1	5	23.	25.66	0.15	21.96	15.63	1.20	2.37	57.81	41	6.1
989-E-8	0.75 sea water 0.25 distilled water			16/08/68		260.	800.	0.26	0.00	0.37	0.08	6250.	170.	172.	1592.	10500.	1.78	0.00	0.00	2.3	0.0	141.	3938.	19661.	32025.	7.6	5	1.5	271.9	4.35	12.97	65.79	2.82	33.15	296.10	77	43
990-E-8	Shippegan	56	45	20/08/68	I	395.	420.	3.4	0.00	0.30	0.06	2400.	32.0	168.	682.	4700.	1.00	0.00	0.00	5.9	0.0	136.	2713.	8721.	14510.	7.6	5	15.	104.4	0.82	19.71	34.54	2.75	14.20	132.54	65	20
992-E-8	Shippegan	rain water		20/08/68		3.5	1.0	0.60	0.00	0.03	0.01	1.7	0.5	13.4	1.8	2.7	0.20	2.8	0.00	0.00	0.0	11.0	12.9	21.4	32.7	6.0	5	1.2	0.07	0.01	0.17	0.08	0.22	0.04	0.08	20	0.2
1020-E-8	Shippegan	10	20	21/08/68	I	70.0	8.5	2.4	1.3	0.04	0.08	31.5	2.0	253.	7.2	51.2	0.05	0.00	0.00	12.4	0.0	208.	210.	339.	540.	7.7	5	4.0	1.37	0.05	3.49	0.70	4.15	0.15	1.44	23	0.9
1021-E-8	Shippegan	36	20	21/08/68	I	37.0	10.5	0.25	0.05	0.07	0.20	150.	6.6	123.	36.2	225.	0.08	0.00	0.40	6.8	0.0	101.	136.	629.	970.	7.5	0	2.2	6.87	0.17	1.85	0.86	2.02	0.75	6.35	70.4	5.9
1022-E-8	Shippegan	45	20	21/08/68	I	19.5	5.0	0.96	0.18	0.08	0.11	9.5	3.8	94.7	4.5	10.8	0.05	0.00	0.00	10.1	0.0	77.7	69.3	121.	203.	7.6	5	16.	0.41	0.10	0.97	0.41	1.55	0.10	0.30	21.3	0.5
969-E-8	Gull Lake Peat bog	HB2A	218	14/08/68	IV	75.0	17.6	9.2	5.2	0.08	0.18	8.9	1.6	316.	3.6	18.6	0.18	0.00	0.00	15.6	0.0	259.	260.	346.	536.	7.4	5	44.	0.39	0.04	3.74	1.43	5.18	0.07	0.52	6.3	0.2
985-E-8	Shippegan	100	20	16/08/68	I	29.5	3.7	0.13	0.00	0.41	0.15	10.5	1.2	83.1	8.8	20.0	0.10	0.00	0.12	9.3	0.0	68.2	88.9	133.	228.	7.5	0	0.21	0.46	0.03	1.47	0.30	1.36	0.18	0.56	20.1	1.3
986-E-8	Shippegan Harbor	sea water		16/08/68		325.	1050.	0.70	0.00	0.18	0.06	9250.	225.	187.	2093.	15400.	2.5	0.00	0.30	0.00	0.0	153.	313.	28458.	41542.	7.3	5	0.39	402.4	5.76	16.22	86.35	3.06	43.58	434.3	78.7	71.3
993-E-8	Shippegan	148	20	20/08/68	I	300.	900.	0.70	3.60	0.20	0.06	8600.	210.	3.55	1765.	14800.	2.6	0.31	0.90	5.0	0.0	292.	4449.	26801.	37737.	7.4	0	0.76	374.1	5.37	14.97	74.02	5.82	36.74	417.36	80.0	58.0
972-E-8	Shippegan	73E	30	15/08/68	I	119.	22.0	37.0	2.1	0.15	0.41	51.0	4.4	114.	26.4	300.	0.10	0.00	0.00	2.6	0.0	93.9	388.	633.	668.	7.6	45	0.06	2.22	0.11	5.94	1.81	1.87	0.55	8.46	19.3	1.1
976-E-8	Shippegan	74A	146	15/08/68	III	600.	800.	25.0	7.0	0.62	3.40	7600.	142.	254.	2093.	12800.	1.9	0.00	0.00	5.6	0.0	209.	4787.	24481.	34757.	7.3	15	200.	330.6	3.63	29.94	65.79	4.16	43.6	360.9	76.3	4.8
967-E-8	Gull Lake Peat bog	HB2A	180	14/08/68	III	67.1	17.6	4.8	7.0	0.14	0.22	8.4	1.7	301.	1.8	13.6	0.18	0.00	0:00	11.2	0.0	247.	240.	314.	543.	7.4	5	16.	0.37	0.04	3.35	1.45	4.93	0.04	0.38	6.5	0.7
960-E-8	Gull Lake Peat bog	HB2A	280	8/08/68	V	65.0	8.0	9.8	4.2	0.18	0.43	35.0	1.9	310.	9.6	16.4	0.16	0.00	0.00	19.6	0.0	253.	195.	322.	595.	7.4	5	61.	1.52	0.05	3.24	0.66	5.08	0.20	0.46	26	1.1
1017-E-8	Shippegan	5	20	21/08/68	I	22.0	4.2	18.6	0.12	0.10	0.10	8.9	0.8	78.8	10.6	14.0	0.00	0.00	0.00	7.8	0.0	64.6	72.2	125.	201.	7.6	5	8.3	0.39	0.02	1.10	0.35	1.29	0.22	0.39	15	0.4
1018-E-8	Shippegan	40	20	21/08/68	II	21.5	3.6	6.2	0.00	0.04	0.10	9.5	3.2	68.0	10.0	22.0	0.05	0.00	0.13	7.9	0.0	55.8	68.5	118.	215.	7.2	5	14.	0.41	0.08	1.07	0.30	1.11	0.21	0.62	20	0.5
999-E-8	Shippegan	60	10	20/08/68	I	500.	550.	9.0	0.00	0.15	0.10	3900.	62.0	203.	1026.	7600.	0.25	0.00	0.00	8.2	0.0	167.	3509.	13755.	22040.	7.2	0	27.	169.7	1.59	24.95	45.20	3.33	21.36	214.3	70	29
1013-E-8	Shippegan	18C	20	21/08/68	I	164.	335.	27.	1.5	0.43	0.27	2500.	46.0	0.0	455.	4900.	0.40	0.00	0.00	1.0	0.0	0.0	1801.	8430.	14590.	4.2	45	160.	108.8	1.18	8.18	27.55	0.0	9.47	138.2	74	26
1016-E-8	Shippegan	41	20	21/08/68	I	21.0	2.5	51.	0.66	-	0.39	8.9	0.6	64.1	6.4	16.0	0.05	0.00	0.00	7.2	0.0	53.2	63.8	179.	171.	6.9	0	17.	0.39	0.06	1.05	0.21	1.05	0.13	0.45	-	-
963-E-8	Gull Lake Peat Bog	HB2A	250	14/08/68	V	80.0	13.5	9.4	6.8	0.25	0.83	8.3	1.5	318.	2.7	13.6	0.16	0.00	0.00	15.2	0.0	262.	255.	308.	540.	7.3	0	18.	0.36	0.04	3.99	1.11	5.21	0.06	0.38	5.9	0.2
966-E-8	Shippegan Portage	HB1A	180	14/08/68	III	44.4	4.0	5.8	1.7	0.07	0.05	11.2	0.8	157.	4.6	12.9	0.09	0.00	0.00	15.2	0.0	129.	132.	178.	295.	7.3	80	36.	0.49	0.03	2.22	0.33	2.57	0.10	0.36	15	0.4
3035-E	Gull Lake Peat Bog	HB2A	20	18/12/68	I	56.0	7.1	<.02	0.61	0.13	0.12	34.5	2.8	213.	70.5	16.4	-	-	<0.02	12.0	5.2	175.	168.9	305.	550.	8.6	15	7.3	1.50	0.07	2.79	0.58	3.49	1.47	0.46	36	1.2
987-E-8	Shippegan Gully	64A	30	16/08/68	I	63.4	7.7	4.2	1.0	0.03	0.03	12.0	1.7	241.	2.6	12.8	0.20	0.13	0.00	17.0	0.0	198.	190.	242.	404.	7.6	45	25.	0.52	0.04	3.16	0.63	3.95	0.05	0.36	11.4	0.4
3044-E	Shippegan Portage	HB1A	200	15/12/67	III	25.2	3.1	<.02	0.34	<0.04	0.08	18.0	1.2	100.4	16.2	11.2	-	-	<0.02	11.3	0.0	82.4	73.6	136.	251.	8.0	10	125.	0.78	0.03	1.26	0.25	1.65	0.34	0.32	33.5	0.9
3037-E	Shippegan Portage	HB1A	60	13/12/67	II	37.6	2.8	<.02	1.4	<0.04	0.01	9.5	0.7	150.	0.8	10.0	-	-	<0.02	11.6	0.0	123.	105.	148.	290.	8.2	40	115.	0.41	0.02	1.88	0.23	2.46	0.02	0.28	16	0.4
3037-E 3045-E	Shippegan Portage	HB1A	220	16/12/67	IV	45.0	3.1	<.02	0.03	<0.02	0.02	20.0	1.8	160.	18.6	12.0	-	-	<0.02	12.0	0.0	131.	125.	192.	300.	8.3	50	600.	0.87	0.05	2.25	0.25	2.62	0.39	0.34	25.2	0.8
3027-E	Gull Lake Peat Bog	HB2A	260	19/12/67	V	60.0	21.0	<.02	0.27	<0.05	0.04	165.0	4.4	191.	273.	140.	-	-	<0.02	11.6	0.0	157.	236.	769.	1285.	8.4	30	3.3	7.18	0.11	2.99	1.73	3.13	5.68	3.95	59.7	4.7
3034-E	Gull Lake Peat Bog	HB2A	160	18/12/67	III	40.0	6.3	<.02	0.18	<0.05	0.02	25.0	4.3	194.	18.6	10.4	-	-	<0.02	11.6	5.8	160.	125.	194.	415.	8.5	15	0.6	1.09	0.11	2.00	0.52	3.19	0.39	0.29	29.2	1.97
3033-E	Gull Lake Peat Bog	HB2A	140	18/12/67	II	44.0	6.6	<.02	0.37	0.21	0.02	21.5	3.3	214.	9.7	18.4	-	-	<0.02	10.2	5.3	176.	137.	211.	400.	8.6	60	0.12	0.94	0.08	2.20	0.54	3.51	0.20	0.29	24.8	0.8
3032-E	Gull Lake Peat Bog	HB2A	120	18/12/67	II	46.0	6.9	<.02	0.61	0.10	0.01	16.0	2.5	213.3	1.6	10.0	-	-	<0.02	10.2	5.6	175.	143.	197.	371.	8.6	15	4.2	0.61	0.06	2.30	0.57	3.50	0.03	0.28	17.1	0.51
3031-E	Gull Lake Peat Bog	HC2A	100	18/12/67	II	46.0	6.6	<.02	0.41	<.02	0.02	17.0	3.0	207.8	0.8	9.6	-	-	<0.02	10.9	3.8	170.5	142.	197.	357.	8.5	100	0.53	0.74	0.08	2.30	0.54	3.41	0.02	0.27	20.2	0.62
3030-E	Gull Lake Peat Bog	HB2A	80	18/12/67	II	52.0	6.6	<.02	0.76	<.02	0.04	22.0	2.8	212.7	1.6	9.4	-	-	<0.02	11.3	5.5	174.5	158.	213.	364.	8.6	30	94.	0.96	0.05	2.59	0.54	3.49	0.03	0.27	22.9	0.76
311	Shippegan	2-3	25	17/03/67	I	113.	39.5	0.04	0.04	-	-	164.	2.7	104.	44.0	480.	0.09	0.06	2.0	11.	0.0	85.3	445.	908.	174.	7.4	5	-	7.13	0.03	5.64	3.25	1.70	0.92	13.5	44	3.4
1080	Shippegan	2	25	6/08/64	I	50.0	72.4	0.28	0.02	0.02	0.02	450.	15.	122.	124.	835.	0.14	0.0	2.8	10.0	0.0	100.	423.	1619.	3150.	7.2	10	1.	19.6	0.38	2.50	5.95	2.00	2.58	23.49	68.9	9.5
3442-G	Shippegan	2	25	2/08/67	I	19.2	4.6	0.11	0.008	-	-	1425.	41.0	77.2	5.7	14.0	0.07	0.09	0.05	9.0	0.0	63.3	66.7	100.	274.	7.6	5	-	0.38	0.02	0.96	0.38	1.27	0.12	0.39	22	0.46
3443-G	Shippegan	11B	20	30/08/67	I	318.	192.	0.13	0.70	-	-	1425.	41.0	36.7	385.	3120.	0.12	0.07	9.7	7.9	0.0	30.1	1584.	5517.	9785.	6.4	5	-	61.99	1.05	15.87	15.79	0.60	8.02	88.0	65	15
3445-G	Shippegan	38	12	30/08/67	I	15.6	5.4	0.97	0.03	-	-	143.	9.7	94.7	45.2	160.	0.09	0.17	27.9	7.9	0.0	77.7	61.	463.	788.	7.4	5	-	6.22	0.25	0.70	0.44	1.55	0.94	4.51	81	8.0
3444-G	Shippegan	5	37	30/08/67	I	144.	46.0	0.62	0.18	-	-	35.0	2.8	58.6	6.9	395.	0.05	0.09	8.8	9.0	0.0	48.1	549.	677.	1439.	6.8	5	-	1.52	0.07	7.19	3.78	0.96	0.14	11.14	12	0.65
3446-G	Shippegan	60	20	30/08/67	I	475.	405.	0.13	0.04	-	-	2625.	64.5	119.	728.	5350.	0.25	0.09	3.7	8.7	0.0	97.2	2854.	9720.	16400.	7.0	10	-	116.19	1.70	23.7	33.3	1.95	15.16	150.9	66	21
3447-G	Shippegan	27B	20	29/08/67	I	128.	46.2	0.15	0.05	-	-	638.	13.	129.	114.	846.	0.10	0.05	16.8	6.6	0.0	106.	510.	1672.	3280.	7.2	5	-	19.05	0.33	6.39	3.80	2.11	2.37	23.9	64	8.4
3448-G	Shippegan	62B	50	14/08/67	II	5.7	2.9	2.4	0.06	-	-	143.	4.9	126.	32.2	140.	0.13	0.16	0.09	7.5	0.0	103.	26.1	398.	714.	7.5	-	-	6.22	0.13	0.28	0.24	2.07	0.67	3.95	91	12
3449-G	Shippegan	56	25	30/08/67	I	61.9	22.9	23.8	0.20	-	-	134.	2.8	88.0	24.9	321.	0.07	0.03	0.5	2.5	0.0	65.6	249.	634.	1249.	7.5	5	-	5.83	0.07	3.09	1.88	1.31	0.52	9.05	54	3.7
3450-G	Shippegan Harbor	sea water		29/08/67		348.	979.	0.19	0.12	-	-	8375.	378.	123.	1994.	15200.	0.2	0.25	3.0	0.6	0.0	101.	4900.	27340.	40450.	7.0	5	-	364.3	9.67	17.37	80.19	2.02	41.52	428.6	77	32
3451-G	Shippegan	7	12	30/08/67	I	64.	23.8	21.5	0.16	-	-	125.	2.3	68.6	25.9	310.	0.13	0.05	.05	3.9	0.0	56.1	258.	610.	1280.	7.2	5	-	5.44	0.06	3.19	1.96	1.12	0.54	8.74	51	3.6
3452-G	Shippegan	2	25	30/08/67	I	20.0	5.7	0.14	0.01	-	-	9.4	0.6	88.1	5.5	13.0	0.09	0.10	0.06	9.5	0.0	72.3	73.4	107.	196.	8.0	5	-	0.41	0.02	1.00	0.47	1.44	0.11	0.37	22	0.48
3453-G	Shippegan	AC	25	30/08/67	I	83.8	16.2	0.35	0.02	-	-	155.	3.3	117.	48.7	320.	0.08	0.06	29.7	7.3	0.0	95.7	276.	722.	1292.	7.5	5	-	6.74	0.08	4.18	1.33	1.92	1.01	9.02	55	4.1
3454-G	Shippegan	6	40	30/08/67	I	444.	479.	0.71	0.12	-	-	3550.	81.5	152.	881.	6900.	0.34	0.08	5.9	8.5	0.0	125.	3080.	12425.	18960.	7.3	5	-	154.4	2.08	22.2	39.4	2.5	18.3	194.6	71	28
3455-G	Shippegan	21	20	29/08/67	I	550.	993.	0.75	2.1	-	-	8250.	253.	187.	2160.	14660.	0.09	0.03	0.08	5.0	0.0	153.	5460.	26940.	41000.	7.7	5	-	358.9	6.47	27.5	81.7	3.1	45.0	413.4	76	48
3456-G	Shippegan	5	58	30/08/67	I	379.	390.	0.72	0.19	-	-	496.	15.8	48.9	5.3	2950.	0.20	0.07	1.1	8.2	0.0	40.1	3050.	4471.	8500.	6.8	5	-	21.6	0.41	28.9	32.1	0.80	0.11	83.2	26	3.9
3457-G	Shippegan	52	91	25/08/67		243.	42.1	6.3	0.65	-	-	92.8	8.5	251.	728.	8.4	0.14	0.11	0.05	12.7	0.0	206.	780.	1260.	1870.	7.4	10	-	4.04	0.22	12.13	3.46	4.11	15.16	0.24	20	1.4
3458-G	Shippegan	15	17	30/08/67	I	287.	181.	10.5	1.0	-	-	1328.	29.0	115.	382.	2840.	0.16	0.07	3.9	8.2	0.0	94.2	1461.	5116.	8700.	7.1	5	-	57.8	0.74	14.3	14.9	1.88	7.95	80.1	66	15
3459-G	Shippegan	37	18	30/08/67	I	56.2	12.5	22.5	0.1	-	-	116.	4.0	83.6	36.6	230.	0.08	0.05	7.7	5.5	0.0	68.6	192.	123.	965.	7.2	5	-	5.05	0.10	2.80	1.03	1.37	0.76	6.49	56	3.6
3460-G	Shippegan	38	48	30/08/67	II	339.	151.	3.90	0.37	-	-	1225.	17.0	130.	337.	2680.	0.12	0.08	17.5	7.9	0.0	107.	1470.	4840.	8697.	7.2	5	-	53.3	0.43	16.9	12.4	2.13	7.02	75.6	64	16
3461-G	Shippegan	AA	20	23/08/67	I	31.2	5.8	0.14	0.0	-	-	90.0	163.	163.	34.5	90.0	0.10	0.10	7.3	11.2	0.0	134.	102.	353.	651.	7.6	5	-	3.92	0.07	1.56	0.48	2.67	0.72	2.54	65	3.9
3462-G	Gull Pond Peat Bog	34	34	30/08/67	I	10.6	3.4	8.6	1.4	-	-	8.4	0.6	37.2	6.9	16.5	0.10	0.16	0.05	13.1	0.0	30.5	40.3	88.2	132.	6.8	80	-	0.37	0.02	0.53	0.28	0.61	0.14	0.47	31	0.57
3463-G	Shippegan	AB	20	29/08/67	I	40.4	5.9	0.12	0.01	-	-	17.5	2.9	130.	11.0	28.0	0.10	0.08	9.1	8.5	0.0	107.	125.	188.	335.	7.7	5	-	0.76	0.07	2.02	0.49	2.13	0.23	0.80	23	0.68
3464-G	Shippegan	24	20	29/08/67	I	274.	204.	0.14	0.05	-	-	1880.	40.5	134.	814.	3270.	0.15	0.07	5.2	8.0	0.0	110.	1523.	6927.	10200.	7.3	5	-	81.8	1.04	13.67	16.78	2.20	16.94	92.2	72	21
3465-G	Shippegan	14A	20	29/08/67	I	375.	758.	0.16	1.9	-	-	7750.	350.	206.	1020.	13640.	0.09	0.06	2.7	6.5	0.0	169.	4221.	24840.	37460.	7.6	5	-	337.1	8.95	18.71	65.62	3.38	37.09	384.7	78	52
3466-G	Haut Shippegan	64A	20	31/08/67	I	42.8	5.1	0.20	3.0	-	-	10.3	2.3	150.	6.4	15.	0.19	0.07	0.86	7.5	0.0	123.	128.	164.	280.	7.2	20	-	0.45	0.06	2.14	0.42	2.46	0.13	0.42	15	0.40
3467-G	Shippegan	18C	20	30/08/67	I	61.7	346.	58.0	2.9	-	-	3550.	185.	183.	934.	5940.	0.46	0.02	0.04	0.5	0.0	150.	1580.	11110.	18050.	7.4	5	-	154.6	4.73	3.08	28.5	3.00	19.45	167.5	81	39
3468-G	Shippegan	AI	20	30/08/67	I	94.3	51.9	0.48	0.05	-	-	146.	4.3	83.0	51.2	440.	0.09	0.08	37.8	8.0	0.0	68.1	449.	875.	1680.	6.9	5	-	6.35	0.11	4.71	4.27	1.36	1.07	12.4	41	3.9
3469-G	Shippegan	25	25	29/08/67	I	183.	16.5	0.20	0.0	-	-	480.	7.7	121.	240.	900.	0.12	0.08	5.6	8.5	0.0	99.2	525.	1901.	3180.	7.4	5	-	20.88	0.20	9.13	1.36	1.98	5.00	25.4	66	9.1
3470-G	Shippegan	26	15	27/08/67	I	159.	46.4	0.17	0.04	-	-	532.	9.7	147.	130.	1090.	0.12	0.08	10.0	7.0	0.0	121.	588.	467.	3848.	7.6	5	-	23.14	0.25	7.93	3.82	2.41	2.71	30.7	66	9.6
3471-G	Shippegan	AH	25	30/08/67	I	57.7	7.7	0.11	0.01	-	-	48.8	3.6	122.	26.4	94.0	0.05	0.09	27.2	7.7	0.0	99.8	176.	331.	594.	7.6	5	-	2.12	0.09	2.88	0.63	2.00	0.51	2.65	37	1.6
3472-G	Shippegan	19	50	29/08/67	II	565.	968.	4.40	2.6	-	-	8080.	253.	193.	2125.	15400.	0.97	0.04	0.02	5.3	0.0	158.	5395.	27690.	38011.	8.0	5	-	351.5	6.47	28.2	79.6	3.16	44.2	434.3	75	48
3473-G	Haut Shippegan	64A	137	31/08/67	III	92.7	21.3	7.90	1.7	-	-	156.	5.0	168.	69.4	320.	0.21	0.08	0.08	7.8	0.0	138.	319.	755.	1511.	7.4	5	-	6.79	0.13	4.63	1.75	2.75	1.44	9.02	51	3.0
3474-G	Shippegan	rain water		30/08/67		2.8	8.0	1.00	0.8	-	-	6.0	2.5	7.4	-	-	0.09	0.24	0.65	0.3	0.0	6.1	4.0	29.06	69.7	5.0	10	-	0.26	0.06	0.14	0.66	0.12	-	-	64.1	1.3
973-E-8	Shippegan	73B	107	15/08/68	III	50.4	14.5	19.4	0.74	0.14	12.0	570.	6.8	111.	758.	400.	0.60	0.00	0.00	2.6	0.0	91.5	206.	1878.	3025.	7.6	5	0.29	24.8	0.17	2.51	1.19	1.82	15.78	11.28	83.1	17.2
1019-E-8	Shippegan	46	20	21/08/68	I	18.5	4.6	5.8	0.00	0.05	0.06	11.5	3.0	79.8	11.3	12.4	0.05	0.00	0.00	7.1	0.0	65.6	65.1	116.	203.	7.2	10	63.	0.50	0.08	0.92	0.38	1.66	0.23	0.35	23.9	0.6

APPENDIX B

DATA ON WELLS AND PIEZOMETERS, TAYLOR ISLAND, NEW BRUNSWICK

Well or piezometer number	Elevation of top of pipe or casing in feet	Height of top above ground level in feet	Original depth in feet	Depth in 1968 in feet	Diameter in inches	Depth of piezometer point below ground level in feet	Remarks
1			104	0	6		plugged
2	13.73	3.00	103	85	12		pumping
3	13.28	2.00	100	65	6		pumping
4A	11.317	0.40	75.5	0	12		plugged
5	11.31	0.80	88	57	6		
6	12.64	2.18	69	49	6		
7	11.61	2.00	77	20.8	6		
8	10.23		120	0	6		plugged
9	9.42	1.66	90.0	16.6	6		
10	8.64	0.94	84	80.1	6		
11A			100				covered
12					2		pumping
13A					4		pumping
14A					6		pumping
14B	6.42	0.70	57	26.6	4		
15	9.49	0.95	46	17.4			
16	9.11	1.20	42	0	6		plugged
17	9.72	1.43	55	30.9	6		
18A		0.80	84	19.4	8		
18B	6.42	-1.32	85	41.5	8		
18C	6.52	-1.30	125	78	10		
18D	8.53	0.00	85	81	8		
19		1.85			10		pumping

DATA ON WELLS AND PIEZOMETERS, TAYLOR ISLAND, NEW BRUNSWICK Continued

Well or piezometer number	Elevation of top of pipe or casing in feet	Height of top above ground level in feet	Original depth in feet	Depth in 1968 in feet	Diameter in inches	Depth of piezometer point below ground level in feet	Remarks
20			90		8		pumping
24			90		8		pumping
25			92		6		pumping
26			150		8		pumping
27A			55		6		pumping
27B			55				pumping
28	15.01	3.00	82	42.15	6		pumping
29	13.58	2.03	58.5	55.8	8		
30	12.21	1.00	125	106	6		
31	11.52	0.80	57	49.5	6		
32			105		8		water tower
33	13.30	1.06	80	59.14	8		pumping
34	14.62	2.20	142	124	8		
35	9.45	1.15	133	8.35	8		plugged
36	11.27	1.70	60	44.30	6		
37	9.18	0.00	68	46.95	6		
38	9.62	0.60	59	48.00	6		
39	12.14	1.60	66	27.40	6		
40	9.70	0.40	87	18.60	6		
41	12.54	2.00	180	62.30	8		
42	11.34	0.72	82	35.78	6		
43	10.85	0.00	64	43.7	6		
44	14.38	0.46	65	34.54	6		
45	13.72	1.05	92	26.75	6		
46	13.47	1.85	87	19.5	6		
47	12.97	1.18	89	65	10		
48	14.02	1.52	52	32.38	10		
49	8.75	2.07	85	55.0	6		

DATA ON WELLS AND PIEZOMETERS, TAYLOR ISLAND, NEW BRUNSWICK Continued

Well or piezometer number	Elevation of top of pipe or casing in feet	Height of top above ground level in feet	Original depth in feet	Depth in 1968 in feet	Diameter in inches	Depth of piezometer point below ground level in feet	Remarks
50	8.85	1.20	204	127	8		
51		1.10	100	82.8	10		
52	10.91	1.70	140	90.9	8		
53	7.19	0.75	85	25	6		
54	8.71	0.00	43	43	6		
55	8.47	0.35		25.6	6		
56	8.45	0.20		77.6	6		
57	14.78	0.70	28	27.6	6		
58	14.37	0.78	44	44	4		
59	15.18	0.65		30	6		
60	6.98	0.00		25.4	6		
61A	14.65	1.15	180	180	2	179.89	
61B	12.96	0.00	83		4		
61C	14.02	1.30	82.5		2	76.35	
61D	13.59	0.00	90		4		
61E	14.09	0.44			2	25.61	
62B	8.17	0.20	125		2	83.13	
62C	7.98	0.20			2	39.19	
62D	8.22	0.25			2	10.49	
63A	13.04	1.30	150		2	147.48	
63B	11.64	0.00	84		4		
63C	11.70	0.00	84		4		
63D	11.84	0.25	26		2	29.91	
63E	13.28	1.54	75		2	60.24	
64A	13.62	0.33	135		6		
64B	13.48	0.10	57.2		4		
64C	13.05	0.00	55		4		
64D			58		4		
65A	10.39	0.20	130		6		

DATA ON WELLS AND PIEZOMETERS, TAYLOR ISLAND, NEW BRUNSWICK Continued

Well or piezometer number	Elevation of top of pipe or casing in feet	Height of top above ground level in feet	Original depth in feet	Depth in 1968 in feet	Diameter in inches	Depth of piezometer point below ground level in feet	Remarks
66A	12.25	0.20	138		6		
67A	13.45	1.10	130		2	128.05	
67B	13.37	0.20	91		2		
67C	12.89	0.00	90		4		
67D	13.59	0.17	90		2	86.58	
67E	14.58	1.35	30		2	25.70	
68A	6.75	0.00			6		
69A	10.07	0.50	179		2	176.34	
69B	10.62	1.06	140		2	137.30	
69C	10.04	0.81	53.5		2	50.80	
69D	11.67	1.97	15		2	13.15	
69E	10.39	0.70			2	32.79	
70		1.64	40		6		
71	14.68	1.89		40.00	6		
72				85	10		
73A	7.89	0.58	149.7		2	147.04	
73B	7.93	0.58	110.0		2	107.34	
73C	7.79	0.40	42.0		2	39.34	
73D	8.39	1.14	46.6		6		
73E	7.80	0.43	15		2	13.00	
73F	8.14	0.40	28		2	25.16	
74A	6.08	0.58	150		2	146.04	
74B	6.28	0.35	102		2	98.34	
74C	5.56	0.00	41		2	38.84	
74D	6.23	0.90	10		2	6.93	
74E	6.64	1.56			2	20.63	
75A	10.08	0.41	72.2		6		

DATA ON WELLS AND PIEZOMETERS, TAYLOR ISLAND, NEW BRUNSWICK Continued

Well or piezometer number	Elevation of top of pipe or casing in feet	Height of top above ground level in feet	Original depth in feet	Depth in 1968 in feet	Diameter in inches	Depth of piezometer point below ground level in feet	Remarks
75B	11.23	0.35	140		2	132.90	
75C	11.34	0.80	68		2	63.59	
75D	12.11	1.67	16.94		2	14.09	
75E	10.90	0.20	38.90		2	37.27	
76	6.90	2.00	46		6		
77	7.21	1.20	68		10		
78A	13.05	0.20	112		6		
78B	12.77	0.00	107		4		
78C	13.34	0.00	107		4		
79	11.12	0.80	66		2		
80		2.65			2		
81A	8.88	1.17	110.5		2	103.94	
81B	8.88	0.91	54		2	51.55	
81C	8.94	0.94	10		2	7.86	
82A	13.19	1.28	96.5		2	92.61	
82B	12.83	1.15	62		2	60.01	
82C	14.11	2.37	25.5		2	18.96	
83A	10.13	1.00	111.5		2	103.72	
83B	10.36	1.24	55.5		2	53.15	
83C	10.46	1.34	14		2	11.87	
84A	8.81	1.82	101.3		2	92.64	
84B	8.68	0.60	54		2	50.30	
84C	8.36	0.40	4.81		2		
85A	13.77	1.25	87		2	83.81	
83D	10.07	1.02	10			7.43	
84D	8.52	0.50			2	9.11	
85B	13.90	1.31			2	62.98	

DATA ON WELLS AND PIEZOMETERS, TAYLOR ISLAND, NEW BRUNSWICK Continued

Well or piezometer number	Elevation of top of pipe or casing in feet	Height of top above ground level in feet	Original depth in feet	Depth in 1968 in feet	Diameter in inches	Depth of piezometer point below ground level in feet	Remarks
85C	13.63	1.09			2	40.75	
85D	13.01	0.42			2	6.92	
86	10.87	0.55	65		5		
101		0.67		9.96	6		
102		0.50		14.6	6		
NB1A	13.14	1.10	240	218	6		
NB2A	13.70	0.30	300	280	6	81.84	
NB2C	12.97	0.33	85		4		
NB2D	14.07	0.20	9.8		2	8.45	
1WA	13.68	1.57	72		8		
2WA	14.12	1.60	52		8		
2WB	13.14	0.65	42		6		
3WA	14.72	1.65	50		8		
3WB	14.60	1.65	40		6		
4WA	15.10	1.31	56		8		
4WB			40		6		

APPENDIX C

ABBREVIATED LITHOLOGIC LOGS
OF VERTICAL BOREHOLES,
TAYLOR ISLAND, NEW BRUNSWICK

APPENDIX C

ABBREVIATED LITHOLOGIC LOGS OF VERTICAL BOREHOLES, TAYLOR ISLAND, NEW BRUNSWICK

Borehole 61A

August 9, 1967, Public Works Drill, Site 61, Figure 5.

From	Description	To	Unit No.
0	clay till	4	
4	sandstone	25	I
25	claystone	30	I
30	sandstone	80	I
80	claystone	165	Ia
165	sandstone	180	I
180	end of hole		

Borehole 62A

August 7, 1967, Public Works Drill, Site 62, Figures 4 and 5.

From	Description	To	Unit No.
0	till	2	
2	claystone	35	II
35	sandstone	45	IIa
45	claystone	82	II
82	sandstone	125	III
125	end of hole		

Borehole 63A

August 6, 1967, Public Works Drill, Site 63, Figures 4 and 5.

From	Description	To	Unit No.
0	till	3	
3	sandstone	30	I
30	claystone	50	II
50	sandstone	84	IIa
84	claystone	105	II
105	sandstone	150	III
150	end of hole		

Borehole 63C

July 4, 1968, Public Works Drill, Site 63, Figures 4 and 5.

From	Description	To	Unit No.
0	sandy till	3	
3	sandstone	26	I
26	claystone	55.5	II
55.5	sandstone	83.8	IIa
84	claystone	84.5	III
84.5	end of hole		

Borehole 64A

August 11, 1967, Public Works Drill, Site 64, Figure 5.

From	Description	To	Unit No.
0	till	3	
3	sandstone	56	I
56	claystone	65	Ia
65	sandstone	80	I
80	claystone	87	II
87	sandstone	135	III
135	end of hole		

Borehole 66A

August 8, 1968, Public Works Drill, Site 66, Figure 5.

From	Description	To	Unit No.
0	till	3	
3	sandstone	39	I
39	claystone	40	II
40	sandstone	65	IIa
65	claystone	107	II
107	sandstone	120	III
120	claystone and sandstone	140	III
140	end of hole		

Borehole 67A

August 7, 1967, Public Works Drill, Site 67, Figure 5.

From	Description	To	Unit No.
0	till	3	
3	sandstone	42.5	I
42.5	claystone	63	II
63	sandstone	90	IIa
90	claystone	116	II
116	sandstone	131	III
131	end of hole		

Borehole 68A

July 16, 1968, Public Works Drill, Site 68, Figures 4 and 5.

From	Description	To	Unit No.
0	till	2	
2	sandstone	46.5	I
46.5	claystone	47	Ia
47	sandstone	59.5	I
59.5	claystone	60	II
60	end of hole		

Borehole 69A

June 28, 1968, Public Works Drill, Site 69, Figure 4.

From	Description	To	Unit No.
0	sandy till	3.5	
3.5	sandstone	61	I
61	claystone	128	II
128	sandstone	179	III
179	end of hole		

Borehole 74A

June 13, 1968, Public Works Drill, Site 74, Figure 4.

From	Description	To	Unit No.
0	sandy till	2	
2	claystone	12	Ia
12	sandstone	44	I
44	claystone	68	II
68	sandstone	74	IIa
74	claystone	75	II
75	sandstone	80	IIa
80	claystone	92	II
92	sandstone	103	III
103	claystone	104	III
104	sandstone	115.5	III
115.5	claystone	116.5	III
116.5	sandstone	150	III
150	end of hole		

Borehole 73A

June 19, 1968, Public Works Drill, Site 73A, Figure 4.

From	Description	To	Unit No.
0	sandy till	2	
2	sandstone	15	I
15	claystone	19	Ia
19	sandstone	48	I
48	claystone	73	II
73	sandstone	75	IIa
75	claystone	106	II
106	sandstone	150	III
150	end of hole		

Borehole 75B

June 11, 1968, Public Works Drill, Site 75A, Figure 4.

From	Description	To	Unit No.
0	clayey till	2.5	
2.5	sandstone	30	I
30	claystone	33	Ia
33	sandstone	70	I
70	claystone	129	II
129	sandstone	140	IIa
140	end of hole		

Borehole 77

June 26, 1968, E. Deschenes Drilling, Site 77, Figure 4.

From	Description	To	Unit No.
0	till	21	
21	sandstone	65	I
65	claystone	68	II
68	end of hole		

Borehole 78A

July 11, 1968, Public Works Drill, Site 77, Figure 5.

From	Description	To	Unit No.
0	sandy till	3.5	
3.5	sandstone	24.5	I
24.5	claystone	44.7	I
44.7	sandstone	112	I
112	end of hole		

Borehole NB2B

July 8, 1968, Public Works Drill, Site NB2, Figures 4 and 5.

From	Description	To	Unit No.
0	peat moss	1	
1	clayey till	8	
8	sandstone	30	I
30	claystone	31	
31	sandstone	44.5	I
44.5	claystone	48.5	Ia
48.5	sandstone	83.3	I
83.3	claystone	85	II
85	end of hole		

Borehole 1W

May 20, 1969, Hopper Brothers Drilling, Site 1W, Figures 4 and 5.

From	Description	To	Unit No.
0	sandy till	3	
3	sandstone	68	I
68	claystone	72	II
72	end of hole		

Borehole 2WA

May 28, 1969, Hopper Brothers Drilling, Site 2W, Figure 5.

From	Description	To	Unit No.
0	sandy till	2	
2	sandstone	42	I
42	claystone	62	II
62	end of hole		

Borehole 3WA

June 3, 1969, Hopper Brothers Drilling, Site 3W, Figure 5.

From	Description	To	Unit No.
0	sandy till	2	
2	sandstone	45	I
45	claystone	50	II
50	end of hole		

Borehole 4WA

June 6, 1969, Hopper Brothers Drilling, Site 4W, Figure 5.

From	Description	To	Unit No.
0	sandy till	1	
1	sandstone	52	I
52	claystone	56	II
56	end of hole		

Borehole 81A

June 16, 1969, Hopper Brothers Drilling, Site 81, Figure 5.

From	Description	To	Unit No.
0	clayey till	6	
6	sandstone	39	I
39	claystone	48.5	Ia
48.5	sandstone	80	I
80	claystone	105	II
105	sandstone	110	IIa
110	end of hole		

Borehole 82A

June 10, 1969, Hopper Brothers Drilling, Site 82, Figure 5.

From	Description	To	Unit No.
0	sandy till	2	
2	sandstone	60	I
60	claystone	84.5	Ia
84.5	sandstone	96	I
96	end of hole		

Borehole 83A

June 24, 1969, Hopper Brothers Drilling, Site 83, Figure 5.

From	Description	To	Unit No.
0	clayey till	3	
3	sandstone	19.5	I
19.5	claystone	25.5	Ia
25.5	sandstone	26.5	I
26.5	claystone	41	II
41	sandstone	69.6	IIa
69.6	claystone	103	II
103	sandstone	113.5	III
113.5	end of hole		

Borehole 84A

June 27, 1969, Hopper Brothers Drilling, Site 84, Figure 5.

From	Description	To	Unit No.
0	sandy till	2.4	
2.4	sandstone	7.9	I
7.9	claystone	9	II
9	sandstone, siltstone	14	II
14	claystone	41.5	II
41.5	sandstone	54	IIa
54	claystone	97	II
97	sandstone	100.8	III
100.8	end of hole		

Borehole 85A

July 1, 1969, Hopper Brothers Drilling, Site 85, Figure 5.

From	Description	To	Unit No.
0	sandy till	1	
1	sandstone	38	I
38	claystone	74	II
74	sandstone	84	IIa
84	claystone	87	II
87	end of hole		

Borehole 86

July 3, 1969, Hopper Brothers Drilling, Figure 4.

From	Description	To	Unit No.
0	sandy till	2	
2	sandstone	64	I
64	claystone	65	II
65	end of hole		

Borehole 104

July 8, 1969, Deschenes Drilling, Figure 4.

From	Description	To	Unit No.
0	till	5	
5	sandstone	11	I
11	claystone	44	II
44	sandstone	45	IIa
45	claystone	63.5	II
63.5	end of hole		

Borehole 105

July 14, 1969, Deschenes Drilling, Figure 4.

From	Description	To	Unit No.
0	sandy till	2	
2	sandstone	45	I
45	claystone	46.5	II
46.5	end of hole		

Borehole 2

June 17, 1968, Deschenes Drilling, Figure 4.

From	Description	To	Unit No.
0	sandy till	1	
1	sandstone	65	I
65	claystone	85	II
85	end of hole		

Borehole 4A

June 30, 1968, Deschenes Drilling, 200 feet south of well 2, Figure 4.

From	Description	To	Unit No.
0	till	2	
2	sandstone	66	I
66	claystone	75.5	II

Borehole NB1A

December 12, 1967, Figures 4 and 5.

From	Description	To	Unit No.
0	sandy till	2	
2	sandstone	55	I
55	claystone	135	II
135	sandstone	145	IIa
145	claystone	160	II
160	sandstone and claystone	205	III
205	claystone	240	IV
240	end of hole		

Borehole NB2A

December 17, 1967, Figures 4 and 5.

From	Description	To	Unit No.
0	clayey till	3	
3	sandstone	85	I
85	claystone	145	II
145	sandstone	200	III
200	claystone with	245	IV
245	sandstone with claystone	290	V
290	claystone	300	VI
300	end of hole		

APPENDIX D

TIME-DRAWDOWN AND TIME-RECOVERY DATA FROM SELECTED PUMP TESTS IN WELLS IN THE UPPER SANDSTONE AQUIFER (UNIT I)

APPENDIX D

TIME-DRAWDOWN AND TIME-RECOVERY DATA FROM SELECTED PUMP TESTS IN WELLS IN THE UPPER SANDSTONE AQUIFER (UNIT I)

Pump test on well 2WP, 19:33 hr., July 23 to 19:10 hr., July 26, 1969. Pumping rate Q = 336 imp. gal./min. Observation well 2WB at distance r_1 = 14.9 feet from 2WP, and observation well 2WA at distance r_2 = 46.3 feet from 2WP.

Time since pump test started, t min.	Drawdown s, in observation well 2WB in feet	Drawdown s, in observation well 2WA in feet
0.5	0.18	-
1	0.25	0.02
2	0.26	0.02
3	0.28	0.05
6	0.28	0.06
10	0.30	0.06
15	0.31	0.07
19	0.32	0.08
26	0.33	0.08
35	0.35	0.09
44	0.35	0.09
57	0.35	0.10
80	0.35	0.09
320	0.34	0.11
840	0.34	0.12
990	0.34	0.14

Recharge to the aquifer by return of discharged water is apparent after 57 minutes of pumping in observation well 2WB.

Pump test of reservoir site 320 feet north of well 2WP, 14:15 hr., December 28, 1969 to 13:48 hr., January 3, 1970. Pumping rate Q = 4000 Imp. gal./min. Distance of observation well 2WB from reservoir site r_1 = 320 ft., distance of observation well 4WA from reservoir site r_2 = 1800 feet.

Time since pump test started t, min.	Drawdown s, in observation well 2WB in feet	Drawdown s, in observation well 4WA in feet
70	0.23	0.01
120	0.37	0.02
210	0.43	0.02
380	0.64	0.02
720	0.72	0.03
1440	0.83	0.08
1560	0.85	0.10
2880	1.02	0.21
4320	1.22	0.37
5060		0.45
5760		0.54
6480		0.65
7200		0.77

Time-drawdown plots are shown in Figures 27 and 28.

Pump test on well 4WP, 19:42 hr., August 4 to 10:15 hr., August 6, 1969. Distance of observation well 4WA to 4WP, r = 38.6 feet.

Time since pump test started, t min.	Drawdown s, in observation well 4WA in feet
1	0.24
2	0.26
3	0.25
4	0.26
5	0.27
6	0.28
7	0.28
8	0.28
9	0.28
10	0.29
18	0.28
20	0.28
22	0.29
24	0.29
26	0.30
28	0.31
36	0.31
40	0.31
45	0.31
60	0.31
70	0.31
83	0.31
100	0.31

Recharge to the aquifer by return of discharged water is apparent after 28 minutes of pumping in observation well 4WA. Time-drawdown plots are shown in Figure 23.

Pump test on well 2, started 6:19 p.m. June 18, 1964. Recovery period June 22, 1964, 1:00 p.m. to 2:06 p.m. Pumping rate Q = 900 Imp. gal./min. Distance of observation well 1 from pumping well 2, r = 50 feet.

Time since pumping started t, min.	Time since pumping stopped, t^1, min.	Residual Drawdown s^1, ft.	Calculated Recovery $(s-s^1)$ ft.
1442	2	1.16	3.00
1444	4	1.03	3.13
1446	6	0.94	3.22
1448	8	0.86	3.30
1450	10	0.86	3.30
1452	12	0.80	3.36
1456	16	0.79	3.37
1460	20	0.72	3.44
1464	24	0.68	3.48
1468	28	0.66	3.50
1472	32	0.66	3.50
1476	36	0.62	3.54
1486	46	0.51	3.65
1496	56	0.53	3.63
1506	66	0.49	3.67

A plot of this time-recovery data is given in Figure 25.

Pump test on well 2, started June 21, 1964, 1:00 p.m. Recovery period, June 22, 1964, 1:00 p.m. to 2:06 p.m. Pumping rate Q = 900 Imp. gal./min. Distance of observation well 3 to well 2, r = 100 feet.

Time since pump test started t, min.	Time since pump test stopped, t^1, min.	Ratio t/t^1	Residual Drawdown s^1 in feet
1442	2	721	1.21
1444	4	361	0.96
1446	6	253	0.86
1448	8	181	0.80
1450	10	145	0.80
1452	12	121	0.70
1456	16	92	0.67
1460	20	73	0.63
1464	24	52	0.63
1468	28	52.5	0.56
1472	32	46	0.56
1476	36	46	0.55
1486	46	41	0.47
1496	56	32	0.41
1506	66	23	0.45

A plot of this residual drawdown against t/t^1 is given in Figure 26.

Pump test on well 2, started August 16, 1969, 9:10 hr. Pumping rate Q = 380 Imp. gal./min. Time of observations t = 10 minutes after pumping started.

Observation Well	Drawdown s in observation well in feet	Distance of observation well from pumping well, r in feet
3	0.42	99
86	0.39	125
79	0.32	198
5	0.135	606
68A	0.08	950
6	0.06	1060
30	0.03	1180

A plot of this distance-drawdown data is given in Figure 19.

APPENDIX E

WELL OR PIEZOMETER READINGS

Well Number: NB2C
1 Casing Length: 0.33
2 Elevation of Top: 12.97

	1969			1969 - 1970							
Date	D.T.W.[3]	Elev.[4] of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.
6/18	3.24	9.40	11/28	2.57	10.07						
6/24	4.08	8.56		1970							
7/01	4.53	8.11	1/03	2.17	10.47						
7/08	5.51	7.13	1/16	4.37	8.27						
7/14	5.97	6.67	2/13	7.79	4.85						
7/23	6.08	6.56	2/27	8.06	4.58						
7/29	6.54	6.10	3/13	8.28	4.36						
8/05	6.61	6.03	3/27	8.10	4.54						
8/12	6.09	6.55									
8/18	5.99	6.65									
8/26	6.14	6.50									
9/09	7.11	5.53									
9/13	5.99	6.65									
9/19	6.22	6.42									
9/26	6.65	5.99									
10/03	6.76	5.88									
10/10	6.55	6.09									
10/17	5.27	7.37									
10/24	5.38	7.26									
11/03	5.78	6.86									
11/07	5.92	6.72									
11/14	1.62	11.02									
11/21	1.76	10.88									

1-All measurements in ft. 2-Elevations relate to a m.s.l. datum. 3-Depth to water below ground level. 4-Elevation of water level.

Well Number: 2WB
[1] Casing Length: 0.65
[2] Elevation of Top: 13.14

	1969			1969 - 1970			1970				
Date	D.T.W.[3]	Elev.[4] of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.
6/04	3.34	9.15	11/03	6.91	5.58	7/15	7.15	5.34			
6/05	3.44	9.05	11/07	7.00	5.49	7/22	7.66	4.83			
6/09	4.01	8.48	11/14	3.32	9.17	7/29	8.09	4.40			
6/17	4.53	7.96	11/21	4.19	8.30	8/04	6.57	5.92			
6/23	5.06	7.43	12/05	5.43	7.06	8/13	8.95	3.54			
6/24	5.15	7.34	12/22	4.81	7.68	8/18	9.06	3.43			
7/01	5.76	6.73	12/26	4.43	8.06						
7/08	6.44	6.05		1970							
7/15	6.87	5.62	1/03	4.27	8.22						
7/22	7.00	5.49	1/10	5.61	6.88						
7/29	7.41	5.08	1/16	6.44	6.05						
8/06	7.60	4.89	1/30	7.77	4.72						
8/12	7.82	4.67	2/13	7.81	4.67						
8/18	6.92	5.57	2/27	8.13	4.36						
8/25	7.04	5.45	3/03	8.92	3.57						
9/09	7.64	4.85	3/27	8.71	3.78						
9/13	6.99	5.50	5/25	4.92	7.57						
9/20	6.93	5.56	6/01	4.42	8.07						
9/26	7.23	5.26	6/08	3.93	8.56						
10/03	7.55	4.94	6/15	4.84	7.65						
10/10	7.31	5.18	6/23	5.61	6.88						
10/17	6.36	6.13	7/01	6.12	6.37						
10/24	6.60	5.89	7/06	7.55	4.94						

1-All measurements in ft. 2-Elevations relate to a m.s.l. datum. 3-Depth to water below ground level. 4-Elevation of water level.

Well Number: 4WA
[1] Casing Length: 1.31
[2] Elevation of Top: 15.10

	1969			1969 - 1970			1970				
Date	[3] D.T.W.	Elev. [4] of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.
6/23	6.33	7.46	12/22	5.99	7.80	8/18	10.29	3.50			
7/01	7.08	6.71	12/26	5.46	6.33						
7/08	6.73	7.06		1970							
7/14	8.17	5.62	1/03	5.64	6.15						
7/22	8.25	5.54	1/10	5.91	7.88						
7/29	8.31	5.48	1/16	7.93	5.86						
8/12	9.54	4.25	1/30	9.29	4.50						
8/18	8.16	5.63	2/13	9.51	4.28						
8/25	8.25	5.54	2/27	9.69	4.10						
9/08	9.15	4.64	3/13	10.51	3.28						
9/13	8.40	5.39	3/27	10.39	3.40						
9/19	8.48	5.31	5/25	5.19	8.60						
9/26	8.71	5.08	6/01	5.79	8.00						
10/03	9.01	4.78	6/08	5.51	8.28						
10/10	8.91	5.88	6/15	6.21	7.58						
10/17	8.01	5.78	6/23	7.02	6.77						
10/24	8.05	5.74	7/01	7.69	6.10						
11/03	8.31	5.48	7/06	9.17	4.62						
11/07	8.63	5.16	7/15	7.15	6.64						
11/14	4.46	9.33	7/22	7.02	6.77						
11/21	4.95	8.44	7/29	9.51	4.28						
11/28	5.99	7.80	8/04	9.81	3.98						
12/05	6.71	7.08	8/13	10.52	3.27						

1-All measurements in ft. 2-Elevations relate to a m.s.l. datum. 3-Depth to water below ground level. 4-Elevation of water level.

Well Number: 61B
1 Casing Length: 0.0
2 Elevation of Top: 13.33, 12.96 after 8, 14, 1969

	1968			1969			1969 - 1970			1970	
Date	D.T.W.[3]	Elev. of W.L.[4]	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.
8/19	9.94	3.39	2/22	9.30	4.03	8/18	7.69	5.84	2/27	10.42	2.56
8/27	9.98	3.35	3/02	8.24	5.09	8/26	7.67	5.86	3/03	10.30	2.66
9/02	10.18	3.25	3/08	8.69	5.64	9/08	8.66	4.30	3/27	10.09	2.87
9/10	10.18	3.25	3/15	8.96	5.37	9/13	7.84	5.12			
9/15	10.43	2.90	3/23	9.22	4.11	9/20	7.97	4.99			
9/21	10.60	2.73	3/30	7.85	5.48	9/26	7.29	5.67			
9/28	10.70	2.63	5/03	1.78	11.55	10/03	8.51	4.45			
10/05	10.58	2.75	5/05	1.96	11.37	10/10	8.41	4.55			
10/12	10.66	2.67	5/12	2.06	11.27	10/17	7.64	5.32			
10/19	10.62	2.71	5/20	2.99	10.34	10/24	7.58	4.08			
10/27	6.70	6.63	5/26	3.28	10.05	11/03	7.92	4.04			
11/02	5.48	7.85	6/02	3.88	9.45	11/07	8.17	4.59			
11/16	3.85	9.48	6/09	4.75	8.58	11/14	3.69	9.27			
11/23	2.44	10.89	6/17	5.28	8.05	11/21	4.38	7.58			
11/30	2.94	10.39	6/23	5.94	7.39	11/28	5.56	7.40			
12/07	4.05	9.28	6/24	5.04	7.49	12/05	6.27	6.69			
12/16	3.03	10.30	7/01	6.59	6.94	12/22	5.67	7.29			
12/31	5.02	8.31	7/08	7.23	6.30	12/26	5.20	7.76			
	1969		7/15	7.53	6.00		1970				
1/11	4.30	9.03	7/29	8.11	5.42	1/03	4.87	8.09			
1/25	7.41	5.92	8/05	8.25	5.28	1/16	7.67	5.29			
2/21	6.62	6.71	8/06	8.24	5.29	1/30	8.99	3.97			
2/08	6.62	7.11	8/12	7.68	5.85	2/13	10.16	2.80			

1-All measurements in ft. 2-Elevations relate to a m.s.l. datum. 3-Depth to water below ground level. 4-Elevation of water level.

Well Number: 63C
1 Casing Length: 0.0
2 Elevation of Top: 11.70

	1968 - 1969			1969			1969			1970	
Date	3 D.T.W.	Elev. 4 of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.
8/19	8.92	2.78	3/02	7.23	4.47	7/30	7.07	4.63		1970	
8/27	8.80	2.90	3/05	7.93	3.77	8/05	7.45	4.25	1/03	4.23	7.47
9/02	9.23	2.47	3/08	7.28	4.42	8/06	7.44	4.26	1/16	6.07	5.63
9/10	9.39	2.31	3/15	8.24	3.41	8/13	7.09	4.61	1/30	7.25	4.45
9/14	9.71	1.99	3/23	8.46	3.24	8/19	6.90	4.80	2/13	8.33	3.37
9/21	9.85	1.85	3/29	6.27	5.43	8/26	6.99	4.71	2/27	8.67	3.03
9/28	9.95	1.75	4/07	6.36	5.35	9/08	7.94	3.76	3/13	8.73	2.97
10/12	9.91	1.79	4/19	3.72	7.98	9/13	7.13	4.57	3/27	8.61	3.09
10/19	9.90	1.80	4/28	3.67	8.02	9/19	7.18	4.52			
10/27	5.57	6.13	5/05	3.43	8.27	9/26	7.46	4.24			
11/02	5.41	6.29	5/12	3.58	8.12	10/03	7.63	4.07			
11/16	4.28	7.42	5/20	4.01	7.69	10/10	7.51	4.29			
11/20	3.48	7.86	5/26	4.04	7.66	10/17	6.72	4.98			
11/23	4.14	7.56	6/03	4.49	7.21	10/24	6.72	5.08			
11/30	4.42	7.28	6/09	4.87	6.83	11/03	6.96	4.74			
12/07	4.10	7.60	6/17	5.26	6.44	11/07	7.33	4.37			
12/13	3.95	7.75	6/19	5.29	6.41	11/14	4.15	7.55			
12/31	3.85	7.85	6/24	5.60	6.10	11/21	4.61	7.09			
1/11	1969 3.27	8.43	7/01	5.98	5.72	11/28	4.93	6.77			
1/25	6.26	5.44	7/08	6.45	5.25	12/05	5.59	6.11			
2/02	7.50	4.20	7/15	6.73	4.97	12/22	5.00	6.70			
2/05	7.18	4.52	7/23	7.02	4.68	12/26	4.51	7.19			
2/22	6.83	4.87	7/29	7.30	4.40						

1-All measurements in ft. 2-Elevations relate to a m.s.l. datum. 3-Depth to water below ground level. 4-Elevation of water level.

Well Number: 64A
1 Casing Length: 0.30
2 Elevation of Top: 13.77, 13.32 after 8/7/68

	1967			1968			1969			1969 - 1970	
Date	3 D.T.W.	Elev. 4 of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.
8/17	11.95	1.52	6/09	11.40	2.07	5/12	8.49	4.99	10/24	10.45	2.87
8/19	11.85	1.62	7/16	11.59	1.88	5/20	9.93	3.55	11/03	11.02	2.30
8/31	11.87	1.60	7/31	11.55	1.93	5/26	10.41	3.07	11/07	11.17	2.15
10/31	12.20	1.27	8/06	11.81	1.67	6/02	10.49	2.99	11/14	8.24	5.08
10/15	12.16	1.31	9/13	11.67	1.81	6/09	10.91	2.57	11/21	9.25	4.07
10/01	12.60	0.87	8/17	11.65	1.83	6/17	11.08	2.40	11/28	10.45	2.87
12/02	11.60	1.88	8/18	11.58	1.90	6/24	10.99	2.49	12/05	10.44	2.88
12/14	10.57	2.90	8/23	11.68	1.80	7/01	11.32	2.16	12/22	10.17	3.15
12/28	12.50	0.97	8/27	11.53	1.95	7/08	11.48	2.00	12/26	10.03	3.29
12/29	11.75	1.72	9/10	12.11	1.37	7/15	11.39	2.09		1970	
	1968		9/14	11.57	1.91	7/22	11.38	2.10	1/03	9.67	3.65
4/21	6.00	7.47	9/21	12.02	1.46	7/29	11.58	1.90	1/06	9.79	3.53
4/28	7.29	6.18	9/28	11.87	1.61	8/05	11.58	1.90	1/30	11.37	1.95
5/10	9.94	3.53	10/05	11.66	1.82	8/12	10.87	2.45	2/13	12.82	0.50
5/20	11.04	2.43	10/12	11.95	1.53	8/18	10.87	2.45	2/27	13.31	0.01
5/27	11.10	2.37	10/19	11.64	1.84	8/26	10.83	2.50	3/13	11.55	1.77
6/03	11.25	2.21	10/27	9.32	4.16	9/08	11.36	1.96	3/27	11.21	2.11
6/07	11.37	2.10	11/02	9.26	4.22	9/13	11.07	2.25			
6/09	11.34	2.13	11/13	10.51	2.97	9/19	11.04	2.28			
6/10	11.41	2.06	11/16	8.77	4.71	9/26	11.18	2.14			
6/18	11.52	1.95		1969		10/03	11.21	2.11			
6/24	11.30	2.17	5/05	7.69	5.79	10/10	11.17	2.15			
6/29	11.23	2.24	5/06	7.81	5.67	10/17	10.47	2.85			

1-All measurements in ft. 2-Elevations relate to a m.s.l. datum. 3-Depth to water below ground level. 4-Elevation of water level.

Well Number: 65A
[1] Casing Length: 0.20
[2] Elevation of Top: 10.39

	1968			1968			1969			1969 - 1970	
Date	D.T.W.[3]	Elev.[4] of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.
5/27	4.85	5.23	11/16	2.76	7.32	7/26	2.94	7.14	11/07	6.52	3.67
6/03	5.15	4.93	11/23	2.67	7.41	6/02	3.20	6.88	11/14	3.41	6.78
6/10	5.66	4.42	11/30	2.53	7.55	6/09	4.33	5.75	11/21	3.13	7.06
6/18	6.12	3.96	12/07	2.62	7.46	6/17	4.58	5.50	11/28	3.97	7.22
6/24	6.22	3.86	12/16	0.93	9.15	6/24	5.15	4.93	12/05	4.61	5.58
7/01	6.26	3.82	12/23	1.20	8.88	7/01	5.43	4.65	12/22	4.17	6.02
7/09	6.54	3.54	12/31	0.44	9.64	7/08	6.26	3.82	12/26	3.94	6.25
7/16	6.77	3.31		1969		7/14	6.57	3.51		1970	
7/23	7.18	2.90	1/15	2.15	7.93	7/22	6.75	3.33	1/03	3.79	6.40
7/30	7.57	2.51	1/25	4.36	5.72	7/29	7.00	3.08	1/15	5.44	4.75
8/06	8.20	1.88	2/08	4.35	5.73	8/05	6.97	3.11	1/30	6.67	3.52
8/13	7.75	2.33	2/22	6.52	3.56	8/12	6.45	3.63	2/13	8.21	1.98
8/19	8.28	1.80	3/01	7.10	2.98	8/18	6.48	3.60	2/27	8.36	1.83
8/27	8.50	1.58	3/15	7.30	2.78	8/26	6.19	3.89	3/13	8.60	1.59
9/10	8.54	1.54	3/21	4.82	5.26	9/08	6.98	3.21	8/27	8.42	1.77
9/14	8.45	1.63	3/22	7.13	2.95	9/13	6.24	3.95			
9/21	8.90	1.18	4/01	6.02	4.06	9/19	6.48	3.71			
9/27	8.38	1.70	4/07	6.05	4.03	9/27	7.70	3.49			
10/05	8.70	1.38	4/19	2.67	7.41	10/03	6.65	3.54			
10/12	8.86	1.22	4/28	1.85	8.23	10/10	6.82	3.37			
10/19	8.54	1.54	5/05	1.92	8.16	10/17	5.02	5.17			
10/27	5.52	4.56	5/12	2.07	8.01	10/24	6.14	4.05			
11/10	4.50	5.58	5/20	2.41	7.69	11/03	6.29	3.90			

1-All measurements in ft. 2-Elevations relate to a m.s.l. datum. 3-Depth to water below ground level. 4-Elevation of water level.

Well Number: 66A
1 Casing Length: 0.20
2 Elevation of Top: 12.24, 12.25 after 8/7/68

	1967			1968			1969			1969 - 1970	
Date	3 D.T.W.	Elev. 4 of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.
8/02	7.87	4.17	6/22	5.30	6.75		1969		10/10	6.05	6.00
8/24	7.86	4.18	6/29	5.66	6.39	5/05	1.70	10.34	10/17	5.08	6.97
8/31	8.01	4.03	7/02	5.66	6.39	5/12	1.82	10.22	10/27	5.23	6.82
10/01	8.01	4.03	7/09	6.13	5.92	5/20	2.39	9.65	11/03	5.56	6.49
10/04	6.85	5.19	7/23	7.04	5.01	5/26	2.60	9.44	11/07	5.85	6.20
10/31	7.35	4.69	7/29	7.36	4.69	6/02	2.46	9.58	11/14	3.92	8.13
11/22	7.90	4.14	7/30	7.59	4.46	6/09	3.01	9.04	11/21	3.09	8.96
11/26	6.43	5.61	8/06	7.79	4.26	6/17	4.11	7.93	11/28	3.62	8.43
12/02	6.63	5.41	8/19	8.07	3.98	6/24	4.63	7.41	12/05	4.01	8.04
12/12	7.13	4.91	8/27	7.57	4.48	7/01	4.66	7.38	12/22	3.63	8.42
12/15	5.58	6.46	9/02	7.97	4.08	7/08	5.22	6.82	12/26	3.31	8.74
12/28	6.01	6.03	9/10	8.31	3.74	7/15	5.46	6.58		1970	
	1968		9/14	8.34	3.71	7/22	5.76	6.58	1/03	3.20	8.85
1/27	7.51	4.53	9/21	8.50	3.55	7/29	6.17	5.87	1/16	4.93	7.12
2/24	7.83	4.21	9/28	7.70	4.35	8/05	5.88	6.17	1/30	6.39	5.66
3/19	8.41	4.63	10/05	7.72	4.33	8/12	5.31	6.74	2/13	8.24	3.81
3/21	7.83	4.21	10/12	8.31	3.74	8/18	5.53	6.52	2/27	8.54	3.51
3/29	6.63	5.41	10/19	8.33	3.72	8/26	5.39	6.66	3/13	8.50	3.55
4/21	2.14	9.90	10/27	6.21	5.84	9/08	7.67	4.38			
5/27	4.07	7.98	11/04	5.41	6.64	9/13	5.57	6.48			
6/03	4.47	7.58	11/06	6.78	5.26	9/19	5.92	6.13			
6/10	4.99	7.06	11/23	6.82	5.22	9/26	6.29	5.76			
6/18	5.36	6.68	12/01	8.93	3.11	10/03	6.36	5.69			

1-All measurements in ft. 2-Elevations relate to a m.s.l. datum. 3-Depth to water below ground level. 4-Elevation of water level.

Well Number: 67B
1 Casing Length: 0.20
2 Elevation of Top: 13.37

	1969			1969 - 1970							
Date	3 D.T.W.	Elev. 4 of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.
5/05	1.73	11.44	10/10	8.03	5.14						
5/12	1.92	11.25	10/17	7.29	5.86						
5/20	2.64	10.53	10/24	7.12	6.05						
5/26	2.89	10.28	11/03	7.43	5.74						
6/03	3.60	9.57	11/07	7.72	5.45						
6/09	4.42	8.75	11/14	3.52	9.65						
6/17	5.14	8.03	11/21	3.79	9.38						
6/24	5.57	7.60	11/28	5.07	8.01						
7/01	6.23	6.94	12/05	6.78	6.39						
7/08	6.84	6.33	12/22	5.08	8.09						
7/15	7.28	5.89	12/26	4.57	8.60						
7/23	7.45	5.72		1970							
7/29	7.84	5.33	1/03	4.25	8.92						
7/30	7.87	5.30	1/16	6.32	6.85						
8/05	8.03	5.14	1/30	8.20	4.97						
8/12	7.55	5.62	2/13	9.56	3.61						
8/18	7.37	5.80	2/27	9.83	3.34						
8/26	7.45	5.72	3/13	9.69	3.48						
9/08	8.27	4.90	3/27	9.53	3.64						
9/13	7.63	5.54									
9/19	7.59	5.58									
9/26	7.91	5.26									
10/03	9.16	4.01									

1-All measurements in ft. 2-Elevations relate to a m.s.l. datum. 3-Depth to water below ground level. 4-Elevation of water level.

Well Number: 75A
1 Casing Length: 0.41
2 Elevation of Top: 9.67

	1969			1969 - 1970			1970				
Date	D.T.W.[3]	Elev.[4] of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.
3/15	7.38	2.39	9/08	8.44	1.23	3/27	8.06	1.61			
3/23	7.23	2.44	9/13	8.40	1.27						
3/29	7.18	2.49	9/19	7.87	1.80						
4/07	6.61	3.06	9/27	8.02	1.65						
4/19	6.09	3.58	10/03	7.83	1.84						
4/28	5.03	4.64	10/10	7.84	1.83						
5/03	5.82	3.85	10/17	6.64	3.03						
5/05	5.67	4.00	10/27	7.16	2.51						
5/12	5.83	3.84	11/03	7.47	2.20						
5/20	6.51	3.16	11/07	7.68	1.99						
5/26	6.76	2.91	11/14	7.47	2.93						
6/02	6.54	3.13	11/21	7.97	1.70						
6/17	8.05	1.62	11/28	6.59	3.08						
6/23	7.52	2.15	12/05	6.56	3.11						
6/24	7.44	2.23	12/22	4.19	5.48						
7/01	6.93	2.74	12/26	5.02	4.65						
7/08	7.55	2.12		1970							
7/15	7.63	2.04	1/03	5.87	3.80						
7/23	8.11	1.56	1/16	6.87	2.80						
7/30	7.90	1.77	1/30	7.60	2.07						
8/05	8.08	1.59	2/13	8.39	1.28						
8/13	7.48	2.19	2/27	8.27	1.40						
8/26	7.01	2.66	3/13	8.30	1.37						

1-All measurements in ft. 2-Elevations relate to a m.s.l. datum. 3-Depth to water below ground level. 4-Elevation of water level.

Piezometer Number: 81A
1 Casing Length: 1.17
2 Elevation of Top: 8.88

	1969			1969 - 1970			1970				
Date	3 D.T.W.	Elev. 4 of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.
6/24	1.66	6.05	12/05	1.47	6.24	7/29	3.67	4.10			
7/01	1.99	5.72	12/22	1.31	6.40	8/04	3.84	3.87			
7/08	2.45	5.26	12/26	0.97	6.74	8/13	4.19	3.52			
7/15	2.80	4.91		1970		8/18	3.41	4.30			
7/22	3.95	3.76	1/03	0.75	6.96						
7/29	3.22	4.49	1/06	2.03	5.68						
8/06	3.31	3.40	1/30	3.21	4.50						
8/12	3.17	4.54	1/16	2.03	5.68						
8/18	3.00	4.71	2/13	3.71	4.00						
8/25	2.92	4.79	2/20	3.95	3.76						
9/08	3.51	4.20	2/27	4.29	3.42						
9/13	3.25	4.46	3/13	4.53	3.18						
9/20	3.14	4.57	3/27	4.38	3.33						
9/27	2.86	4.85	5/01	2.26	5.45						
10/03	3.26	4.45	5/25	1.56	6.15						
10/10	3.42	4.29	6/01	1.37	6.34						
10/17	3.07	4.64	6/08	1.31	6.40						
10/24	2.76	4.95	6/15	1.43	6.28						
11/03	2.92	4.79	6/23	1.74	5.97						
11/07	3.12	4.59	7/01	2.31	5.40						
11/14	2.16	5.55	7/06	3.51	4.20						
11/21	0.71	7.00	7/15	3.02	4.69						
11/28	1.09	6.62	7/22	3.07	4.64						

1-All measurements in ft. 2-Elevations relate to a m.s.l. datum. 3-Depth to water below ground level. 4-Elevation of water level.

Piezometer Number: 81B
1 Casing Length: 0.91
2 Elevation of Top: 8.88

	1969			1969 - 1970							
Date	3 D.T.W.	Elev. 4 of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.
6/24	1.78	6.19	12/05	1.65	6.32						
7/01	2.20	5.77	12/22	1.52	6.45						
7/08	2.84	5.13	12/26	0.67	7.30						
7/15	3.02	4.95		1970							
7/22	3.28	4.69	1/03	0.51	7.46						
7/29	3.56	4.41	5/25	1.62	6.35						
8/06	3.67	4.30	6/01	1.19	6.78						
8/12	3.15	4.82	6/08	0.97	7.00						
8/18	3.17	4.80	6/15	1.66	6.31						
8/25	3.14	4.83	6/23	2.04	5.93						
9/08	3.97	4.00	7/01	2.82	5.15						
9/13	3.53	4.44	7/06	2.50	5.47						
9/20	3.44	4.53	7/15	3.51	4.46						
9/27	4.65	3.32	7/22	3.66	4.31						
10/03	3.81	4.16	7/29	4.29	3.68						
10/10	3.80	4.17	8/04	4.51	3.46						
10/17	2.93	5.04	8/13	4.75	3.22						
10/27	2.91	5.06	8/18	4.79	3.18						
11/03	3.38	4.59									
11/07	3.44	4.53									
11/14	+0.20	8.17									
11/21	0.23	7.74									
11/28	1.36	6.61									

1-All measurements in ft. 2-Elevations relate to a m.s.l. datum. 3-Depth to water below ground level. 4-Elevation of water level.

Piezometer Number: 81C
1 Casing Length: 0.94
2 Elevation of Top: 8.94

	1969			1969 - 1970			1970				
Date	3 D.T.W.	Elev. 4 of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.
6/24	2.97	5.03	12/05	2.56	5.44	8/04	5.03	2.97			
7/01	4.13	3.87	12/22	2.48	5.52	8/13	5.13	2.87			
7/08	3.78	4.22	12/26	1.96	6.04	8/18	5.13	2.87			
7/15	3.30	4.70		1970							
7/22	4.12	3.88	1/03	1.75	6.25						
7/29	3.20	4.80	1/16	3.25	4.75						
8/06	4.23	3.77	1/30	4.61	3.39						
8/12	3.62	4.38	2/13	4.70	3.30						
8/18	3.89	4.11	2/27	5.07	2.93						
8/25	3.92	4.18	3/13	5.28	2.72						
9/08	4.63	3.37	3/27	5.04	2.96						
9/13	4.74	3.26	5/01	2.84	5.16						
9/20	4.26	3.74	5/25	2.51	5.49						
9/27	4.29	3.71	6/01	2.26	5.74						
10/03	4.44	3.56	6/08	1.88	6.12						
10/10	4.47	3.53	6/15	2.47	5.53						
10/17	3.51	4.49	6/23	2.97	5.03						
10/27	3.68	4.82	7/01	3.58	4.42						
11/03	4.20	3.80	7/06	2.88	5.12						
11/07	4.11	3.89	7/15	4.28	3.72						
11/14	1.02	6.98	7/22	4.33	3.67						
11/04	1.49	6.51	7/29	4.81	3.19						
11/28	2.48	5.52									

1-All measurements in ft. 2-Elevations relate to a m.s.l. datum. 3-Depth to water below ground level. 4-Elevation of water level.

Piezometer Number: 82A
1 Casing Length: 1.28
2 Elevation of Top: 13.19

1969			1969 - 1970			1970					
Date	3 D.T.W.	Elev. 4 of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.
6/17	4.60	7.31	11/28	4.55	7.36	6/29	7.53	4.38			
6/24	5.04	6.87	12/05	4.80	7.11	8/04	7.83	4.08			
7/01	5.36	6.55	12/22	4.67	7.24	8/13	8.17	3.74			
7/08	6.18	5.73	12/26	4.26	7.65	8/18	8.10	3.81			
7/15	6.64	5.27		1970							
7/22	6.53	5.38	1/03	3.94	7.97						
7/29	6.97	4.94	1/16	5.59	6.32						
8/06	6.57	5.34	1/30	7.01	4.90						
8/12	6.83	5.08	2/13	7.15	4.76						
8/18	6.49	5.42	1/20	7.55	4.36						
8/25	6.40	5.51	2/27	7.93	3.98						
9/08	7.24	4.67	3/13	8.16	3.75						
9/13	6.79	5.12	3/27	7.96	3.95						
9/20	6.76	5.15	5/01	5.53	6.38						
9/27	6.90	5.01	5/25	4.85	7.06						
10/03	7.00	4.91	6/01	4.50	7.41						
10/10	7.15	4.76	6/08	4.39	7.52						
10/17	6.52	5.39	6/15	4.95	6.96						
10/27	6.14	5.77	6/23	4.97	6.94						
11/03	6.52	5.39	7/01	6.05	5.86						
11/07	6.52	5.39	7/06	5.85	6.06						
11/14	4.84	7.07	7/15	6.74	5.17						
11/21	3.56	8.53	7/22	6.64	5.27						

1-All measurements in ft. 2-Elevations relate to a m.s.l. datum. 3-Depth to water below ground level. 4-Elevation of water level.

Piezometer Number: 82B
1 Casing Length: 1.15
2 Elevation of Top: 12.83

	1969			1969 - 1970			1970				
Date	3 D.T.W.	Elev. 4 of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.
6/17	4.73	6.95	11/28	4.95	6.73	7/29	7.95	3.73			
6/24	5.43	6.25	12/05	5.39	6.29	8/04	7.20	4.48			
7/01	5.81	5.87	12/22	5.21	6.47	8/13	8.50	3.18			
7/08	6.48	5.20	12/26	4.46	7.22						
7/15	6.65	5.03		1970							
7/22	6.91	4.77	1/03	4.25	7.43						
7/29	7.19	4.49	1/16	6.42	5.26						
8/06	7.36	4.32	1/30	7.09	4.69						
8/12	6.78	4.90	2/13	7.85	3.83						
8/18	6.80	4.88	2/20	8.26	3.42						
8/25	6.83	4.85	2/27	8.42	3.26						
9/03	7.67	4.01	3/13	8.54	3.14						
9/13	6.89	4.79	3/27	8.41	3.27						
9/20	7.12	4.56	5/01	3.68	8.00						
9/27	7.27	4.41	5/25	5.16	6.52						
10/03	7.50	4.18	6/01	4.86	6.82						
10/10	7.48	4.20	6/08	4.58	7.10						
10/17	6.61	5.07	6/15	5.26	6.42						
10/24	5.67	6.01	6/23	5.74	5.94						
11/03	7.04	4.64	7/01	6.47	5.21						
11/07	7.17	4.51	7/06	6.56	5.12						
11/14	3.51	8.17	7/15	7.19	4.49						
11/27	3.90	7.78	7/22	7.40	4.28						

1-All measurements in ft. 2-Elevations relate to a m.s.l. datum. 3-Depth to water below ground level. 4-Elevation of water level.

Piezometer Number: 82C
[1] Casing Length: 2.37
[2] Elevation of Top: 14.11

	1969			1969 - 1970			1970				
Date	[3] D.T.W.	Elev. [4] of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.
6/17	4.73	7.01	11/28	4.98	6.76	7/29	7.96	5.78			
6/24	5.47	6.27	12/05	5.48	6.26	8/04	8.20	3.54			
7/01	5.85	5.89	12/22	5.36	6.38	8/13	8.51	3.23			
7/08	6.52	5.22	12/26	4.59	7.15	8/18	8.47	3.27			
7/15	6.58	5.16		1970							
7/22	6.92	5.82	1/03	4.38	7.36						
7/29	7.24	4.50	1/16	6.45	4.39						
8/06	7.39	4.35	1/30	7.69	4.05						
8/12	6.82	4.92	2/13	7.88	3.86						
8/19	6.84	4.90	2/20	8.26	3.48						
8/26	5.90	5.34	2/27	8.44	3.30						
9/08	7.70	4.04	3/13	8.68	3.06						
9/13	6.91	4.83	3/27	8.52	3.22						
9/20	7.16	4.58	5/01	5.70	6.04						
9/27	7.28	4.46	5/25	5.17	6.57						
10/03	7.53	4.21	6/01	4.86	6.88						
10/10	7.50	4.24	6/08	4.60	7.14						
10/17	6.65	5.09	6/15	5.29	6.45						
10/27	6.70	5.04	6/23	5.76	5.98						
11/03	7.07	4.67	7/01	6.46	5.28						
11/07	7.23	4.51	7/06	6.58	5.16						
11/14	3.55	8.19	7/15	7.21	4.53						
11/21	3.96	7.78	7/22	7.23	4.51						

1-All measurements in ft. 2-Elevations relate to a m.s.l. datum. 3-Depth to water below ground level. 4-Elevation of water level.

Piezometer Number: 83A
1 Casing Length: 1.00
2 Elevation of top: 10.13

	1969			1969 - 1970			1970				
Date	3 D.T.W.	Elev. 4 of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.
7/01	7.95	1.18	12/22	5.98	3.15	8/13	6.71	2.42			
7/08	7.50	1.63	12/26	5.64	3.49	8/18	6.51	2.62			
7/15	7.32	1.81		1970							
7/22	7.21	1.92	1/03	5.44	3.69						
7/29	7.19	1.94	1/06	5.81	3.32						
8/06	7.27	1.86	1/30	4.69	3.44						
8/12	7.19	1.94	2/13	6.81	2.32						
8/18	7.19	1.94	2/20	5.80	3.33						
8/25	7.84	1.29	2/27	5.85	3.28						
9/08	6.73	2.40	3/13	6.06	3.07						
9/13	6.66	2.47	3/27	5.84	3.29						
9/19	6.69	2.44	5/01	6.40	2.73						
9/27	6.52	2.61	5/25	6.32	2.81						
10/03	7.46	1.67	6/01	6.26	2.87						
10/10	6.43	2.70	6/08	6.28	2.85						
10/17	6.36	2.77	6/15	6.25	2.88						
10/24	6.32	2.81	6/23	6.23	2.90						
11/03	6.30	2.83	7/01	6.38	2.75						
11/07	6.28	2.85	7/06	6.56	2.57						
11/14	6.24	2.89	7/15	6.35	2.78						
11/21	6.18	2.95	7/22	6.35	2.78						
11/28	6.11	3.02	7/29	6.34	2.79						
12/05	6.07	3.06	8/04	6.44	2.69						

1-All measurements in ft. 2-Elevations relate to a m.s.l. datum. 3-Depth to water below ground level. 4-Elevation of water level.

Piezometer Number: 83B
1 Casing Length: 1.24
2 Elevation of Top: 10.36

	1969			1969 - 1970			1970				
Date	3 D.T.W.	Elev. 4 of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.
7/01	4.14	4.98	12/22	3.99	5.13	8/13	5.28	3.84			
7/08	4.60	4.52	12/26	3.85	5.27	8/18	5.12	4.00			
7/15	4.51	4.61		1970							
7/22	5.68	3.43	1/03	3.61	5.51						
7/29	4.60	4.52	1/16	4.21	4.91						
8/06	4.49	4.63	1/30	5.67	3.45						
8/12	4.55	4.57	2/13	4.71	4.41						
8/18	4.50	4.62	2/20	5.08	4.04						
8/25	4.51	4.61	2/27	5.22	3.90						
9/08	4.91	4.21	3/13	5.10	4.02						
9/13	4.59	4.53	3/27	4.93	4.19						
9/19	4.82	4.30	5/01	4.54	4.50						
9/27	4.76	4.36	5/25	4.19	4.93						
10/03	3.31	5.81	6/01	5.18	3.94						
10/10	4.73	4.39	6/08	4.97	4.15						
10/17	4.50	4.62	6/15	4.33	4.79						
10/27	4.50	4.62	6/23	4.09	5.03						
11/03	4.68	4.44	7/01	4.35	4.77						
11/07	3.56	5.56	7/06	4.48	4.64						
11/14	4.18	4.94	7/15	4.79	4.33						
11/21	2.80	6.32	7/22	4.81	4.31						
11/28	4.20	4.92	7/29	5.06	4.06						
12/05	4.06	5.06	8/04	5.00	4.12						

1-All measurements in ft. 2-Elevations relate to a m.s.l. datum. 3-Depth to water below ground level. 4-Elevation of water level.

Piezometer Number: 83C
1 Casing Length: 1.34
2 Elevation of Top: 10.46

	1969			1969 - 1970							
Date	3 D.T.W.	Elev. 4 of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.
7/01	1.56	7.56	12/22	0.19+	9.31						
7/08	2.28	6.84	12/26	0.67+	9.79						
7/15	2.42	6.70		1970							
7/22	2.83	6.29	5/25	0.92	8.20						
7/29	3.24	5.88	6/01	0.44	8.68						
8/06	3.36	5.76	6/08	0.33	8.79						
8/12	2.84	6.28	6/15	0.94	8.18						
8/18	2.75	6.37	6/23	1.78	7.34						
8/25	2.88	6.24	7/01	2.35	6.77						
9/08	3.75	5.37	7/06	2.46	6.66						
9/13	3.03	6.09	7/15	3.30	5.82						
9/19	3.03	6.09	7/22	3.89	5.23						
9/27	3.41	5.71	7/29	4.26	4.86						
10/03	4.59	4.53	8/04	4.65	4.47						
10/10	3.47	5.64	8/13	4.95	4.17						
10/17	2.54	6.58	8/18	5.68	3.44						
10/24	2.22	6.90									
11/03	2.56	6.56									
11/07	2.81	6.31									
11/14	0.87+	9.99									
11/21	0.72+	9.84									
11/28	0.11	9.01									
12/05	0.65	8.47									

1-All measurements in ft. 2-Elevations relate to a m.s.l. datum. 3-Depth to water below ground level. 4-Elevation of water level.

Piezometer Number: 83D
1 Casing Length: 1.02
2 Elevation of Top: 10.07

	1969			1969 - 1970							
Date	3 D.T.W.	Elev. 4 of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.
7/01	1.63	7.42	12/26	+0.52	8.53						
7/08	2.08	6.97		1970							
7/15	2.46	6.59	5/25	0.46	8.59						
7/22	2.60	6.45	6/01	0.43	8.62						
7/29	2.96	6.09	6/08	0.38	8.67						
8/12	3.04	6.01	6/15	0.40	8.65						
8/08	2.85	6.20	6/23	0.73	8.32						
8/25	2.76	6.29	7/01	1.30	7.75						
9/08	3.29	5.76	7/06	1.43	7.62						
9/13	3.28	5.77	7/15	2.18	6.87						
9/19	3.11	5.94	7/22	2.75	6.30						
9/27	3.14	5.91	7/29	3.16	5.89						
10/03	4.45	4.60	8/04	3.58	5.47						
10/10	3.41	5.64	8/13	3.83	5.22						
10/17	3.16	5.89	8/18	4.36	4.69						
10/24	2.73	6.32									
11/03	2.52	6.53									
11/07	2.60	5.45									
11/14	2.01	7.04									
11/21	0.71	8.34									
11/28	0.17	8.88									
12/05	0.23	8.82									
12/22	+0.22	9.27									

1-All measurements in ft. 2-Elevations relate to a m.s.l. datum. 3-Depth to water below ground level. 4-Elevation of water level.

Piezometer Number: 84A
1 Casing Length: 1.82
2 Elevation of Top: 8.81

	1969			1969 - 1970			1970				
Date	3 D.T.W.	Elev. 4 of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.
7/01	3.34	3.65	12/05	3.40	3.59	8/04	4.77	2.22			
7/05	4.03	2.96	12/22	3.23	3.76	8/13	5.12	1.87			
7/08	4.23	2.76	12/26	3.28	3.71	8/18	4.82	2.17			
7/15	4.39	2.60		1970							
7/22	4.53	2.46	1/03	3.03	3.96						
7/29	4.45	2.54	1/16	3.72	3.27						
8/06	4.51	2.48	1/30	4.36	2.63						
8/12	4.05	2.94	2/13	4.57	2.42						
8/18	4.05	2.94	2/20	4.75	2.24						
8/25	3.93	3.06	2/27	5.03	1.96						
9/08	4.67	2.32	3/13	4.49	2.90						
9/13	4.30	2.69	3/27	3.91	3.08						
9/20	4.54	2.45	5/01	3.96	3.03						
9/27	4.58	2.41	5/25	5.08	1.91						
10/03	4.16	2.83	6/01	3.76	3.23						
10/10	4.50	2.49	6/08	3.56	3.43						
10/17	3.77	3.22	6/15	3.90	3.09						
10/27	3.98	3.01	6/23	3.83	3.16						
11/03	4.30	2.69	7/01	4.14	2.85						
11/07	4.29	2.70	7/06	4.30	2.69						
11/14	3.01	3.98	7/15	4.62	2.37						
11/21	2.77	4.22	7/22	4.72	2.27						
11/28	3.56	3.43	7/29	4.87	2.12						

1-All measurements in ft. 2-Elevations relate to a m.s.l. datum. 3-Depth to water below ground level. 4-Elevation of water level.

Piezometer Number: 84B
1 Casing Length: 0.60
2 Elevation of Top: 6.68

	1969			1969 - 1970			1970				
Date	3 D.T.W.	Elev. 4 of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.
7/05	3.83	4.25	12/22	3.49	4.59	8/18	4.78	3.30			
7/08	4.04	4.04	12/26	3.51	4.56						
7/15	3.38	4.20		1970							
7/22	4.10	3.98	1/16	3.56	4.42						
7/29	4.02	4.06	1/30	4.20	3.88						
8/06	4.03	4.05	2/13	4.30	3.78						
8/12	3.87	4.21	2/20	4.42	3.66						
8/18	3.88	4.20	2/27	4.57	3.51						
8/25	3.89	4.19	3/13	4.50	3.58						
9/08	4.33	3.75	3/27	4.33	3.75						
9/13	4.06	4.02	5/01	4.14	3.94						
9/20	4.27	3.81	5/25	3.89	4.19						
9/27	4.00	4.08	6/01	3.86	4.22						
10/03	3.88	4.20	6/08	5.64	3.44						
10/10	4.19	3.89	6/15	3.85	4.23						
10/17	3.95	4.13	6/23	3.73	4.35						
10/27	3.94	4.14	7/01	4.00	4.08						
11/03	4.13	3.95	7/06	4.09	3.99						
11/07	3.98	4.10	7/15	4.47	3.61						
11/14	3.75	4.33	7/22	4.48	3.60						
11/21	3.34	4.74	7/29	4.76	3.32						
11/28	3.71	4.37	8/04	4.67	3.41						
12/05	3.37	4.71	8/13	4.98	3.10						

1-All measurements in ft. 2-Elevations relate to a m.s.l. datum. 3-Depth to water below ground level. 4-Elevation of water level.

Piezometer Number: 84C
1 Casing Length: 0.40
2 Elevation of Top: 8.36

	1969			1969 - 1970			1970				
Date	3 D.T.W.	Elev. 4 of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.
7/01	2.25	5.71	12/05	1.56	6.40	8/13	4.22	3.74			
7/05	2.64	5.32	12/22	1.64	6.32	8/18	4.26	3.70			
7/08	2.69	5.27	12/26	0.60	7.36						
7/18	1.71	6.25		1970							
7/22	2.55	5.41	1/03	3.26	4.70						
7/29	2.18	5.78	1/16	2.94	5.02						
8/06	2.16	5.80	1/30	3.79	4.17						
8/12	2.34	5.62	1/13	4.51	3.45						
8/18	2.38	5.58	1/20	4.13	3.83						
8/25	2.78	5.18	1/27	4.49	3.47						
9/08	3.11	4.85	3/13	5.02	2.94						
9/13	2.27	5.69	3/27	4.79	3.17						
9/20	2.77	5.19	5/25	4.15	3.81						
9/27	3.08	4.88	6/01	1.66	6.30						
10/03	3.22	4.74	6/08	1.85	6.11						
10/10	2.73	5.23	6/15	2.65	5.31						
10/17	3.36	4.60	6/23	2.85	5.11						
10/24	2.50	5.46	7/01	2.38	5.58						
11/03	2.68	5.28	7/06	2.32	5.64						
11/07	2.46	5.50	7/15	3.45	4.51						
11/14	1.00	6.96	7/22	3.60	4.36						
11/21	1.11	6.84	7/29	4.04	3.92						
11/28	1.58	6.38	8/04	3.89	4.07						

1-All measurements are in ft. 2-Elevations relate to a m.s.l. datum. 3-Depth to water below ground level. 4-Elevation of water level.

Piezometer Number: 84D
1 Casing Length: 0.50
2 Elevation of Top: 8.52

	1969			1969 - 1970							
Date	3 D.T.W.	Elev. 4 of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.
7/01	2.31	5.71	12/05	1.55	6.47						
7/05	2.50	5.72	12/22	1.45	6.57						
7/07	2.47	5.55	12/26	0.84	7.18						
7/08	2.58	5.44		1970							
7/15	2.04	5.98	5/25	2.13	5.89						
7/22	2.72	5.30	6/01	1.71	6.31						
7/29	2.69	5.33	6/08	1.76	6.26						
8/06	2.61	5.41	6/15	2.41	5.61						
8/12	2.52	5.50	6/23	2.66	5.36						
8/18	2.52	5.50	7/01	2.53	5.49						
8/25	2.76	5.25	7/06	2.52	5.50						
9/08	4.32	3.70	7/15	4.46	3.56						
9/20	2.83	5.19	7/22	3.71	4.31						
9/27	3.14	4.88	7/29	3.13	4.89						
10/03	2.71	5.31	8/04	4.20	3.82						
10/10	2.93	5.09	8/13	4.39	3.63						
10/17	3.46	4.56	8/18	4.39	3.63						
10/24	2.53	5.49									
11/03	2.73	5.29									
11/07	2.67	5.35									
11/14	0.67	7.35									
11/21	0.97	9.05									
11/28	1.40	6.62									

1-All measurements in ft. 2-Elevations relate to a m.s.l. datum. 3-Depth to water below ground level. 4-Elevation of water level.

Piezometer Number: 85A
1 Casing Length: 1.25
2 Elevation of Top: 13.77

	1969			1970							
Date	3 D.T.W.	Elev. 4 of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.
7/08	6.58	5.94	1/03	4.51	8.01						
7/15	6.92	5.60	1/16	6.45	6.07						
7/22	7.08	5.44	1/30	7.68	7.84						
7/29	7.38	5.14	2/13	7.93	4.59						
8/06	7.58	4.94	2/20	8.25	4.37						
8/13	7.37	5.15	2/27	8.53	3.99						
8/18	7.04	5.48	3/13	8.97	3.55						
8/25	7.08	5.44	3/27	8.77	3.75						
9/08	7.77	4.75	5/01	6.12	6.40						
9/13	7.46	5.06	5/25	5.44	7.08						
9/20	7.47	5.05	6/01	5.21	7.31						
10/03	7.67	4.85	6/08	5.14	7.38						
10/10	7.67	4.85	6/15	5.39	7.13						
10/17	7.15	5.37	6/23	5.97	6.55						
10/27	5.90	6.62	7/01	6.45	6.07						
11/03	7.10	5.42	7/06	6.71	5.81						
11/07	7.33	5.19	7/15	7.25	5.27						
11/14	5.20	7.32	7/22	7.63	4.89						
11/21	4.38	8.14	7/29	8.08	4.44						
11/28	5.05	7.47	8/04	8.45	4.07						
12/05	5.59	6.93	8/13	8.76	3.76						
12/22	5.05	7.47	8/18	9.01	3.51						
12/26	4.73	7.79									

1-All measurements in ft. 2-Elevations relate to a m.s.l. datum. 3-Depth to water below ground level. 4-Elevation of water level.

Piezometer Number: 85B
1 Casing Length: 1.31
2 Elevation of Top: 13.90

	1969			1969 - 1970							
Date	3 D.T.W.	Elev. 4 of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.
7/01	7.07	5.51	1/30	7.22	5.37						
7/27	7.31	5.28	2/13	7.76	4.83						
8/20	7.45	5.14	2/20	7.94	4.65						
8/25	7.03	5.56	2/27	8.24	4.35						
9/08	7.32	5.27	3/13	8.86	3.73						
9/13	7.36	5.23	3/27	8.71	3.88						
9/20	7.29	5.30	5/01	6.00	6.59						
9/27	7.30	5.29	5/25	4.96	7.63						
10/03	7.35	5.24	5/01	4.94	7.65						
10/10	7.41	5.18	6/08	4.91	7.68						
10/17	7.37	5.22	6/16	4.86	7.73						
10/27	6.72	5.87	5/23	5.17	7.42						
11/03	6.75	5.84	7/01	5.68	6.91						
11/07	6.78	5.81	7/06	6.00	6.59						
11/14	4.66	7.93	7/15	6.48	6.11						
11/21	3.79	8.80	7/22	6.91	5.68						
11/28	3.83	8.76	7/29	7.30	5.29						
12/05	3.90	8.69	8/04	7.49	5.10						
12/22	4.49	8.10	8/13	8.59	4.00						
12/26	4.48	8.11	8/18	7.68	4.91						
	1970										
1/03	4.22	8.37									
1/16	6.96	5.63									

1-All measurements in ft. 2-Elevations relate to a m.s.l. datum. 3-Depth to water below ground level. 4-Elevation of water level.

Piezometer Number: 85C
1 Casing Length: 1.09
2 Elevation of Top: 13.63

	1969			1969 - 1970							
Date	3 D.T.W.	Elev. 4 of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.
7/22	6.67	5.87	1/16	6.49	6.05						
7/29	7.12	5.42	1/30	7.31	5.23						
8/12	7.02	5.52	2/13	7.95	4.59						
8/20	7.35	5.19	2/20	8.09	4.45						
8/25	6.86	5.68	2/27	8.81	3.73						
9/08	7.64	4.90	3/13	8.61	3.93						
9/13	7.16	4.38	3/27	8.48	4.06						
9/26	7.04	5.50	5/01	5.62	6.92						
9/27	7.23	5.31	5/25	4.84	7.69						
10/03	7.57	4.97	6/01	4.54	8.00						
10/10	7.48	5.06	6/08	4.52	8.02						
10/17	6.67	5.87	6/15	4.86	7.68						
10/27	6.63	5.91	6/23	5.59	6.95						
11/03	6.89	5.65	7/01	6.24	6.30						
11/07	7.09	5.45	7/06	6.53	6.01						
11/14	3.74	8.80	7/15	7.11	5.43						
11/04	4.00	8.54	7/22	7.59	4.95						
11/28	4.71	7.83	7/29	8.06	4.48						
12/05	5.30	7.24	8/04	8.43	4.11						
12/22	4.18	8.36	8/13	8.91	3.63						
11/26	4.38	8.16	3/18	8.98	3.56						
	1970										
1/03	4.31	8.24									

1-All measurements in ft. 2-Elevations relate to a m.s.l. datum. 3-Depth to water below ground level. 4-Elevation of water level.

Piezometer Number: 85D
1 Casing Length: 0.42
2 Elevation of Top: 13.01

Date	1969 3 D.T.W.	Elev. 4 of W.L.	Date	1969 - 1970 D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.	Date	D.T.W.	Elev. of W.L.
7/08	6.06	6.53	12/26	4.59	8.00						
7/15	6.64	5.95		1970							
7/22	6.77	5.82	1/03	4.27	8.32						
7/29	7.12	5.17	1/16	6.39	6.20						
8/06	7.39	5.20	1/30	7.47	4.12						
8/12	7.02	5.57	2/13	7.95	4.64						
8/18	6.81	5.78	2/20	8.53	4.06						
8/25	6.85	5.74	2/27	8.50	4.09						
9/08	7.55	5.04	5/01	5.40	7.19						
9/13	7.22	5.37	5/25	4.78	7.81						
9/19	6.80	5.79	6/01	4.55	8.04						
9/27	7.18	5.41	6/08	4.17	8.42						
10/03	7.34	5.25	6/15	4.99	7.60						
10/10	7.43	5.16	6/23	5.77	6.82						
10/17	6.63	6.16	7/01	6.32	6.27						
10/27	5.69	6.90	7/06	6.66	5.93						
11/03	6.92	5.67	7/15	7.32	5.27						
11/07	7.16	5.43	7/22	7.84	4.75						
11/14	3.50	9.09	7/29	8.54	4.05						
11/21	3.85	8.64	8/04	dry							
11/28	4.53	8.06	8/13	dry							
12/05	5.17	7.42	8/18	dry							
12/22	4.77	7.82									

1-All measurements in ft. 2-Elevations relate to a m.s.l. datum. 3-Depth to water below ground level. 4-Elevation of water level.