Province of Nova Scotia

DEPARTMENT OF MINES
Groundwater Section

Report 68-2

HYDROGEOLOGY OF THE LOWER MUSQUODOBOIT RIVER VALLEY, NOVA SCOTIA

by

George F. Pinder

HON. DONALD M. SMITH
MINISTER

J.P. NOWLAN, Ph. D
DEPUTY MINISTER

HALIFAX, NOVA SCOTIA
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PREFACE

The Nova Scotia Department of Mines initiated in 1964 an extensive program to evaluate the groundwater resources of the Province of Nova Scotia. This preliminary report on the hydrogeology of the lower Musquodoboit River Valley forms part of a more comprehensive study of the entire Musquodoboit River Valley and of the broader provincial program.

The initial fieldwork for this study was carried out during the summer of 1967 by the Groundwater Section, Nova Scotia Department of Mines, and is a joint undertaking between the Canada Department of Forestry and Rural Development and the Province of Nova Scotia (ARDA project No. 22042).

It should be pointed out that many individuals and other government agencies cooperated in supplying much valuable information and assistance throughout the period of study. To list a few: Dr. J.D. Wright, Director, Geological Division and the staff on the Mineral Resources section, Nova Scotia Department of Mines, the Nova Scotia Research Foundation, and the Nova Scotia Agricultural College at Truro.

It is hoped that through publication of this preliminary report that information will be made available for immediate agricultural, industrial, municipal, and individual water needs, and that a better understanding will be gained of the interrelationships of groundwater and streamflow. It is planned to publish a comprehensive report on the groundwater resources of the whole Musquodoboit River Valley, when the study is completed.

John F. Jones
Chief, Groundwater Section
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Halifax, June 1, 1968

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HYDROGEOLOGY OF THE LOWER MUSQUODOBOIT RIVER VALLEY, NOVA SCOTIA

ABSTRACT

The Musquodoboit River valley is composed of three distinct physiographic segments. The upper segment is a broad, flat-bottomed valley where thick clay till overlies limestone and shale bedrock of the Windsor Group. Limited quantities of good quality water are obtained from the drift while adequate supplies of excessively hard water are pumped from the bedrock. A narrow, rugged, glacial valley, incised in a granite upland, lined laterally with thick kame deposits and filled with glacial outwash, makes up the middle segment of the valley; the water reserves in this area are not presently utilized. The lower segment of the valley, composed of extensively folded and faulted metasedimentary rocks of the Meguma Group, is an erosional plain of low relief. Adequate supplies of iron-rich, poor quality water are obtained from the bedrock in this area. A glacio-fluvial deposit, overlying granite and slate one-half mile north of Musquodoboit Harbour, is capable of yielding large quantities of water of excellent quality; very little water is pumped from this aquifer at the present, but it can be an excellent source for an industrial or municipal water supply.

Experiments conducted on the interrelationship of groundwater discharge and stream chemistry indicate that the concentration of hardness in surface water is sensitive to small changes in stream discharge. Local rock units also strongly influence the stream chemistry since they dictate the composition of both surface runoff and groundwater discharge.

INTRODUCTION

Purpose and Scope of the Investigation

The purpose of the hydrogeological investigations in the Musquodoboit River valley was to determine the quantity and quality of the subsurface water and to study the relationship between these parameters and the groundwater environment. The quantitative assessment of the groundwater resources involved geological mapping of surficial deposits and a pump test conducted on a promising aquifer. The purpose of the mapping program was to delineate deposits of high transmissibility and to outline the various water-bearing formations within the basin. The water quality program was designed to provide basic information on the chemistry of groundwater, its relation to the reservoir rock, and its influence on the composition of surface water.

Location and Physiography of the Area

The Musquodoboit River valley occupies an area of approximately 275 square miles in Halifax and Colchester counties, Nova Scotia (Figs. 1 and 2). There are three distinct physiographic regions in the Musquodoboit River valley. In the upper segment the headwaters of the river drain a flat-topped plateau of slates and quartzites of the Meguma series. Rocks of this series form the sides of a broad southwest trending valley approximately 25 miles in length which is underlain by the relatively soft limestones and shales of the Windsor group. At Wyse Corners the river turns abruptly through an angle of 15 degrees and flows southeastward over Windsor rocks for three miles before it enters a narrow, rugged valley in a granite upland. This nine mile middle segment extends to within a mile of Musquodoboit Harbour. The lower segment of the river flows over the Meguma slates and quartzites which are eroded to a flat surface nearly at sea level. At Musquodoboit Harbour the river is confined for several hundred feet by a steep, narrow gorge before it empties into the head of an estuary seven miles from the Atlantic Coast.

Previous Investigations

The bedrock of the valley was extensively studied at the turn of the century when there was interest in the Gold-bearing series. There has been little interest in the area since this early work of Faribault (1913) although a preliminary map by Stevenson (1955) of the Shubenacadie area includes the vicinity of Middle Musquodoboit.

The surficial deposits in the valley were mentioned by Goldthwait (1924) although there was little information which could be directly applied to hydrogeology. A preliminary map of the surficial geology of the Shubenacadie area including the upper reaches of the Musquodoboit River valley was prepared by

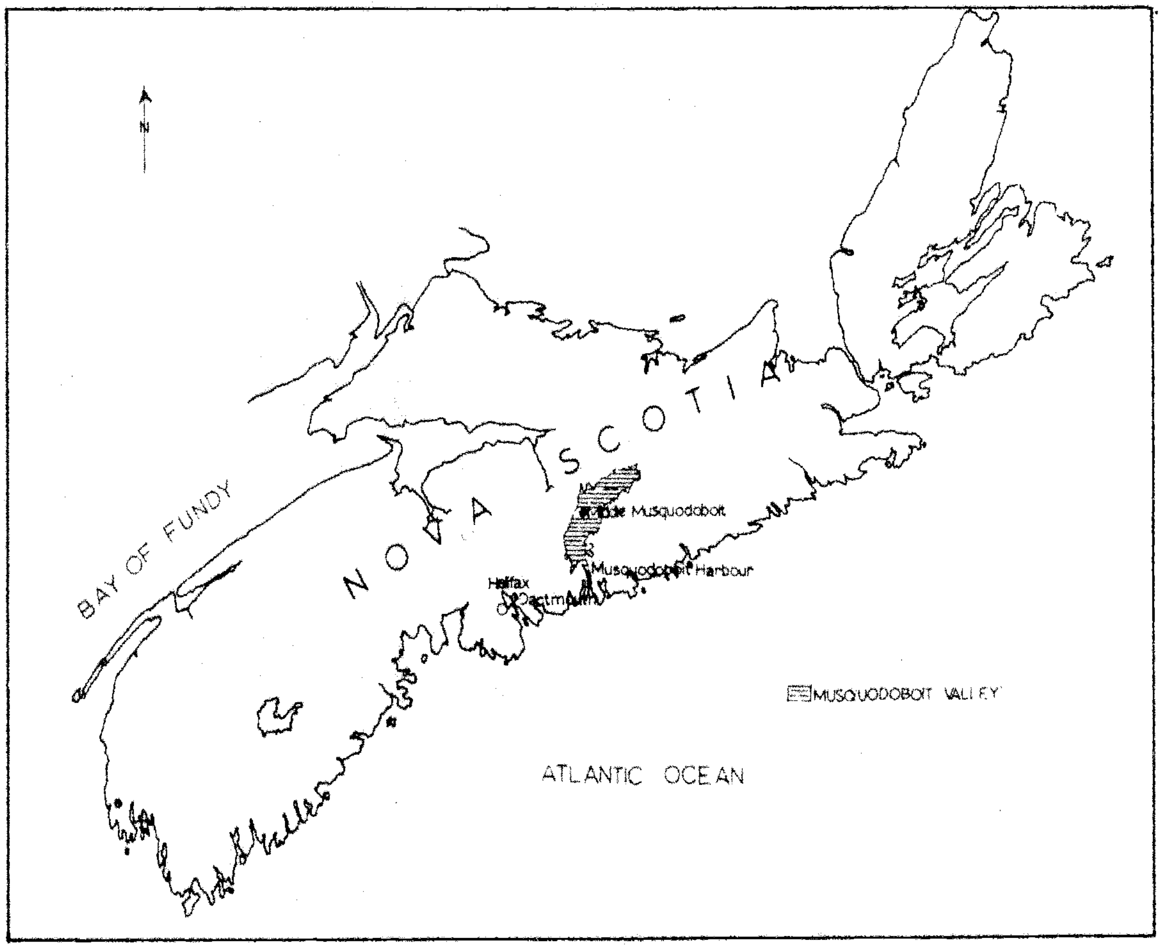

Figure 1. Location of the Musquodoboit River valley.

Hughes (1956). The Soil Survey of Halifax County, by MacDougall, Cann, and Hilchey (1963) is probably the most useful material available on the unconsolidated deposits of the valley. This recent publication shows considerable insight into the mechanics of deposition of the surficial deposits and was very helpful in mapping the Pleistocene geology.

Field Work

During the summer of 1967 the following projects were undertaken in the Musquodoboit River valley:

1. detailed geological mapping of surficial deposits and exposed bedrock south of Middle Musquodoboit (Fig. 2);

2. collection of water samples from selected wells in several lithological units in the valley; these samples were submitted for chemical analysis to the Nova Scotia Agricultural College, Truro;

3. daily collection of water samples from the Musquodoboit River and a tributary during an interval bounded by two major storms;

4. collection of water samples from the Musquodoboit River throughout the summer months at three-day intervals; the samples from (3) and (4) were analyzed in the field; and

5. a pump test of a promising aquifer at Musquodoboit Harbour; water level recorders were installed at selected locations on this site.

The Nova Scotia Department of Mines supplied the necessary field equipment, aerial photographs and topographic maps for the geological mapping during the summer of 1967. A Department of Mines rotary drill and crew were used to bore the pumping and observation wells and to install the turbine pump and water level recorders. Hammer seismic surveys were attempted at several locations by the Nova Scotia Research Foundation with limited success. Selected water samples were submitted to the Nova Scotia Department of Public Health to be tested for bacteriological contamination.

GEOLOGY

Introduction

This section is a discussion of the geologic aspects of the various bedrock and surficial units in the Musquodoboit River valley. Hydrologic aspects of each unit will be discussed in the section on hydrostratigraphic units.

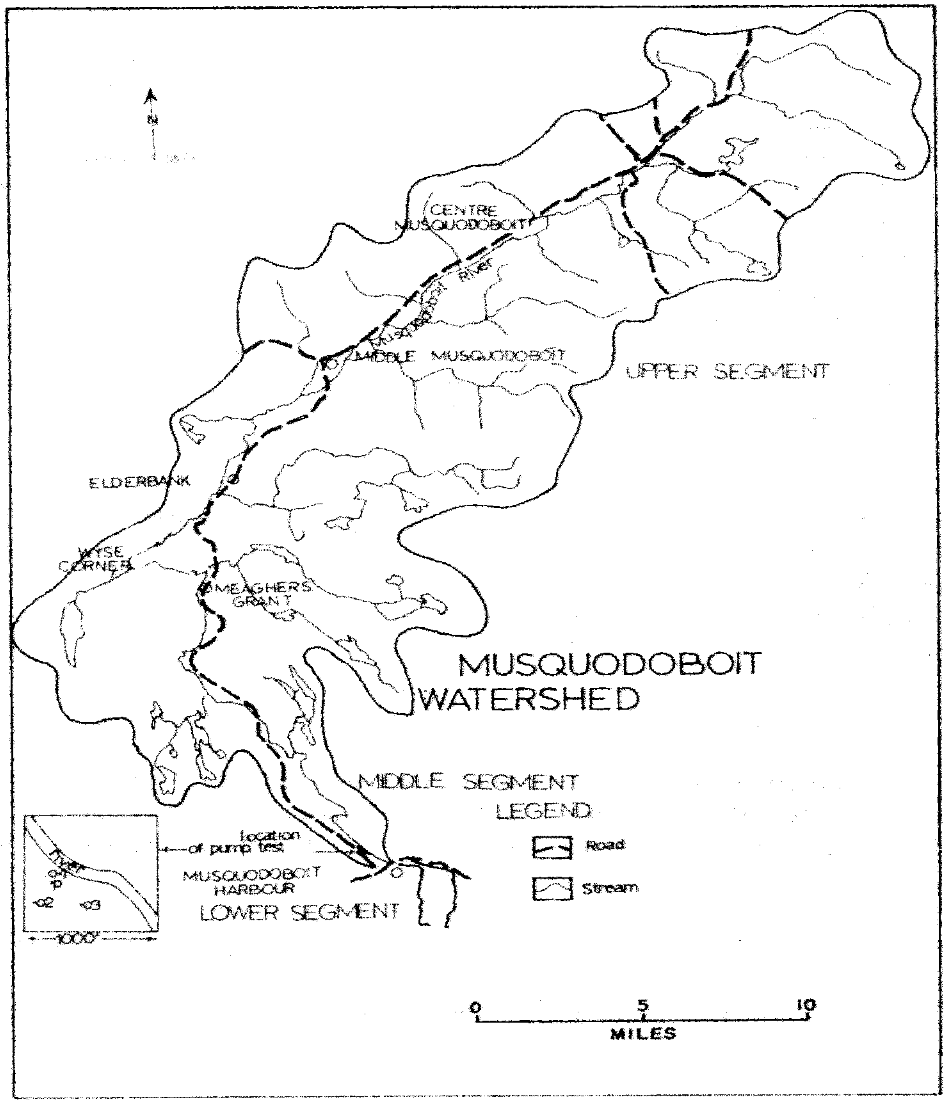

Figure 2. Musquodoboit River basin and the Musquodoboit Harbour well field.

Rock Units

Meguma Group

The Meguma Group outcrops extensively in many areas of the basin. It is found primarily in the lower segment of the valley (Fig. 2 and Map 1) but is also found on the valley sides in the upper segment. The following descriptions are taken from Stevenson (1955): The oldest rocks in the area are those of the Goldenville Formation (Lower Ordovician or possibly pre-Ordovician). They consist of alternating bands of quartzite and slate with quartzite predominant. The quartzite is grey to greenish grey, breaks with a conchoidal fracture, and commonly passes into narrow bands of siliceous, micaceous slate. The Goldenville Formation is conformably overlain by bluish black, ferruginous, graphitic slates of the Halifax Formation (Lower Ordovician). These slates contain narrow bands of schistose, greyish green quartzite rarely exceeding a few feet in thickness. Both the slates and quartzites commonly contain pyrite crystals along the bedding planes.

The Meguma Group of sedimentary rocks has been folded into a series of parallel, northeast-striking folds. The folds are tightly compressed and the strata commonly dip at angles ranging from 60 to 90 degrees. Schistosity is particularly well developed in the more competent quartzitic beds of the Halifax Formation.

Granite

The rugged gorge between Meaghers Grant and Musquodoboit Harbour was eroded in a granite intrusive (Devonian) which trends east-northeast across the valley. The rock consists mostly of a light grey or reddish grey, coarse, porphyritic, biotite granite which is generally studded with large phenocrysts of white or pink-white feldspar. The granite intrudes the Meguma rocks without affecting structures in them. Near the boundary with the Meguma rocks, however, contact metamorphism is apparent and there is generally a gradual transition from slate and quartzite to granite (Faribault, 1913).

Windsor Group

The Meguma Group and granite are overlain unconformably by lower Windsor rocks of Mississippian age. Outcrops of this unit are rare in the valley since it occurs only in the lowland areas where it is obscured by thick drift sequences. Available exposures indicate that the unit consists of nearly flat-lying, interbedded calcareous sandstone, shale and limestone.

Surficial Deposits

Glacial Till

The oldest unconsolidated deposits in the valley are the glacial till units of probable Wisconsin age. The sandy till deposits overlying resistant slates and quartzites of the Meguma Group are generally less than 10 feet thick. Limestones and shales of the Windsor Group, however, are covered by a hard, grey, clayey till which has been found to depths exceeding two hundred feet. Figure 3 illustrates the grain size distribution of these two units, but since each curve represents only one sample, no meaningful quantitative parameters may be determined.

Due to the distribution of the consolidated rock units, the lowlands are covered primarily by clay till while a thin sandy till layer is found over extensive upland areas. The relatively sharp transition between the two till units at bedrock boundaries reflects the close relationship between bedrock lithology and the granulometric and petrographic composition of the overlying till. There is no conclusive evidence in the map area that these units are of different ages and they are subdivided in this discussion only on the basis of lithology.

Lacustrine Deposits

Lacustrine sand, silt and clay is found in many localities in the upper segment of the valley. In many instances the lakes occupied depressions developed by glacial scour. The majority of lakes, however, were remnants of an extensive drainage network fed by glacial meltwater during dissolution of the last ice sheet. Deposits of this type are particularly widespread in a locality immediately south of Middle Musquodoboit (Map 1).

Glacio-fluvial Deposits

The meltwater channels mentioned above were filled by deposits of sand and gravel. This material may be found anywhere in the valley but is particularly abundant in the middle and lower segments. At several points in the middle segment, the underfit Musquodoboit River flows quietly in a U-shaped valley filled with glacial outwash. Along the sides of this valley, numerous kame deposits of angular, medium to coarse sand and fine gravel are present (see Fig. 3). A kame moraine, deposited across part of the valley north of Musquodoboit Harbour, acts as a dam at one end of Kevin Lake. Many of these kame deposits are now exploited as a source of raw material for highways and building construction.

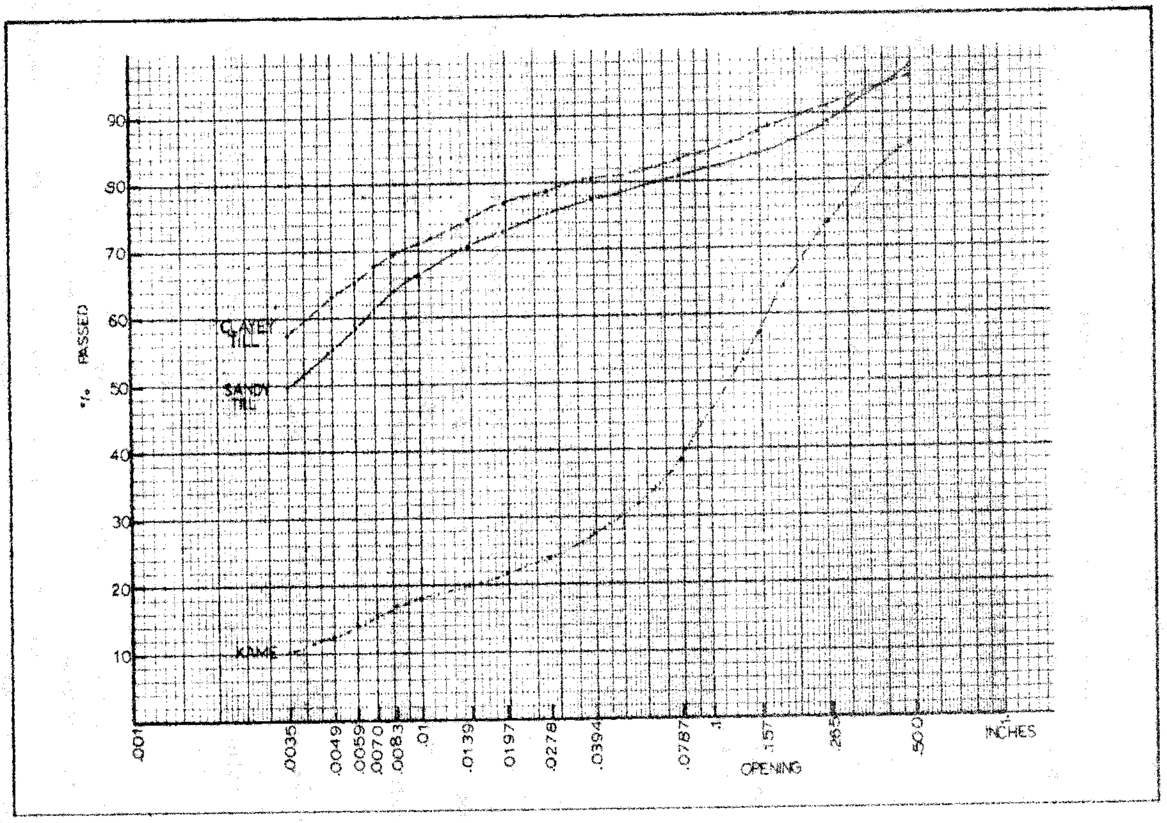

Figure 3. Grain size distribution curves for samples of three different glacial deposits.

Swamp Deposits

Swamp deposits of muck and peat are found in many depressions both in the lowland areas and on the uplands. In the valley bottom the low hydraulic gradient and the relatively impermeable clay till impede vertical drainage and favour the collection of surface water in local depressions. In the middle segment of the valley, the water-table remains near the surface because the glacio-fluvial deposits act as a discharge area for the adjacent highlands and collect surface runoff. As a result large sections of the floodplain in this area are composed of muck and humus and receive clay, silt and fine sand when the river overflows its banks during floods. Swamps in the upland areas are due primarily to the low permeability of the bedrock and to the poorly developed drainage system. Surface water is unable to percolate into the ground after draining to depressions resulting from glacial scour.

Recent Alluvium

Recent alluvial deposits are present along most of the major streams in the upper segment of the valley. They are particulary well developed along the Musquodoboit River south of Middle Musquodoboit and in the vicinity of Meaghers Grant. It is difficult, however, to differentiate glacio-fluvial and recent alluvial deposits in many areas, and the extent of alluvial material in the valley may be overestimated. Limited test boring in the Musquodoboit Harbour area suggests that thick sequences of sands and gravels beneath the present flood plain of the river are, indeed, of glacio-fluvial origin.

On the upland areas and in the middle segment of the valley the streams are actively downcutting their channels and little alluvial material is being deposited.

Recent Beach and Bar Deposits

Recent beach and bar deposits of sand are found only along the Atlantic coast at Martinique Beach and Naufft's Point. Headland cliffs of glacial till predominate at other locations along the coast; in this high energy environment, beaches of cobble and boulder-sized material have been formed.

Geomorphology and Glacial History

Goldthwait (1924) suggested that the headwaters of the Musquodoboit River were located to the northwest of Wyse Corners prior to the first ice advance into Nova Scotia. Recent test drilling in this area indicates that Gay River may, indeed, have been a branch of the present Musquodoboit in pre-glacial times because the present surface is distinctly different from the bedrock topography.

During the early stages of glaciation, narrow tongues of ice made their way along the existing lowlands. The main ice front probably moved southeastward along the Shubenacadie River valley and entered the Musquodoboit River valley at Wyse Corners. The highland of resistant Meguma rocks on the north side of the valley may have acted as an effective barrier to the advancing ice front during these early stages. As the glacier moved southward across the granite upland, it incorporated large blocks of bedrock and reshapped the rugged pass into a typical U-shaped glacial valley. After the ice sheet thickened, local topography no longer dictated the direction of ice movement. Eventually the ice sheet covered the entire area as it advanced southeastward towards the continental shelf and the sea.

After the ice front began to retreat, large quantities of meltwater discharged down the Musquodboit River, and outwash gravels and sands were deposited in the middle and lower segments of the valley. It seems unlikely that the narrow gorge at Musquodoboit Harbour could conduct such volumes of water, and a spillway into Petpeswick Harbour to the west may have existed temporarily. Water may also have discharged down a channel through Bayer Lake north of the present river bed.

Large granite erratics were deposited as ablation material throughout the lower segment of the valley. Some of them were incorporated into kame deposits, particularly along the valley walls. The absence of similar deposits to the north of the granite body is the main reason for proposing a southeast rather than a northwest movement of the ice sheet. This does not, however, preclude the possibility of a later northwest advance of the ice at least as far as the granite gorge.

The ice front retreated northward without developing any recognizable recessional moraines until the ice margin reached the area of Wyse Corners. At this point a thick drift sequence with isolated lenses of stratified sand was deposited, forming a ridge locally known as Nuttall Hill. If the Musquodoboit River once flowed from the northwest, this moraine effectively blocked the passage at this point. The history of the valley above Middle Musquodoboit is uncertain since this area has not been mapped in detail.

HYDROSTRATIGRAPHIC UNITS

Introduction

The petrologic, petrographic, and fossil criteria which classically serve to define a stratigraphic unit for descriptive or correlation purposes may have little bearing on the hydrologic properties of that rock unit. The term hydrostratigraphic unit is introduced to describe a group of geologic materials which have similar water-bearing properties and such units, therefore, may or may not coincide with previously defined stratigraphic units.

The hydrologic properties of particular interest to the geohydrologist are permeability, porosity, aquifer compressibility and the compressibility of the liquid in the interstices of the porous medium. In the following discussion the various geologic units occurring in the basin will be considered in the light of these parameters.

Bedrock Hydrostratigraphic Units

Slate, Quartzite and Granite

The porosity of these rocks is very low due to consolidation, cementation and recrystallization. The permeability in this unit must be attributed to interconnected joints or local porous zones associated with fault planes. Rock units of this type can be considered as porous media only on a very large scale and it is unlikely that a test well would intersect a sufficient number of joints to permit a valid calculation of the aquifer coefficients of storage and transmissibility. Moreover, it is questionable whether the flow of water to the well in such a medium is laminar and, therefore, whether the principles of classical well hydraulics are valid. According to drillers' logs the average yield for nine wells in this unit was 6 igpm, ranging from 3 to 26 igpm. These figures are of little significance in themselves since the driller's pump test generally is of short duration and the local boundary conditions, which are very important in fracture permeability, are completely ignored.

A quantitative discussion of this hydrostratigraphic unit is most meaningful when approached statistically. The probability of intersecting a sufficient number of open joints to provide a domestic supply when drilling to a specified depth can be calculated but has not been attempted in this area. Satisfactory domestic supplies are usually obtained at well depths of 100 to 200 feet. Beyond this depth the joints are more likely to be tight with a resultant decrease in permeability and lower probability of obtaining a satisfactory water supply. Cleavage joints are the most common in the slate, and, since the orientation of the cleavage approaches the vertical in many areas, few joints are likely to be encountered in drilling a vertical hole. The more homogeneous quartzite and granite units generally have fewer joints, but, because their joint patterns depend upon local stress conditions, there is less preference for a vertical orientation.

Limestone and Shales

Limestone and shale units depend primarily on fracture permeability to conduct large quantities of water to a well. Under suitable physical conditions, however, the permeability of limestones can be increased by solution of the rock mass along joints or faults. In such cases groundwater movement may be thought of as open channel rather than porous media flow, and presently there is no meaningful way of treating the dynamics of such a system. The problems associated with limestone aquifers, however, more often involve water quality than quantity (see the discussion of groundwater quality).

The average flow in limestone aquifers in the valley during pump tests is 6 igpm according to reports in drillers' logs. The average well depth for a satisfactory domestic supply is from 100 to 150 feet. It should be noted, however, that thick drift deposits are normally associated with limestone bedrock and more than 100 feet of the well may be cased-off glacial drift.

Shale beds are not generally found to be satisfactory water - yielding zones. Shale has a very low permeability unless it is highly fractured or bedding joints are open and continuous. In the Musquodoboit River valley the shales are believed to be interbedded with limestone and it is difficult to determine which rock type is the source of the water supply.

Surficial Hydrostratigraphic Units

Glacial Till

Because of the porous nature of sandy till, it should yield satisfactory domestic supplies where it is found in sufficiently thick saturated deposits. Unfortunately it generally occurs as a thin veneer on the upland areas and has not been utilized as a source of water supplies.

Extensive agricultural areas are underlain by clay till, and many farms in the valley depend upon it as a source of water for the home and livestock. Water moves primarily along joint planes or through sand or gravel lenses in clay till because it is relatively impermeable to porous flow. Wells in this unit are generally hand dug to less than 30 feet with the result that water shortages are common during dry periods. Many wells are located haphazardly with little regard for the local topography and the potential distribution within the basin. Where sand lenses are encountered, high pumping rates are often possible and water of excellent quality can be anticipated. Springs provide reliable domestic supplies in many locations where permeable water-bearing zones outcrop along valley sides.

Glacio-fluvial and Alluvial Deposits

Glacio-fluvial and alluvial deposits are found in all segments of the valley. Where they are located adjacent to a body of water they are generally saturated to within a few feet of the surface. The high porosity and transmissibility of these deposits, their proximity to recharge boundaries, and their association with discharge areas in the regional flow system indicate that these sediments are capable of supplying large quantities of groundwater for an extended period of time. Few residents in the valley are presently utilizing this source of groundwater.

The thickest sequences of glacio-fluvial material are found adjacent to the Musquodoboit River. On the flood plain north of Musquodoboit Harbour these deposits consist of angular, coarse sand and fine gravel overlain in places by recent alluvial silts, clays, and fine sands. A pump test was run on a well constructed in this aquifer in order to determine the aquifer coefficients of transmissibility and storage, and to evaluate the aquifer as a potential supply for Musquodoboit Harbour where most wells in the slate bedrock yield limited amounts of poor quality water. The flood plain at this point is approximately 4,800 feet wide and extends along the river for about 5,700 feet. Granite bedrock confines the aquifer on three sides; slate and glacial till bound the deposit to the south. At the pumping well, 75 feet of interbedded medium sand to fine gravel (71 feet of which were saturated at the time of the pump test) overlie granite bedrock. The aquifer is fairly uniform in thickness near the river because there are 71 feet of sand and gravel 200 feet from the pumping well. The well field consisted of a six-inch pumping well and three four-inch observation wells (note the location of wells in Fig. 2). The test was conducted using a pumping rate of 350 imperial gallons per minute over a 36 hour period. The coefficients of transmissibility and storage were calculated using time-drawdown data and distance-drawdown data for the three observation wells. The average transmissibility, 150,000 imperial gallons per day/foot, is the highest yet determined for a glacio-fluvial aquifer in Nova Scotia. The coefficient of storage, 7×10^{-2}, is in the water-table range. These coefficients indicate that a properly constructed well in this aquifer could be pumped at 2,000,000 gallons per day for short periods. Since the optimum long term pumping rate is dependent upon the boundary conditions of this hydrologic system, an electric analogue model was built to study it further. This model is being tested and a long-term prediction of the water-yielding potential of this hydrostratigraphic unit will soon be available.

A check on the coefficients of transmissibility and storage of a flood plain aquifer can be made by monitoring the potential in the flood plain during fluctuations in the river stage. This is possible because the movement of water into flood plain sediments during a high river stage and flow to a well are governed by the same principles. Water level recorders have been installed on wells completed for the pump test at Musquodoboit Harbour. Records from these recorders will be used to determine the aquifer coefficients. It will be interesting to see if the aquifer coefficients determined by this method are consistent with the values obtained from the pump test.

CHEMICAL CHARACTERISTICS OF GROUNDWATER

Introduction

Several programs involving water chemistry were conducted in the valley during the field season. In this discussion the quality of groundwater in the various hydrostratigraphic units and the interrelationship of the surface and groundwater chemistry will be considered. Chemical analyses commonly are expressed in parts per million by weight (ppm) and, therefore, only comparisons between concentrations of the same ion are meaningful. In order to compare concentrations of different ions, the analyses should be expressed in equivalents per million (epm).

The pH and the concentrations of calcium, magnesium, sodium, iron, manganese, sulphate, chloride, nitrate, alkalinity, and hardness were determined in the chemical analyses of groundwaters collected in the Musquodoboit River valley. Only hardness, sulphate, and iron will be considered in the following discussion because they are the most important items governing the quality of water for general domestic purposes in the valley.

Groundwater Quality

Hardness

The chemical compounds which cause hardness in water form insoluble residues when they react with soap. They may also produce an insoluble precipitate when the groundwater is exposed to atmospheric temperature and pressure. Temporary hardness, which can be removed through boiling, is due to calcium and magnesium carbonates. Permanent hardness is due to calcium and magnesium sulphates and is unaffected by boiling.

Water from wells in limestone and shale is, on the average, excessively hard (Fig. 4). Although solution of the calcite matrix usually accounts for the hardness in limestone aquifers, the high sulphate concentration in these samples suggests that calcium and magnesium sulphate compounds from gypsum deposits or shale contribute permanent hardness. Groundwater pumped from slate and quartzite may be considered hard by some residents, but concentrations of 100 ppm calcium carbonate should not seriously impair its use for most purposes. The softest well water was collected from drift wells; it was only slightly harder than surface runoff samples collected in the same area.

Sulphate

The most common rocks contributing sulphate to groundwater are shales, which may contain large quantities of ferrous sulphide, and evaporites where calcium sulphate in the form of gypsum and anhydrite is often abundant (Hem, 1959). Groundwaters in limestones and shales contain the only appreciable

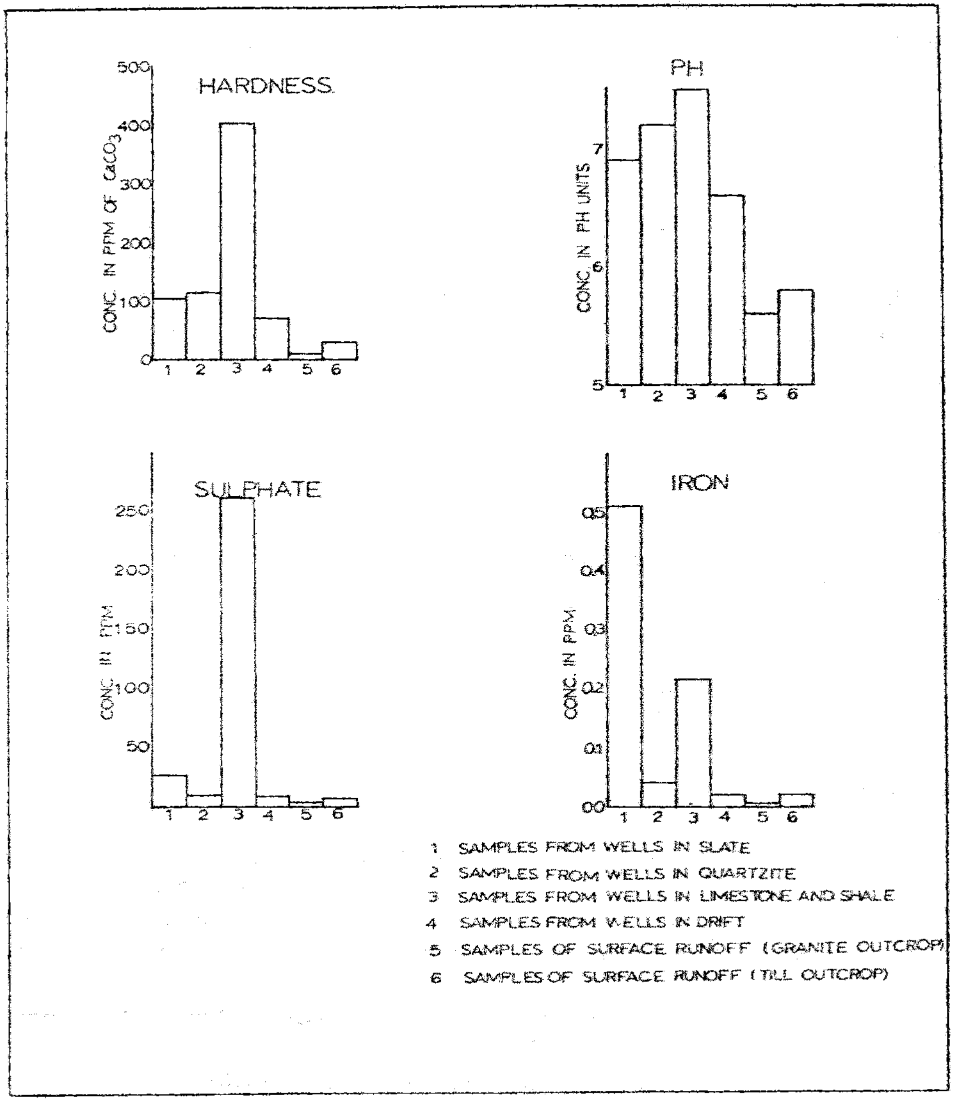

Figure 4. Bar graphs of the average pH and average concentrations of hardness, sulphate, and iron for water samples collected from wells in different hydrostratigraphic units and from surface runoff.

concentration of sulphates (Fig. 4). An examination of the relative concentrations (expressed in epm) of the calcium, magnesium, and iron in these analyses suggests that the sulphate occurs primarily in combination with calcium and magnesium. The drinking water standards as established by the U. S. Public Health Service (1962) suggest an upper limit on the sulphate ion concentration of 250 ppm; samples from the Windsor group are, on the average, slightly higher in sulphate concentration than this recommended limit.

Iron

Iron generally occurs in groundwater in the reduced ferrous state. Ferrous salts, however, are unstable in the presence of oxygen or air and are changed to ferric hydroxide upon exposure to the atmosphere. The solubility of ferric hydroxide is so low in the normal pH range that most of it is precipitated as a rusty deposit.

The precipitation of iron hydroxide is an important problem in the town of Musquodoboit Harbour where most water supplies are obtained from the slate bedrock (Fig. 4). In many domestic and commercial supplies the high iron content makes the water unsuitable for most purposes. Ion exchangers are commonly used to remove the excess iron, but some domestic systems add polyphosphates to the water to stabilize the iron and prevent its precipitation.

Groundwater Discharge and its Effect on Stream Chemistry

Introduction

The concentration of dissolved solids is generally higher in groundwater than in surface runoff (Fig. 4). Thus, the fluctuations in stream chemistry during a storm should indicate quantitatively the contribution of groundwater to the stream through this period. An experiment was conducted to determine:

1. the relationship between the size of the stream and the water chemistry,

2. the variation in water chemistry with position along the stream, and

3. the changes in water chemistry in response to changes in stream discharge.

Water samples were selected from three equidistant points along the length of two streams at 24 hour intervals for a period of ten days. Sampling locations 1, 2 and 3 are situated along the Musquodoboit River at Jam Falls, Meaghers Grant and Middle Musquodoboit, respectively. Samples 4, 5 and 6 were collected along Flip Brook, located 2.5 miles south of Musquodoboit Harbour. Sampling was initiated immediately after a major storm and continued until low stream flow made accurate sampling impracticable. The samples were analyzed in the field for total hardness and the data analyzed statistically using analysis of variance on a factorial arrangement of treatments.

Effect of Stream Size on the Water Chemistry

The two histograms in figure 5 illustrates the variation in hardness between the two streams sampled. The total hardness is significantly higher in Flip Brook than in the Musquodoboit River. There is also a greater difference between the upper (3 and 6), middle (2 and 5) and lower (1 and 4) sampling locations along the brook than along the river. The rate of increase of hardness with time and the maximum value attained are also higher in the brook.

The higher value for hardness in the brook may be due to the composition of the underlying bedrock. The brook is underlain entirely by carbonates but these rocks are present only along one-half of the river. A second possibility is that the ratio of groundwater flow to surface runoff is greater in the brook than in the river, and there is less dilution of the carbonate-rich subsurface flow. Another factor which may produce a higher concentration in the smaller stream is the composition of the runoff. It is evident from data given in figure 4 that runoff from till deposits, (similar to those found along Flip Brook) contains more hardness than does the granite runoff which is discharged into the Musquodoboit River along the middle segment of the valley.

Effect of Sampling Location on the Water Chemistry

In Flip Brook, the hardness decreases with distance upstream from the river mouth (Fig. 5); concentration in the Musquodoboit River, however, increases upstream (Figs. 5 and 6). In the case of Flip Brook the increase in hardness downstream may be a consequence of the composition of the surficial deposits. The upstream segment of the brook is located in lacustrine deposits which may have a lower calcite content than the glacial till. Surface runoff and shallow groundwater discharge from the lacustrine deposits, therefore, may be softer. A decrease in drift thickness downstream or a change in the composition of the bedrock could also account for the observed concentrations.

The changes occurring in the Musquodoboit River are more easily observed in figure 6 where sampling was continued for 45 days at three-day intervals. The decrease in hardness downstreams is probably due to the change in composition of the drift and the bedrock. In the upstream area (upper valley segment of Fig. 2) limestone bedrock would contribute carbonate-rich groundwater, and the mantling till would supply relatively hard surface runoff. Similar bedrock and a thick till sequence is lacking in the lower reaches of the river. Surface and subsurface discharge from this area would tend to dilute the hard waters contributed from further upstream.

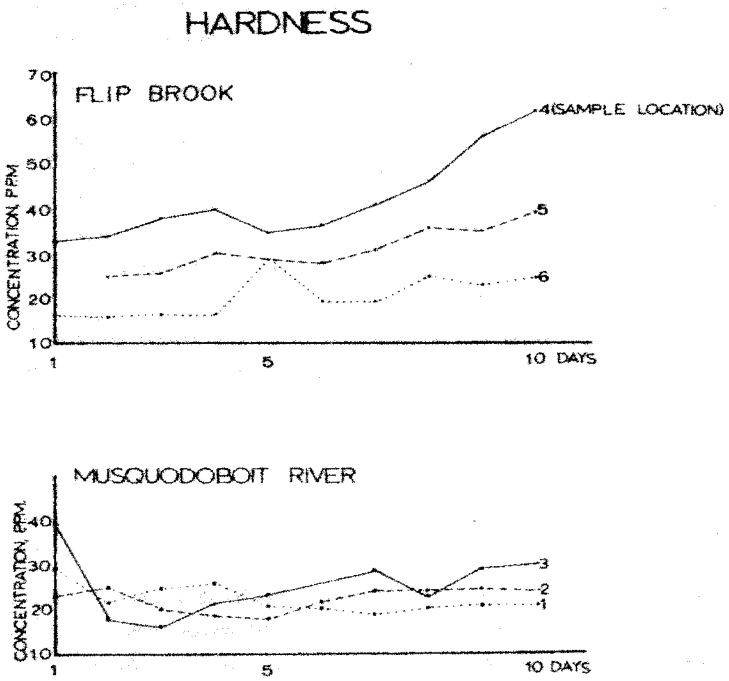

Figure 5. Histograms of hardness concentration versus time for a 10 day period on the Musquodoboit River.

Effect of Discharge Rate on the Water Chemistry

The pronounced effect of stream discharge on stream chemistry is apparent in figures 5 and 6. In both the river and the brook the hardness increases as the stream discharge decreases. The increase in hardness is probably due to the higher proportion of hard groundwater discharge as the stream approaches base flow. The sensitivity of the stream chemistry to changes in discharge is clearly indicated in figure 6. It is of interest to note the movement of the hardness peak downstream after the twenty-seventh sampling day; this peak corresponds to a period of low discharge on the hydrograph.

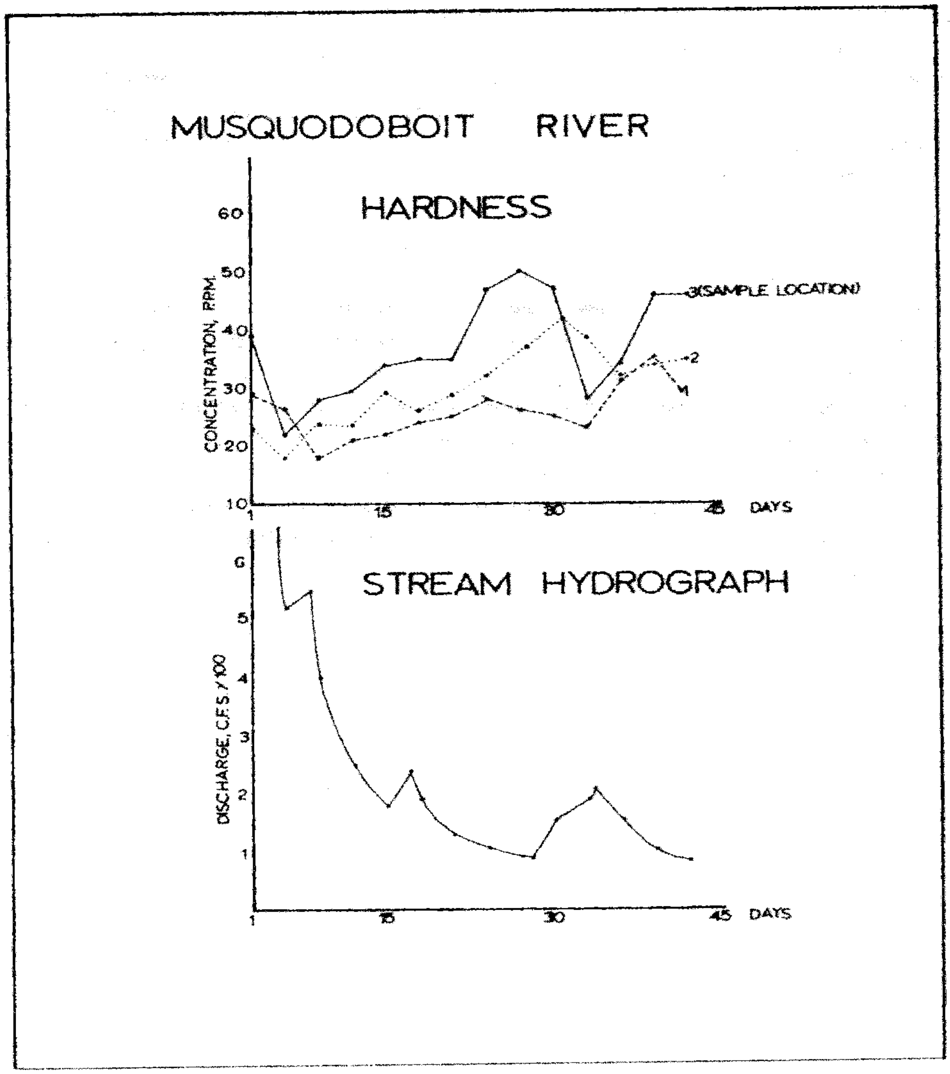

Figure 6. Histograms of hardness contration and a hydrograph for a 45 day period on the Musquodoboit River.

CONCLUSIONS

Groundwater is widely used in the Musquodoboit River valley but generally is obtained from shallow dug wells which may go dry during drought periods or bedrock wells which generally yield water of poor quality. The valley, however, is endowed with abundant groundwater reserves of excellent quality in glacio-fluvial sand and gravel aquifers. These deposits are generally adjacent to the river, and often are overlain by recent alluvium. For example, an extraordinarily good aquifer is located less than one-half mile north of the town of Musquodoboit Harbour. The very high transmissibility of this aquifer (150,000 imperial gallons per day/foot) is due to the very clean, angular, coarse sands and fine gravels derived primarily from the granite highland to the north. This glacio-fluvial deposit yields very large quantities of high quality water over the short run; further evaluation of the long term potential yield of the aquifer is presently underway. The water obtained from this unit has less than 5 ppm hardness and has so few dissolved solids that industries may be attracted to this location on the basis of this resource.

The chemistry of surface streams is strongly influenced by the bedrock and surficial deposits within a basin because the hardness in surface runoff and groundwater discharge comes from these deposits. Stream chemistry is also sensitive to fluctuations in discharge. The influence of groundwater discharge as the stream approaches baseflow is indicated by an increase in the hardness of the water. During periods of surface runoff, the harder groundwaters are diluted by the relatively solute-free water of the ephemeral streams. The stream chemistry is so sensitive to changes in discharge that it should be possible to determine the component of stream flow due to groundwater at any point under the stream hydrograph. Experiments along these lines are presently underway in several areas of Nova Scotia.

REFERENCES CITED

Faribault, E. R., 1913, The Goldbearing series of Nova Scotia, in Geol. Survey of Canada, Guide Book No. 1, Excursion in Eastern Quebec and the Maritime Provinces, pt. 1, p. 158 - 191.

Goldthwait, J.W., 1924, Physiography of Nova Scotia: Geol. Survey of Canada, Mem. 140, 178 p.

Hem, J.D., 1959, Study and interpretation of the chemical characteristics of natural water: U. S. Geol. Survey, Water-Supply Paper 1473, 269 p.

Hughes, O.L., 1956, Surficial geology of Shubeanacdie map area, Nova Scotia: Geol. Survey of Canada, Paper 56-3, 10 p.

MacDougal, J. I., D. B. Cann, and J. D. Hilchey, 1963, Soil Survey of Halifax County, Nova Scotia: N.S. Dept. of Agric. and Canada Dept. of Agric., Rept. 13, 53 p.

Stevenson, I. M., 1956, Shubenacadie, Nova Scotia: Geol. Survey of Canada, Paper 55-27, map with marginal notes.

Todd, D. K., 1959, Ground Water Hydrology: John Wiley and Sons, New York, 336 p.