Province of Nova Scotia

DEPARTMENT OF MINES

Memoir 6

GROUNDWATER RESOURCES AND HYDROGEOLOGY of the ANNAPOLIS-CORNWALLIS VALLEY, NOVA SCOTIA

by

Peter C. Trescott

HON. DONALD M. SMITH
MINISTER

J.P. NOWLAN, Ph. D.
DEPUTY MINISTER

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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. The first detailed study of this program was directed to the Annapolis-Cornwallis Valley because of the immediate need for development of the groundwater resources in that area. This study was a joint undertaking between the Canada Department of Forestry and Rural Development and the Province of Nova Scotia (ARDA project Nos. 3043 and 22042) with the field work carried out during the summers of 1964 to 1967 by the Groundwater Section of the Nova Scotia Department of Mines.

A preliminary report of this investigation was submitted as a thesis by the author to the University of Illinois in June, 1967 in partial fulfillment of the requirements for the degree of Doctor of Philosophy. The text of this thesis subsequently has been modified, particularly the section on water chemistry, and includes some additional information obtained during the 1967 field season.

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 this study, not only will detailed information be made available for agricultural, industrial, municipal and individual water needs, but also that existing supplies of this important resource will be utilized more efficiently. The information herein will serve as a guide for the future exploration, development and use of the hitherto largely undeveloped groundwater resources of the Annapolis-Cornwallis Valley.

John F. Jones
Chief, Groundwater Section
Nova Scotia Department of Mines

Halifax, March , 1968

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Groundwater Resources and Hydrogeology of the Annapolis - Cornwallis Valley, Nova Scotia

ABSTRACT

The largest resource of fresh water in the Annapolis-Cornwallis Valley is that stored in the ground. Major aquifers are present in the Triassic bedrock and in the overlying surficial deposits. The most extensive aquifers are the Triassic Wolfville sandstones and conglomerates, which underlie the entire Valley. It is often possible to construct wells in these aquifers which will yield several hundred imperial gallons per minute. The most important aquifers locally, however, are the glacial sand and gravel deposits which are found mostly in the eastern and central parts of the Valley. A well has been constructed in one of these aquifers which will yield over one thousand imperial gallons per minute. The surficial deposits and pertinent bedrock boundaries in the Valley have been mapped at a scale of 1 inch to 1 mile. A second map at the same scale has been made of the bedrock hydrostratigraphic units, the saturated thickness of sand and gravel, and the depth to the water-table. Information on the hydraulic properties of the aquifers was obtained in selected areas with pump tests.

With the limited information available, a general hydrologic budget was calculated for the Upper Annapolis River basin. Of 42 inches of precipitation in this basin during a "normal" year, about 53 per cent is discharged as storm and snowmelt runoff, 17 per cent as groundwater runoff, and 30 per cent as evapotranspiration. It is estimated that groundwater runoff during a "normal" year for the Annapolis-Cornwallis Valley from Annapolis Royal to the Minas Basin is about 170,000 acre-feet of water. As a comparison, only 6,400 acre-feet of groundwater are currently being utilized by man each year in the Valley.

Four piezometer nests, used to measure fluid potentials at different depths in the same location, were installed in a line perpendicular to the Cornwallis River east of Berwick on the south side of the Cornwallis Valley. From information obtained on the groundwater flow system in this area, it was observed that groundwater flow in the more permeable surficial sand and gravel deposits is nearly independent of the flow system in the Triassic bedrock.

It is suggested that Stein's two-stage method be used to determine the number of water samples needed in a regional survey of groundwater quality. A statistical analysis was used to determine similarities and significant differences in the chemical quality of groundwater among the various hydrostratigraphic units. In general, groundwater chemistry in every unit is suitable for irrigation, domestic use, and many industrial uses. Iron and calcium carbonate may be present in some areas in objectionable amounts for certain domestic and industrial uses.

Although groundwater pollution is not a serious problem at this time, care must be taken, particularly in the case of surficial aquifers, not to impair the natural quality of groundwater. Several potential or actual sources of groundwater pollution exist in the Valley. These sources include poorly located and/or maintained individual septic tanks, abandoned dug wells now used as septic tanks or garbage receptacles, and poorly located garbage dumps. Several cases of groundwater pollution from unlined industrial waste disposal pits and corroded underground gasoline tanks are cited. Pesticides, however, were not found in three samples of groundwater taken from areas sprayed periodically with these chemicals.

GROUNDWATER RESOURCES, ANNAPOLIS-CORNWALLIS VALLEY

INTRODUCTION

Purpose and Scope of the Investigation

Water is the most important natural resource required by man. Until recently, lakes on the adjacent mountains and streams draining the valleys have been adequate to supply the fresh water requirements of the Annapolis-Cornwallis Valley. The population and economy of the Valley, however, are expanding, and with this expansion there are increasing demands for fresh water for domestic, agricultural (particularly for irrigation), and industrial use. With most of the convenient mountain lakes already developed as water supplies and many streams polluted by municipal and industrial wastes, development of more distant lakes and treatment of polluted surface waters will prove to be increasingly expensive.

The large supply of fresh water stored in the ground has been utilized only to a minor extent because little was known of the availability and quality of this supply. Consequently, an investigation of the groundwater resources of the Annapolis-Cornwallis Valley was initiated in 1964. This study included mapping and test-drilling of water-bearing formations (aquifers), and chemical analysis of groundwaters in the various geologic units of the Annapolis-Cornwallis Valley area. To complement this investigation it was deemed necessary to map surficial deposits and bedrock boundaries where previous work was inadequate, to study groundwater movement by use of piezometer nests, and to investigate potential groundwater pollution problems.

General Description of the Area

Location, Access, and Extent of the Area

The Annapolis-Cornwallis Valley is a long narrow lowland which parallels the Bay of Fundy in Annapolis, Kings, and Digby counties, Nova Scotia (Fig. 1). The Valley proper is defined as the area underlain by Triassic sedimentary rocks, and is approximately 62 miles long between the Annapolis Basin at Annapolis Royal and the Minas Basin. It varies in width from 3 miles near Annapolis Royal to 8 miles near Wolfville. The Gaspereau Valley, an adjacent lowland, was also investigated.

The area of investigation lies between 44° 45′ and 45° 15′ north latitude, and between 64° 15′ and 65° 30′ west longitude. Within these limits, the Valley covers an area of about 320 square miles. The Valley is flanked on one side by North Mountain and on the other by South Mountain, both of which are broad uplands.

The main access to the Annapolis-Cornwallis Valley is provided by Highway 1 from Halifax to Yarmouth. In addition, three other trunk highways link Bridgetown, Middleton, and Kentville with the south shore of the province. Most of the 1,642 miles of roads in Annapolis and Kings counties are in and adjacent to the Valley (Nova Scotia Dept. of Trade and Industry, 1964, a and b). Along with county and provincial roads, numerous farm and logging roads provide access to most parts of the Valley. Rail service to the Valley

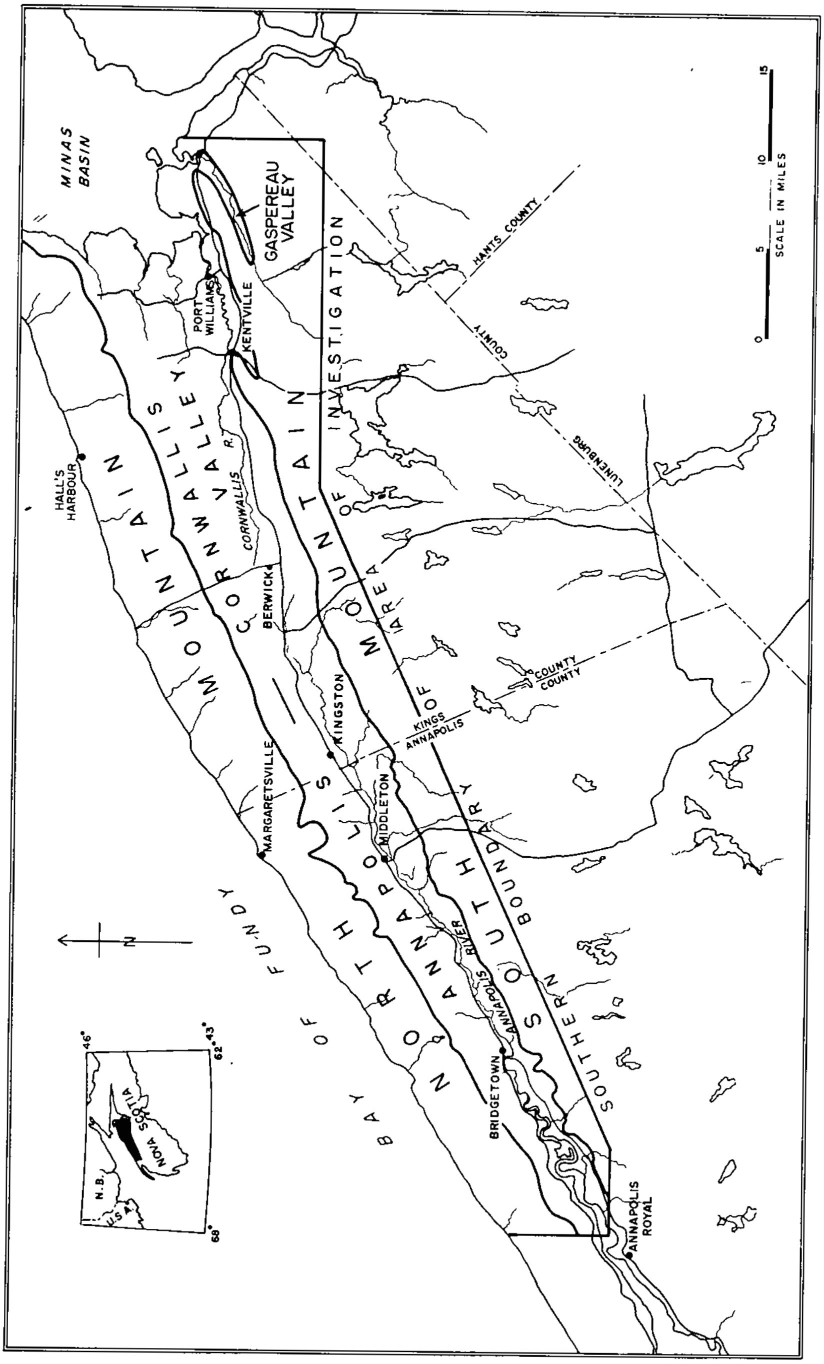

FIGURE 1. Location and physiographic provinces of the area of investigation.

is provided by Canadian Pacific Railways and Canadian National Railways which has a freight line between Middleton and Bridgewater. The nearest commercial airports are the Halifax International Airport and the Yarmouth Airport, but there is a large military air field at Canadian Forces Base (CFB) Greenwood. Port facilities for small ocean-going vessels are provided at Port Williams on the Minas Basin and at Annapolis Royal.

National Topographic System for Location

Nova Scotia was not surveyed into townships and sections because of its early settlement. The Nova Scotia Department of Mines, therefore, adopted in part the National Topographic System for location of areas in the province. Under this system, Canada has been divided into numbered primary quadrangles, each 4° latitude by 8° longitude. Larger scale maps are obtained by subdivision of the primary quadrangles using letters and numbers. For example, the primary quadrangle 21, which includes the study area, is subdivided into maps such as 21 H 2, and parts of maps such as 21 H 2 C (Fig. 2). Each of these parts is subdivided into one hundred and eight mining tracts of approximately 1 square mile each; mining tract 21 H 2 C 75 is shown in figure 2. Mining tracts are further subdivided with letters into sixteen claims, each containing about 40 acres. Claim 21 H 2 C 22 K is illustrated in figure 2. For precise location of test-holes, water samples, etc., a square containing the position of the item within the claim is added to the location. For the claim described above, a complete location would be 21 H 2 C 22 K□.

Physiography

The area of investigation can be divided into three physiographic units: The South Mountain highland, the Triassic lowland, and the North Mountain highland (Fig. 1). Each of these units is closely related to the underlying rock divisions and structures.

South Mountain Highland

South Mountain is the northern escarpment of an extensive highland which occupies much of southwestern Nova Scotia. This highland is underlain by early Palaeozoic slates and quartzites intruded by Devonian granite, except near the Minas Basin where Carboniferous sedimentary rocks overlie the older rocks (Fig. 3). The highest elevations occur near the escarpment because the surface of the highland slopes gently south and west to the Atlantic Ocean (Goldthwait, 1924, p.6). Elevations near the escarpment are chiefly between 600 and 800 feet with isolated highs above an altitude of 950 feet. The surface of this highland is gently undulating with local relief commonly no greater than 300 feet, except along the Gaspereau Valley where scarps rise in places over 600 feet above the valley floor.

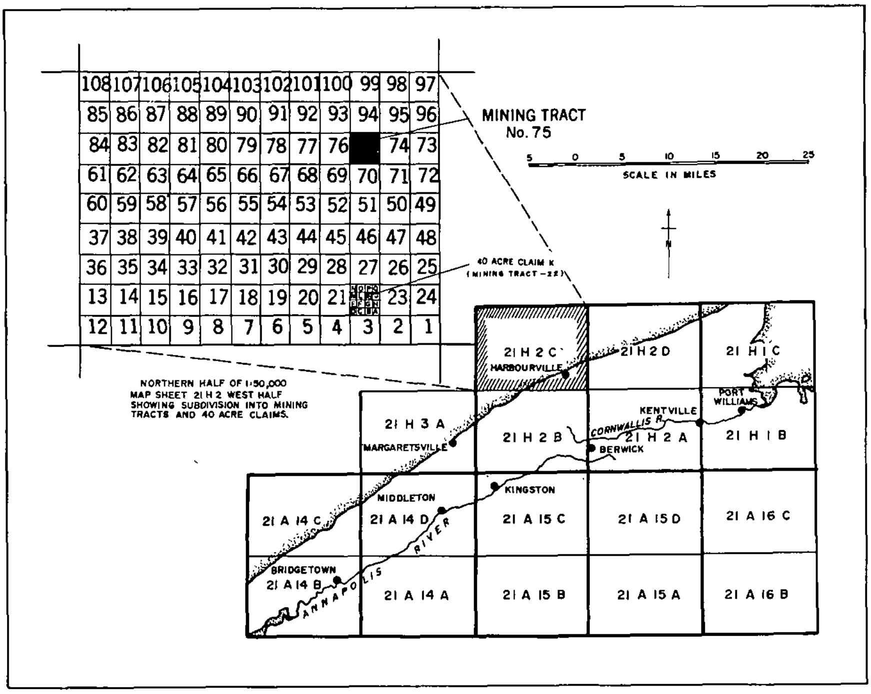

FIGURE 2. National Topographic Series maps which cover the area of study.

Triassic Lowland

The Triassic lowland is formed on sandstone and shale beds of Triassic age. The extremities of the lowland are below sea level forming St. Mary's Bay and the Minas Basin. The Annapolis Basin at the mouth of the Annapolis River is a similar depression with access to the sea through a gap in North Mountain near Digby.

Topography in the Valley is flat to gently rolling depending on the nature of the mantling glacial debris and the depth to which this material has filled in the underlying bedrock topography (see Fig. 4). Triassic rocks have the greatest influence on topography at the eastern end of the Valley where only a thin mantle of glacial drift covers broad, low, discontinuous sandstone ridges. Southwest of Berwick, bedrock is generally exposed only along the bed of the Annapolis River and along the flanks of the Valley where tributary streams have cut through the overlying drift.

The Caribou Peat Bog, at the divide between the Annapolis and Cornwallis River watersheds, has an altitude slightly over 120 feet. West of the bog, elevations gradually descend to sea level at the Annapolis Basin. Between the Caribou Bog and the Minas Basin, more rolling topography is encountered, but maximum elevations seldom rise above 200 feet except along the flanks of the Valley.

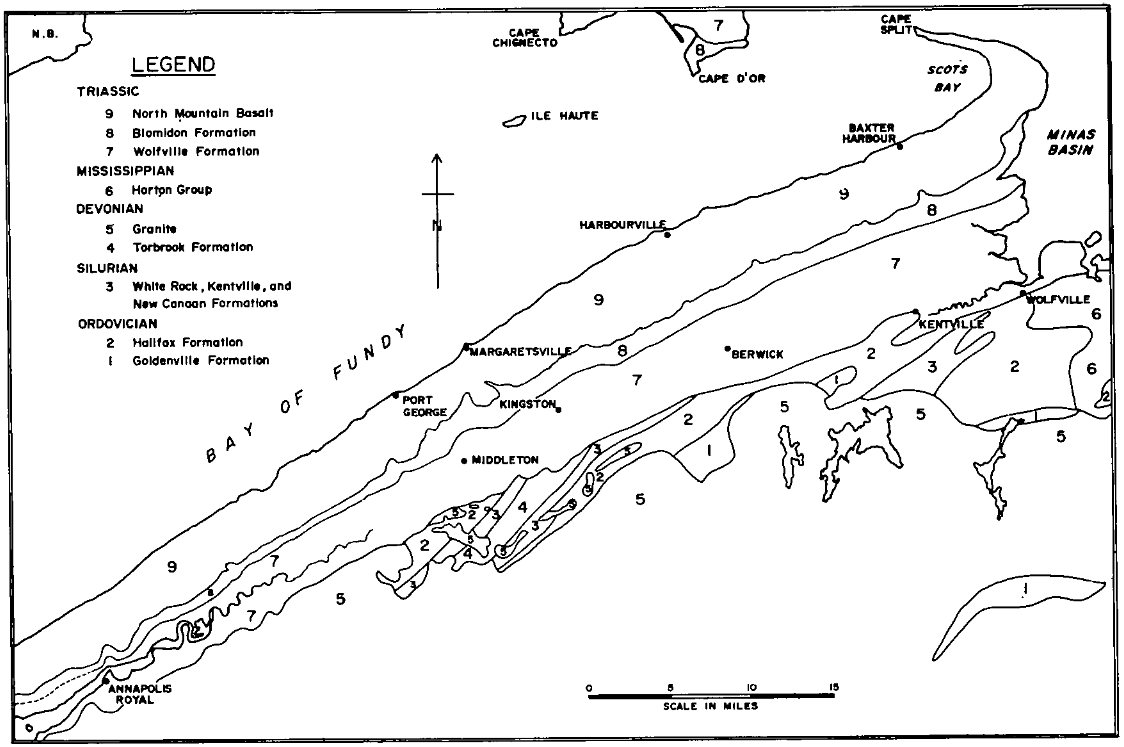

FIGURE 3. *Bedrock geology of the area of study (adapted from the Geological Map of Nova Scotia, Weeks, 1965).*

North Mountain Highland

North Mountain, extending 123 miles from Brier Island to Cape Blomidon is capped by Triassic basalt lava flows which dip 4° to 10° towards the Bay of Fundy. North Mountain, therefore, is a cuesta with the steep scarp-slope facing the Annapolis-Cornwallis Valley and the gentle dip-slope facing the Bay of Fundy (see Fig. 5). The dip-slope is broken in several places by irregular and discontinuous ridges which are erosional remnants of the several flows capping North Mountain. A number of lakes occupy depressions between these ridges. Elevations near the crest (commonly about one-half mile back from the scarp) are usually between 600 and 750 feet. The maximum altitude is over 900 feet.

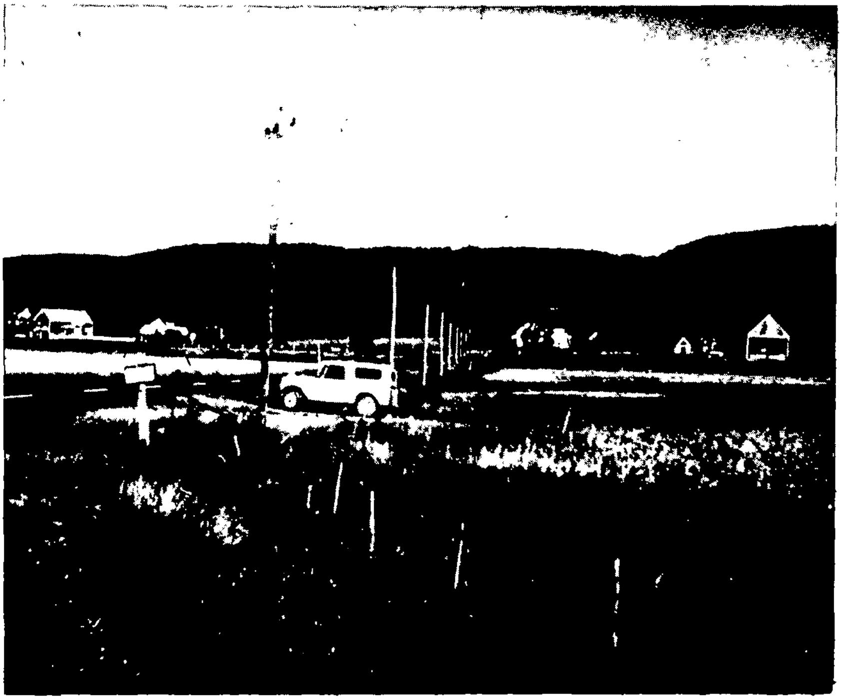

FIGURE 5. A view of the North Mountain Scarp north of Berwick.

Drainage

Surface water and groundwater drainage in and adjacent to the Annapolis-Cornwallis Valley discharges ultimately into the Bay of Fundy. Drainage within the area of investigation can be resolved into three components: the Annapolis River draining into the Annapolis Basin; streams discharging into the Minas Basin; and drainage directly to the Bay of Fundy. Watersheds of these streams are outlined in figure 6. (The Upper Annapolis River basin is outlined because a hydrologic budget is calculated for this watershed). Note that, whereas the Annapolis River drains two-thirds of the Triassic lowland,

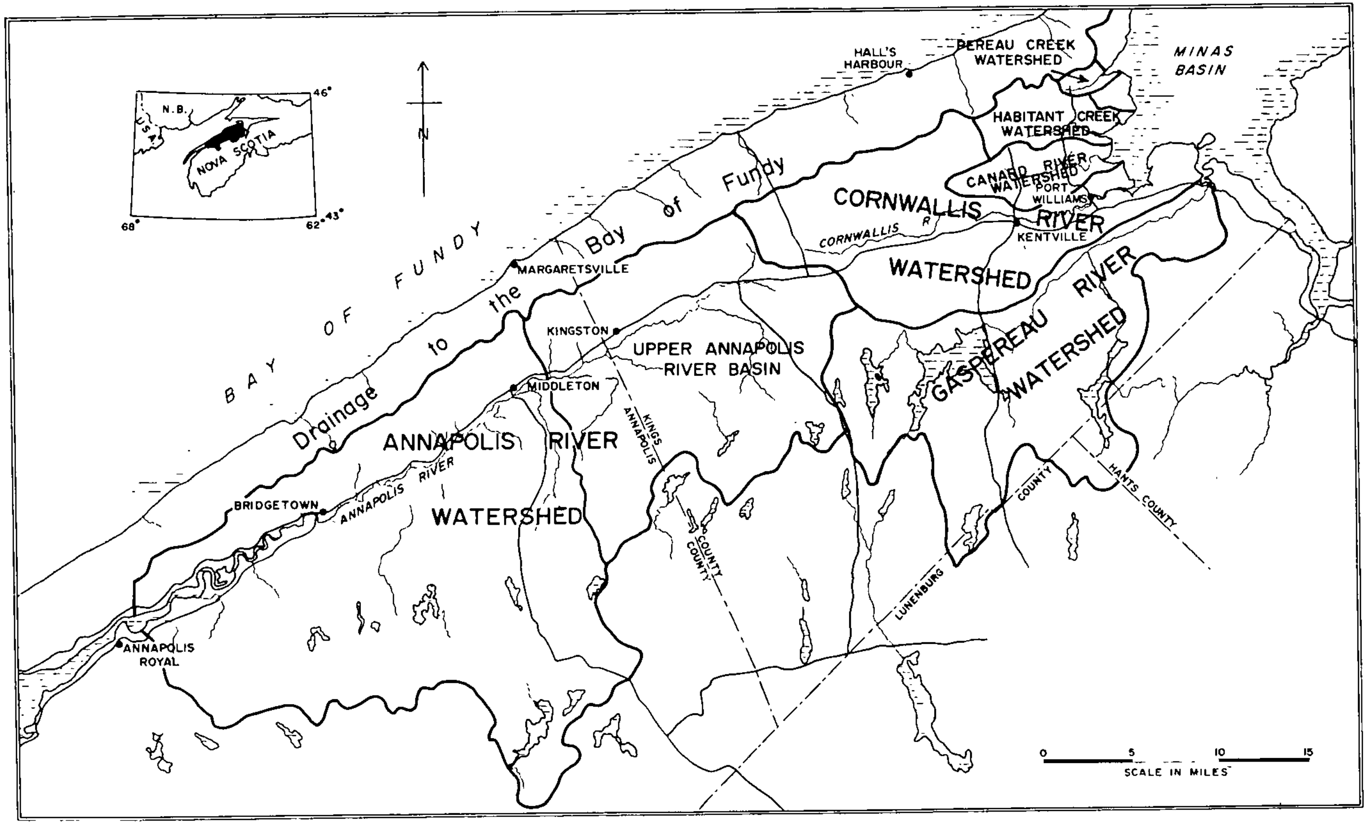

FIGURE 6. *Watersheds within the area of study.*

FIGURE 7. A view eastward of the Cornwallis River dykeland near Port Williams (photo courtesy of N.S. Information Service).

two-thirds of the Annapolis River watershed is within the South Mountain highland. This is important when considering the hydrology of the Annapolis River. In contrast, three-quarters of the Cornwallis River watershed, which drains to the Minas Basin, is within the Triassic lowland. Three smaller streams (Canard River, Habitant and Pereau Creeks) also drain the eastern end of the Valley. The watershed of the Gaspereau River, which drains to the Minas Basin, is entirely within the South Mountain highland. Because of the shape of the North Mountain cuesta, most of the drainage on this highland descends northward in short streams to the Bay of Fundy.

Surface and internal drainage conditions within the Valley are generally good. Drainage is excessive in some areas of sand and gravel deposits where the water-table is many feet below the surface. Poor drainage conditions exist in coarse-textured soils overlain by peat and muck, as well as in fine-textured soils where conditions of low relief and a high water-table exist.

The major modification of natural drainage conditions has been effected along the tidal estuaries where many square miles of salt marsh have been reclaimed by dyking to produce rich pastureland (Fig. 7).

Agriculture and Soils

The existence and nature of agriculture depends primarily on the character of the soil available for farming. The most important factor influencing the kind of soil in the Valley and adjacent areas is the parent material from which the soil is derived. In most of the area, the parent material is of glacial origin - either glacial till or glacio-fluvial sand and gravel deposits. Glacial till is debris eroded from underlying soil and bedrock and deposited as unsorted material by the glacier. Glacio-fluvial material consists of silt, sand, gravel, and boulders deposited by glacial meltwater.

Most parent materials have been modified by vegetation and climate over a period of approximately 10,000 years to produce mature soils. (The nature and productivity of soils is taken from Harlow and Whiteside, 1943, and from Hilchey, Cann, and MacDougall, 1962). In these soils, the top of the C horizon or slightly altered parent material is generally less than three feet below the surface. The original vegetative cover (coniferous forest and mixed coniferous and hardwood associations) along with the climatic conditions (high precipitation; long, cold winters, and short, cool summers) have produced predominantly podzolic soils. These soils are characterized by strong leaching of the A horizon which underlies the organic surface layer. Calcium, magnesium, potassium, iron, and aluminum are removed from the A horizon and deposited in the B horizon, sometimes forming hardpans. In areas of poor drainage, soils may contain a thicker surface organic layer, and the A and B horizons may contain grey reduced zones in a mottled pattern due to reduction of iron by organic matter. Soils containing these reduced zones are termed gleyed podzols and gleysolic soils. Organic deposits of peat, without the typical soil horizons, occupy many depressional areas where a high watertable exists. Finally, along the floodplains and marshes of streams and estuaries, recent alluvium forms rich soil with little horizon development.

On the South Mountain highland, approximately 10 per cent of the area is occupied by lakes and swamps of glacial origin. Of the remaining area, that underlain by granite supports very little farming because it is covered by boulders, thin sandy podzolic soils, and second-growth forest. Those areas underlain by quartzite are similar in nature to the granite terrains. In many areas underlain by slate, however, good clay-loam soils have been formed by glacial action and weathering. These are the only important arable areas on the South Mountain highland.

The Triassic lowland is the most productive agricultural area in the Province. Although only about one-half of the land in the Valley is in use, most of it is arable. In about 50 per cent of the area, the soil is developed on glacial till which is either a sandy- or a clay-loam depending on whether the underlying bedrock is sandstone or shale. In about 30 per cent of the area, soils are developed on coarse glacio-fluvial material. Of the remaining soils, most are developed on estuarine deposits and stream alluvium with some areas of peat and muck.

Soils on the North Mountain highland are mostly derived from thin till containing a large percentage of partly weathered basalt cobbles and boulders. As a result, most of the land is suitable only for forest. Areas of thicker till are sometimes moderately productive farm lands, but the stoniness of the soil and occasional rock outcrops are constant problems.

The nature of agricultural production in the Valley area is shown by data from the 1961 census (Nova Scotia Dept. of Trade and Industry, 1964, a and b). Although production figures cited have been compiled on a county-wide basis, probably 95 per cent of agricultural production in Annapolis and Kings counties comes from the Annapolis-Cornwallis and Gaspereau Valleys. The important tree fruit industry includes about 12,000 acres in orchard: 90 per cent are apple trees, 7 per cent pear trees, and the remaining 3 per cent peach and other fruit trees. Small fruit farming includes about 550 acres, mostly strawberries with some raspberries and blueberries. Two thousand four hundred acres are in vegetable production, predominantly beans, green peas, sweet corn, and cucumbers. Of 41,000 acres in field crops, most are in tame hay, oats, and potatoes with some mixed grain and tobacco. Livestock includes about thirty eight thousand cattle, eleven thousand hogs, and six thousand sheep. More than one million hens and chickens are involved in the production of eggs and dressed poultry. Of the one thousand one hundred fifty two commercial farms (total value of agricultural products sold on a commercial farm is at least $1,200) in Annapolis and Kings counties, 25 per cent are cattle, hog, and sheep farms, 24 per cent are dairy farms, 14 per cent are fruit and vegetable farms, with most of the remainder producing a variety of products.

Population and Industry

Sixty-four thousand six hundred people live in Annapolis and Kings counties; forty-nine thousand seven hundred live in rural areas and fourteen thousand nine hundred live in urban areas (Nova Scotia Dept. of Trade and Industry, 1964, a and b). The economy of the two counties is based on the production and processing of agricultural and forest products. The following information on the value of manufactured goods is based on the 1961 census data, except where noted. The value of food and beverage products was $19,966,000. Wood products production including sawmills, and sash, door, and planing mills amounted to $1,434,000. Other types of manufacturing (concrete products, elastic products, can manufacturing, synthetic screens, feeds and fertilizers, building stone and monuments, furniture manufacturing, boat building and machine shops) produced a total of $1,337,000 worth of goods.

Mining and quarrying is a small industry in Annapolis and Kings counties, with most activity in the production of sand and gravel from numerous pits in glacio-fluvial deposits. Harvesting of peat from the Caribou Bog is on the increase. In addition, there are a couple of small granite quarries.

The landings of three hundred eighty four fishermen, one hundred fifty six of whom are full time (ten months or more per year), yielded a total value of $287,000 in 1964.

It should be noted that national defence is an important part of the economy. CFB Greenwood, the largest Canadian air base, includes about seven thousand air force personnel and dependents.

Climate

The Nova Scotia Department of Trade and Industry (1965) has summarized general information on the climate of the province. Nova Scotia, because of its proximity to the continental land mass, has a humid, temperate, continental climate. This continental climate is modified, however, by the Atlantic Ocean which almost completely surrounds the province, and the Gulf Stream which runs northeasterly parallel to the Atlantic coast. The modifying influence of the ocean tends to prevent extreme temperatures in the summer and winter, and minimizes the number of severe atmospheric storms. The presence of the North and South Mountain highlands influences to some extent precipitation, temperatures, and winds in the Valley.

Detailed climatic data, including figures and tables are presented in in the section on hydrology. The following summary of the fifty year weather records for Kentville will give a general picture of climatic conditions in the Valley (Canada Dept. of Agriculture, Research Station, Kentville, 1961, updated in 1964): Mean annual precipitation is 41.98 inches with extremes of 30.35 inches (1915) and 59.56 inches (1962). Total snow fall for the winter months averages 84.9 inches with extremes of 44.8 inches (1951-52) and 162.8 inches (1955-56). Precipitation is fairly well distributed during the year with slightly higher precipitation occuring during the fall and winter months than during the spring and summer months.

The mean annual temperature is 43.6° F.; the mean temperature in the coldest month (February) is 21.1° F.; and in the warmest month (July) is 66.2° F. Temperatures as cold or colder than -20° F. occured in 15 per cent of the years; temperatures as warm or warmer than 90° F. occured in 42 per cent of the years.

The average frost free period at Kentville is one hundred twenty six days with ninety five days (1943) the shortest and one hundred fifty two days (1937) the longest on record.

Wind velocity records for four years at CFB Greenwood show that the most common velocities are in the ten to twenty miles per hour range. Velocities above thirty-nine miles per hour occur occasionally in November, December, January, March and April. Prevailing wind directions are from the southwest in the summer and the northwest in the winter, with gale winds occasionally coming from the northeast.

Previous Investigations

No work has been done on the hydrogeology of the Annapolis-Cornwallis Valley prior to this report. In fact, it is only since 1960 that hydrologic information on the Valley, other than weather records, has become available. This information includes: A survey of pollution on the Annapolis and Cornwallis Rivers (Dept. of National Health and Welfare, 1962 a and 1962 b); stream discharge records for the Annapolis River at Wilmot and the South Annapolis River at Millville (gauging stations are maintained by the Water Survey of Canada, Inland Waters Branch, Dept. of Energy, Mines and

Resources); and water well drilling records filed with the Nova Scotia Department of Mines mostly since the Well Drilling Act of 1965.

In contrast, a considerable amount of information is available on the bedrock geology within the area of investigation. The most interesting and important areas geologically, the Wolfville map-area and the Nictaux-Torbrook map-area, have been re-mapped and discussed in recent reports by Smitheringale (1960) and Crosby (1962). In these reports, particularly Crosby (1962), there are comprehensive reviews of previous geological investigations. Only the more important early geological reports will be mentioned here.

The first important and comprehensive geological report, including a map, of Nova Scotia was compiled by Sir William Dawson (1855). Additional information on the geology of the Valley area and the rest of the province was included in a supplementary chapter to later editions of the first book.

Southwestern Nova Scotia, including the Valley area from Kingston westward, was mapped at a scale of 8 miles to 1 inch and discussed in greater detail by Bailey (1896).

Fletcher began mapping Nova Scotia at a scale of 1 inch to a mile in the 1870s (Crosby, 1962, p.4). The first of Fletcher's published maps in the Valley area (Fletcher, 1902), and the Kingsport sheet (Fletcher, 1911) cover approximately the area later re-mapped by Crosby. Fletcher's published work includes a detailed map and discussion of the Nictaux-Torbrook iron district (Fletcher, 1904). Although Fletcher worked on the geology of several map sheets in and south of the central part of the Valley, it remained for Hayes (1916) and Faribault (1920) to complete work on a few of them.

Comprehensive studies of the stratigraphy, structure, and palaeontology of the Mississippian Horton and Windsor Groups have been made by Bell (1929 and 1960). Bell (1929) reviewed the previous publications on these rocks.

The Triassic age of the rocks forming the Annapolis-Cornwallis Valley was suggested by Dawson (1848). Powers (1916) made the first regional stratigraphic study of the Triassic rocks in Nova Scotia and included all Triassic sedimentary strata underlying the North Mountain Basalt in the Annapolis Formation. The lower member of the Annapolis Formation was named the Wolfville sandstone, and the upper member, the Blomidon shale. Klein (1962) studied the stratigraphy, depositional environments, and petrography of Triassic rocks in the Maritime Provinces, and proposed including all of them in the Fundy Group and elevating the Wolfville and Blomidon members to formational status.

Dawson (1893) made early observations on the glacial features of Nova Scotia. The "Physiography of Nova Scotia" by Goldthwait (1924) is an important general reference for physiographic features, geomorphic evolution, and the effects of glaciation in Nova Scotia. A surficial geology map has been published for the Central Annapolis Valley from Middleton to Berwick (Hickox, 1962). The surficial geology map in the present report differs only in detail in the area covered by Hickox' map. Some unpublished mapping of surficial deposits in the Valley has been done by Professor R. MacNeill and his students at Acadia University, Wolfville, Nova Scotia. Throughout the Valley, soil maps by Harlow and Whiteside (1943) were used to provide a general, though not detailed, guide to the distribution of surficial deposits.

Field Work and Maps

The Nova Scotia Department of Mines supplied a four-wheel drive vehicle, aerial photographs, topographic maps, and other field equipment during the field season of 1964, when preliminary work was done, and during 1965 and 1966, which the writer spent in the field.

Much of the time in the field was spent mapping the bedrock and surficial geology. The bedrock geological boundaries, except those involving Triassic rocks, were taken from previous work (Smitheringale, 1960; Crosby, 1962; Taylor, 1962; and Weeks, 1965). The Palaeozoic-Triassic boundary was mapped between Kentville and Morristown and checked in several other places. The Wolfville Formation - Blomidon Formation boundary was mapped from outcrops exposed along streams at the eastern end of the Valley, but was drawn in mostly as an assumed contact at the western end of the Valley where outcrops are infrequent. The contact of the Blomidon Formation with the overlying basalt was drawn in from previous work and from aerial photograph interpretation with some field checking. Locations of outcrops and test-holes used to modify or establish the position of bedrock boundaries are shown on map 1.

Mapping of surficial deposits was done in the field on Royal Canadian Air Force aerial photographs (flown 1955) at a scale of 1:24,000. Most information was obtained by examining unaltered surficial deposits in gravel pits, road cuts, and road drainage ditches along public and farm roads. Where necessary, the nature of surficial deposits and the location of boundaries were determined in less accessible areas. The surficial geology map by Hickox (1962) and the soil maps by Harlow and Whiteside (1943) were utilized as much as possible in mapping surficial deposits. In the laboratory, boundaries were sketched using aerial photographs in stereo pairs. This mapping was transferred to topographic maps used as a base for map 1.

To obtain subsurface information, a Department of Mines rotary drilling rig and crew were used to drill stratigraphic test-holes, to install piezometers, and to install wells for water-level recorders and pump tests. A power auger mounted on a jeep supplied by the Nova Scotia Research Foundation was used to gather some stratigraphic information and to drill holes for installation of sand points. The feasibility of obtaining subsurface information in the Valley by use of hammer seismic and gravimeter surveys was investigated by the Nova Scotia Research Foundation. Sieve analyses were run on some surficial deposit samples and on granular test-hole samples by technicians at the Nova Scotia Department of Mines office at Stellarton and at Acadia University.

Water samples for chemical analysis were analyzed at the Nova Scotia Agricultural College, Truro. Water samples to be tested for bacterial contamination were analyzed in the Laboratory of the Nova Scotia Sanitorium, Kentville.

Low flow stream discharge measurements on the Annapolis River were made with a Price current meter loaned by the Water Survey of Canada, Inland Waters Branch, Department of Energy, Mines and Resources, Halifax, Atlantic Region office.

Acknowledgments

This investigation was jointly sponsored by the Canada Department of Forestry and the Province of Nova Scotia under authority of the Agricultural Rehabilitation and Development Act under the direction of the Groundwater Section, Geological Division, Nova Scotia Department of Mines.

The writer is indebted to Professor R.N. Farvolden of the University of Illinois and to John F. Jones, Chief, Groundwater Section, Nova Scotia Department of Mines for guidance and council during preparation of this report. G.F. Pinder provided considerable assistance with statistics and wrote the computer program for the statistical analysis of water chemistry.

Very able assistance in the field and laboratory was provided by Terry Hennigar, Bruce Rogers, and John Power. Some work, carried out in 1964 under the direction of D.J. Mossman, is incorporated in this study. J.B. MacNeil, Department of Mines driller, and his assistants were very helpful with problems in the field. Professor R. MacNeill gave advice and information on Pleistocene geology and was instrumental in procuring free laboratory space for the field parties at Acadia University during the summers of 1964 and 1965.

All maps and illustrations have been drafted by D. Bernasconi and his staff of the Cartographic Division, Nova Scotia Department of Mines. Miss Betsy Chase of the Nova Scotia Research Foundation has devoted some of her time to determining the elevations of many stratigraphic test-holes in the Valley. Dr. D.K.R. Stewart of the Canada Department of Agriculture, Research Station, Kentville, kindly ran gas chromatographic analyses of three groundwater samples being tested for pesticide pollution. The daily task of measuring water levels in the piezometer nests at Berwick was very capably handled by Mr. J.L. Robinson.

Mapping and gathering of basic data were facilitated by the cooperation of many of the residents of the Annapolis-Cornwallis Valley.

GEOLOGY

In the description of the bedrock geologic units, emphasis is placed on the Triassic sedimentary strata which underlie the Annapolis-Cornwallis Valley. Surficial deposits, consisting mostly of glacial till and glacio-fluvial sand and gravel along with the less abundant estuarine deposits and stream alluvium, are described in detail. This section is concluded with a summary of the structural deformation and geomorphic evolution which are responsible for the present distribution of geologic units.

Rock Units

Palaeozoic

The geology of Palaeozoic rocks which form the South Mountain highland and the "basement" beneath Triassic rocks in the Valley is condensed from information in Smitheringale (1960) and Crosby (1962). General information concerning all of the geology within the area of investigation is given in table 1. Refer to map 1 or figure 3 for maps showing the distribution of these geologic units.

Meguma Group

The oldest, most widespread rocks with the greatest stratigraphic thickness are those of the Meguma Group. The older formation of this group, the Goldenville Formation (Lower Ordovician or earlier), is present in a few remote areas on the highland and is, therefore, only of minor importance for this report. It is composed mostly of greywackes and impure quartzites. The younger Halifax Formation (Lower Ordovician), covering a fairly large area adjacent to the Valley, is composed of interbedded slate, siltstone, and quartzite. "The Goldenville-Halifax contact is probably comformable" (Smitheringale, 1960, p. 7).

White Rock, Kentville, New Canaan, and Torbrook Formations

Overlying the Meguma Group and present in two synclinal structures close to the Valley are four formations. The first is the White Rock Formation (Upper Silurian or earlier) consisting of two massive beds of quartzite separated by slates near Kentville. Near Nictaux Falls, however, the White Rock Formation has a highly varied lithology including quartzites, siltstones, rhyolites, and basalt. The lithology of the overlying Kentville Formation (Upper Silurian) is the same as that of the Halifax Formation. Overlying the Kentville Formation in the Wolfville area are marine sedimentary breccias (including many volcanic fragments) which are associated with siltstones, slates, and limestones. Crosby (1962) has described this new unit, naming it the New Canaan Formation (Upper Silurian). The youngest rocks of the metamorphic sequence are present only in the Nictaux-Torbrook area. The Torbrook Formation (Lower Devonian) is noted for its

Table 1. Table of Formations*

ERA	PERIOD OR EPOCH	FORMATION AND THICKNESS (feet)	LITHOLOGY
Cenozoic	Recent	0-160 +	Stream alluvium; peat and muck; dykeland; salt marsh and tidal flat
	Pleistocene	0-200 +	Till; stratified sand and gravel; estuarine deposits
		Unconformity	
Mesozoic	Triassic	Scots Bay Formation 8 - 23	Arenaceous limestone; calcareous sandstone
		Disconformity	
		North Mountain Basalt 900 ± - 1,200 ±	Basalt flows
		Conformable contact	
		Blomidon Formation 700 ± - 1,600 ±	Siltstone; claystone; minor sandstone
		Facies change	
		Wolfville Formation 2,400 ± - 3,000 ±	Red and grey sandstone, siltstone, conglomerate, and claystone
		Angular unconformity	
Palaeozoic	Mississippian	Horton Group 4,000 ±	Grey and red shales, siltstone, sandstone, minor conglomerate

continued

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*Modified with a few additions from Smitheringale (1960), Crosby (1962), and the Geological Map of Nova Scotia, (Weeks, 1965).

Table 1. Table of Formations (cont'd.)

ERA	PERIOD OR EPOCH	FORMATION AND THICKNESS (feet)	LITHOLOGY
Palaeozoic		Angular unconformity	
	Lower and/or Middle Devonian	Granitic and allied rocks	Granitic and allied rocks
		Intrusive contact	
		Mafic sills and dykes	Gabbroic rock
		Intrusive contact	
	Lower Devonian	Torbrook Formation 4,800 +	Fossiliferous quartzite, marine shale and siltstone, and iron formation
		Gradational contact	
	Upper Silurian	New Canaan Formation 1,000 +	Marine breccia; minor siltstone and slate
		Conformable contact	
		Kentville Formation 1,600 +	Slate and minor siltstone
		Conformable contact	
	Upper Silurian or earlier	White Rock Formation 100 - 2,000 ±	Quartzite interbedded with slate, siltstone and occasionally rhyolite and basalt
		Conformable contact	
	Lower Ordovician	Halifax Formation 11,700 ±	Slate, schist, minor quartzite
		Conformable contact	
	Lower Ordovician or earlier	Goldenville Formation	Greywack, quartzite, minor slate

fossiliferous sedimentary iron formation. Also included in this unit are shales, siltstones, quartzites, and limestones.

> "The contacts between the Halifax, White Rock, Kentville, and Torbrook formations are gradational." These formations "... represent more or less continuous accumulation, from Ordovician through Lower Devonian time, of about 19,000 feet of marine-shelf sediments and minor volcanics" (Smitheringale, 1960, p. 7).

Mafic Sills and Dykes, and Granite

The early Palaeozoic metamorphic rocks were intruded by many mafic sills and dykes prior to intrusion of a large granite batholith during the Lower and/or Middle Devonian. Although several different types of granite are present, this rock is typically a quartz-feldspar-biotite granite with large phenocrysts of feldspar.

Horton Group

An erosional surface was formed on lower and middle Palaeozoic rocks before the deposition of Lower Mississippian Horton rocks. The lower one-third to one-half of the Horton Group consists of interbedded conglomerates, grits, sandstones and minor amounts of siltstone and shale. These strata have abundant plant remains. The middle one-quarter to one-third of the group is predominantly shale, while the upper one-fifth to one-third of the group consists of shale, with interbedded grits and sandstones.

> "The lenticular nature of strata, current ripple-marking, cross-bedding, channelling phenomena, and other properties common to the Horton Group are characteristic of fluviatile deposits" (Crosby, 1962, p. 35).

Crossbedding, current ripple-marks, and provenance of coarse constituents indicate that their source was to the south.

Mesozoic

Fundy Group

Underlying the Annapolis-Cornwallis Valley and forming the North Mountain highland are several of the formations (The Wolfville and Blomidon formations, the North Mountain Basalt and the Scots Bay Formation) included in the Triassic Fundy Group (Klein, 1962). These Triassic rocks dip 4 to 12 degrees to the northwest towards the Bay of Fundy and overlie with angular unconformity the deformed Palaeozoic rocks forming the South Mountain highland.

Wolfville and Blomidon Formations. The Wolfville Formation underlies the Annapolis-Cornwallis Valley and increases in thickness northward across the outcrop belt to a maximum of over 3,000 feet in places at the base of the North Mountain scarp (Smitheringale, 1960). This formation is composed of interbedded red and grey conglomerates, sandstones, siltstones, and claystones. The sandstones and conglomerates are poorly sorted, cross-stratified, contain intraformational claystone and siltstone, and show lateral changes in stratification, composition, and thickness.

The composition of the Wolfville Formation may vary widely from place to place (see Table 2). Although the formation has been described as being composed almost entirely of coarse clastics (Klein, 1962, p. 1130), the majority of the section in some places is made up of silty sandstone, arenaceous siltstone, siltstone and claystone.

Logs of surficial deposit test-holes also provide some information on Triassic rocks because they are drilled through the surficial deposits and 10 to 15 feet into bedrock. Of one hundred and six surficial test-holes which penetrated bedrock within the Wolfville Formation, 55 per cent penetrated relatively clean sandstone and conglomerate first; and 45 per cent penetrated silty sandstone, arenaceous siltstone, siltstone and claystone first. The probable explanation for the fact that the finer-grained rocks do not appear often in outcrop is that these rocks are more easily eroded, and the resulting depressions have been filled with surficial deposits.

Table 2. Information from test-holes in Triassic rocks, Annapolis-Cornwallis Valley

AREA	TEST-HOLE NO.	TOTAL DEPTH (feet)	TOTAL BEDROCK PENETRATED (feet)	COMPOSITION OF BEDROCK (per cent)	
				SANDSTONE AND CONGLOMERATE	SILTY SANDSTONE, ARENACEOUS SILTSTONE, SILTSTONE AND CLAYSTONE
Canning	250	711	681	85	15
Sheffield Mills	135	301	276	58	42
Steam Mill Village	211	280	272	28	72
Kentville	216	435	423	55	45
Berwick	200	705	675	41	59
Digby	99	255	242	66	34

The Blomidon Formation, which overlies the Wolfville Formation, forms the flank of North Mountain and may be over 1,600 feet thick in places (Smitheringale, 1960). The Blomidon Formation consists of even-bedded, poorly sorted sandstone, thinly laminated claystone, and thin- to medium-bedded siltstone. Two facies are designated within the Blomidon Formation: a Del Haven Facies for the even-bedded Blomidon (along the west side of the Minas Basin, Fig. 8) and a Digby Facies (found within the Valley at Central Clarence) "where the Blomidon is characterized by channel stratification and a larger variety of primary structures" (Klein, 1962, p. 1133).

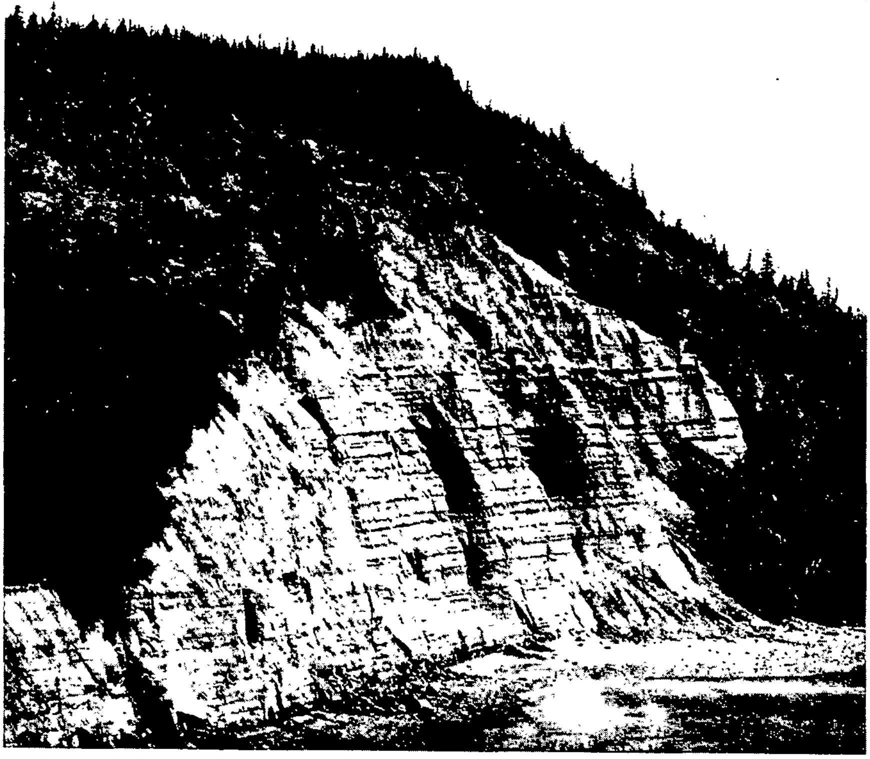


FIGURE 8. Del Haven Facies of the Blomidon Formation, Cape Blomidon (photo courtesy of N.S. Information Service).

Sandstones within the Wolfville and Blomidon Formations can be classified into a variety of rock types. These include arkose, low-and high-rank greywacke, and ortho-quartzite in Krynine's classification. Klein (1962) has explained this diversity as resulting from the variety of rock types in the provenance - the South Mountain highland.

Coarse- to medium-grained clastic rocks of the Wolfville and Blomidon Formations represent alluvial fan, transition zone alluvial fan-flood plain, and some deltaic deposition; the even-bedded siltstones and claystones represent lacustrine deposition (Klein, 1962).

Although now classified as two formations, this entire sedimentary section could be described as one formation with two time equivalent facies - a coarse clastic facies more prevalent in the lower part of the section and an even-bedded, siltstone and claystone facies more prevalent in the upper part of the section. A complete separation of facies, however, would require many contacts which would include numerous lenses and wedge-outs along the Triassic outcrop belt. With the limited information available at the present time, it seems more reasonable to draw a boundary at the stratigraphic horizon which represents the major shift in facies, continuing to call the upper unit the Blomidon Formation and the lower unit the Wolfville Formation. Separation of the units in this manner also has practical value when attempting to evaluate hydrostratigraphic units.

North Mountain Basalt. Capping North Mountain and conformably overlying the Blomidon Formation are a series of basalt flows known as the North Mountain Basalt (Powers, 1916). Klein (1957) has shown that these are tholeiitic basalts. The number of flows varies from seven near Middleton (Smitheringale, 1960) to sixteen near the Minas Basin (Klein, 1962). Columnar jointing is well developed in many places, and several of the flows are abundantly amygdaliodal. A large variety of minerals are present in the amygdaloidal part of the basalt and as joint fillings. Zeolites and various forms of quartz are commonly found.

Scots Bay Formation. Disconformably overlying the basalt, and present only in small areas near Scots Bay, is the Scots Bay Formation. This formation "consists of fine-grained clastic rocks interbedded with limestone, jasperoid, and chert" (Klein, 1962, p. 1134). The Scots Bay Formation is mentioned here only to complete the stratigraphic section within the area of investigation.

Surficial Deposits

Surficial deposits have been mapped in the Annapolis-Cornwallis Valley, in the Gaspereau Valley, and on North Mountain in the vicinity of Port George and Margaretsville (Map 1). These deposits may be over 200 feet thick in some bedrock depressions, but are generally thin and may be missing along bedrock highs. Most of the surficial debris, including some estuarine deposits, were deposited during the Plestocene Glaciations. Till is the most wide-spread glacial deposit, but the largest mass of glacial materials are of glacio-fluvial origin. Recent deposits are generally confined to streams and estuaries.

Pleistocene

Glacio-Fluvial Deposits

Glacio-fluvial deposits may be classified into two main groups:

ice-contact stratified drift, and outwash. Ice-contact stratified drift "embraces a group of deposits...built in immediate contact with wasting ice" (Flint, 1957, p. 137). Included in this group of deposits are kames, kame fields, kame terraces, ice-dammed lake deposits; and eskers. Outwash is "stratified drift that is stream built beyond the glacier itself" (Flint, 1957, p. 136). In the Annapolis-Cornwallis Valley outwash was deposited in extensive outwash plains, in some linear bedrock valleys, and as deltaic fans in bodies of water which existed during deglaciation.

Kames and Kame Fields. Kames are individual hills or mounds of sorted silt, sand and gravel. Groups of such hills are termed a kame field or Kame complex. A kame complex occupies much of the eastern and central Annapolis-Cornwallis Valley. Kame material is also present along secondary depressions in the Valley near the Minas Basin, in many of the tributary valleys along South Mountain, scattered along North Mountain, and along the south side of the Gaspereau Valley.

The composition and internal structural of kame material depends on the nature of the material carried by the glacier and on the amount of reworking by running water. Along the flank of South Mountain, kames include a wide range of materials from silt and clay to boulders many feet in diameter (Fig. 9). Poorly sorted and weakly stratified material alternates with sorted beds of sand and gravel. Good examples of this type of kame deposit can be seen in gravel pits at East Tremont (Fig. 10).

Near the center of the Valley, the bulk of kame material consists of well sorted and stratified sand. Gravel lenses are much less common and boulders very rare. An example of a well sorted and stratified deposit can be seen in sand pits along a discontinuous ridge of sand and gravel (possibly an "open channel" esker deposit) which extends from Aylesford to North Kingston (Fig. 11). Statistical measures for a sample from this deposit (21 A 15 C 107 K ⊡) are reported in table 13. Test-hole 48, section N-O, figure 12, and test-hole 58, section I-J, figure 12 were drilled through this deposit. Other examples of the nature of kame materials can be seen in the logs of test-holes 31, 24, and 25, section E-F, figure 13.

Kame Terraces. A kame terrace is composed of sand and gravel deposited between a melting mass of ice and the side of a valley. As a result, the deposit commonly has a relatively flat surface and is slumped where it bordered the ice mass. If the sand and gravel were deposited partly over ice, a kame and kettle topography would result, and the typical form of a terrace would be obscured. Parts of the kame fields along the flank of South Mountain probably had this origin. The only well defined kame terrace within the area of investigation, however, has a maximum width of about 1,000 feet and extends for four miles southwest of Port George along the Bay of Fundy (see Map 1).

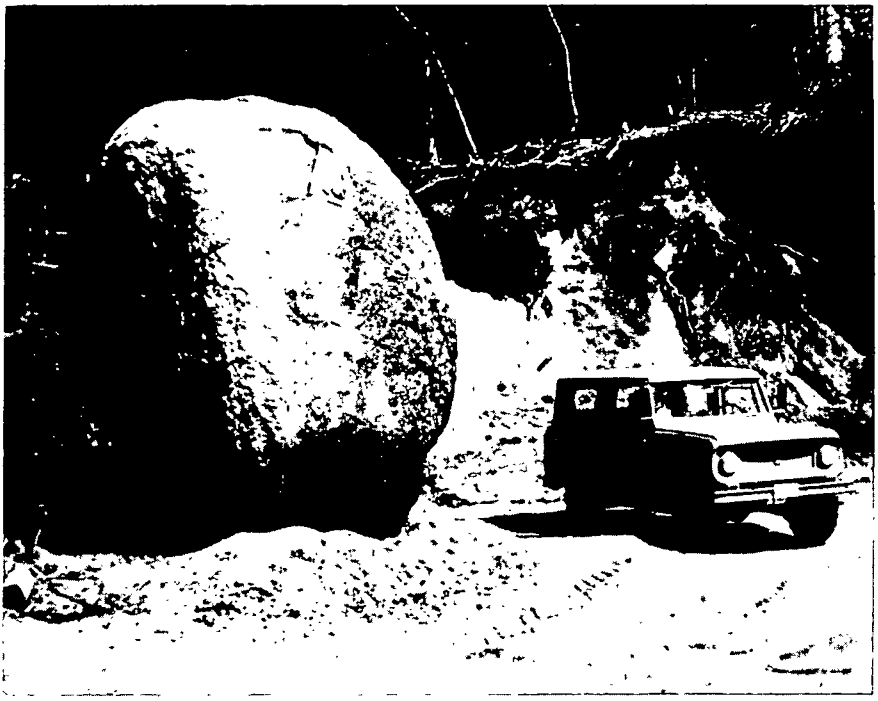


FIGURE 9. Granite boulder in kame near Bridgetown (21 A 14 B 73 F).

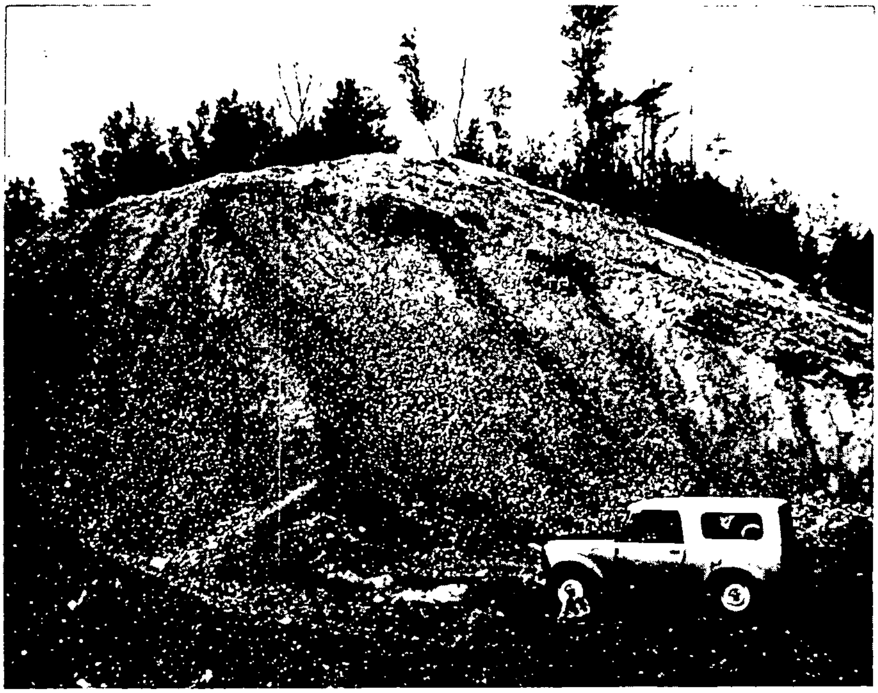


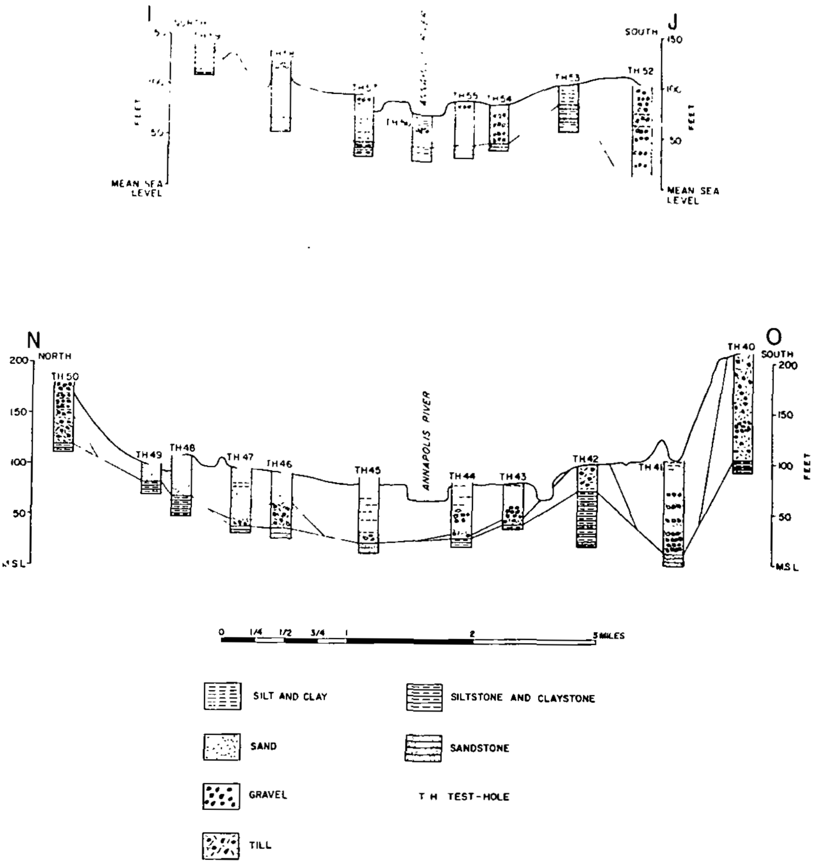
FIGURE 10. Poorly sorted kame deposit at East Tremont (21 A 15 C 65 L).

FIGURE 11. Open channel (?) esker deposit at North Kingston (21 A 15 C 106 O).

Ice-Dammed Lake Deposits. At Melvern Square, a temporary lake, dammed by stratified drift and ice, existed during ablation of the last ice sheet. Deposits in this lake are typically reddish brown, thinly laminated beds of very fine sand and silt. Because these deposits have different hydrologic properties than other stratified drift deposits, the approximate area of the lake is shown on map 1. At the boundaries of the lake, the lacustrine sediments interfinger and grade into coarser clastics. The main source of sediment for the lake probably came from the same meltwaters which deposited the ridge of stratified drift east of Melvern Square (Hickox, 1962).

Eskers. Eskers, which are usually the deposits of sub-glacial channels, are ice-contact deposits, but have been mapped separately because of their distinctive form. Eskers are abundant at several places in the Annapolis-Cornwallis Valley. The trend of most of them parallels the present drainage, suggesting that drainage along the Valley was established soon after dissolution of the ice mass began.

Eskers generally are influenced more by running water than kames, and so usually exhibit better sorted beds than other ice-contact stratified drift. The composition of eskers, as kames, is influenced by the material available. Gravel and boulders are common components of eskers along the

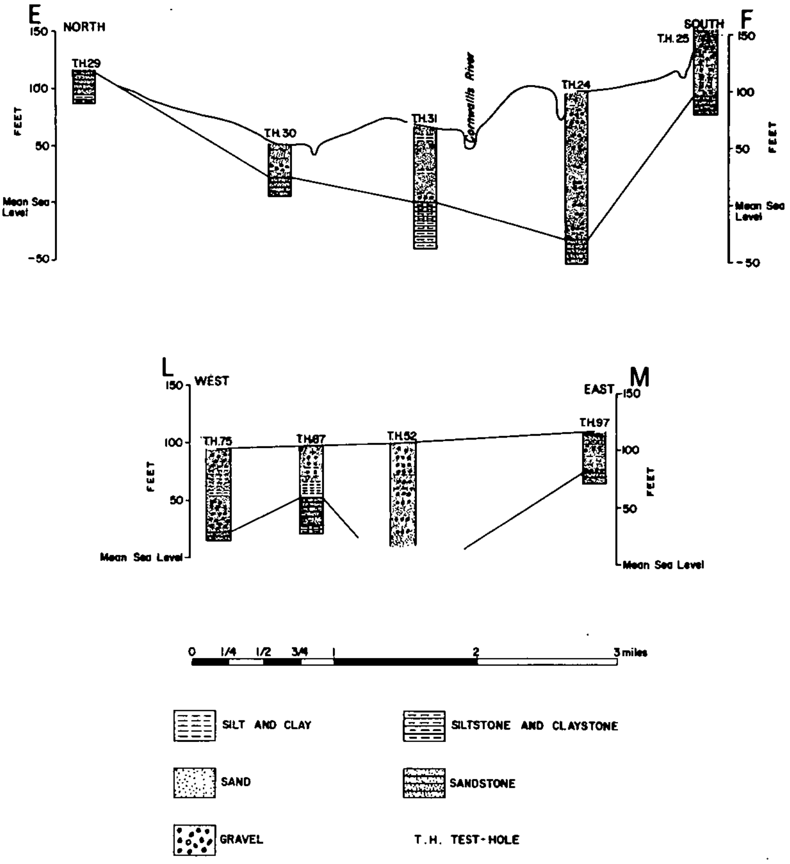


(Sections are located on Map I)

FIGURE 12. Surficial deposit test-hole cross-sections I-J and N-O.

flank of South Mountain (e.g., the eskers east of Nictaux Falls, 21 A 14 D 47 and 48). In contrast, eskers in the center of the Valley may consist almost entirely of well sorted sand with only occasional lenses of pebbles. This is particularly characteristic of the eskers between Auburn and Kingston.

Outwash Plain. An extensive outwash plain occupies much of the central part of the Annapolis-Cornwallis Valley between Berwick and Lawrencetown. Other areas of outwash are found scattered through this Valley and the Gaspereau Valley. Outwash is usually associated with and may overlap the kame fields from which glacial meltwater discharged. Outwash often overlies till or bedrock as shown in section I-J and N-O, figure 12. From Wilmot westward, outwash commonly overlies estuarine deposits of silt and clay (Sec. P-Q, Fig. 14 and Fig. 15).

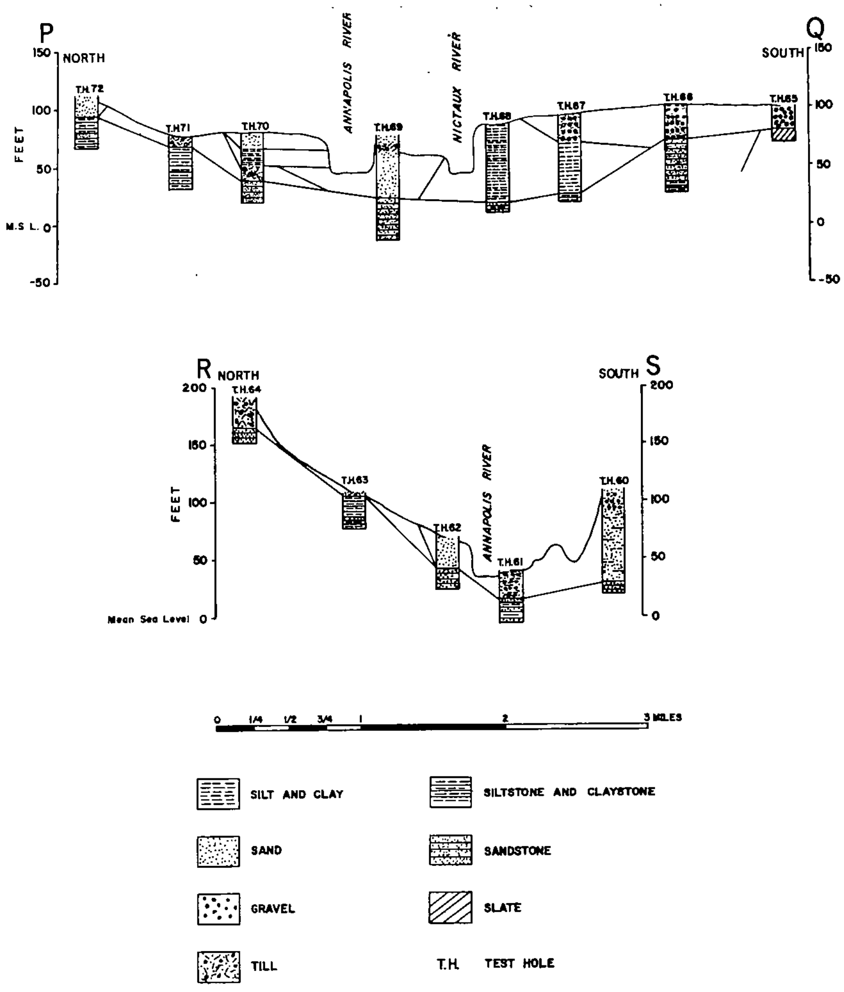


(Sections are located on Map I)

FIGURE 13. Surficial deposit test-hole cross-sections E-F and L-M.

Outwash usually consists of well stratified and cross-bedded fine to coarse sand. Fine to medium sand predominates near the late glacial estuary at the western end of the Valley. Where the outwash was temporarily submerged, it was sometimes reworked into offshore sand bars (Fig. 16). Near the headwaters of meltwater discharge, gravel is often interbedded with sand. Gravel may also be found in the subsurface beneath an outwash plain which is sandy at the surface, indicating that the volume and velocity of water aggarding the plain decreased with time. Outwash, composed predominantly of cobble gravel, spread as a fan northward from Nictaux Falls (test-holes 65 to 67, Sec. P-Q, Fig. 14 and Fig. 17).

Outwash Valleys. Meltwater discharge in some kame fields followed linear bedrock valleys. In these valleys (outlined in Map 1), a considerable thickness of outwash accumulated. Test-holes drilled in outwash valleys re-



(Sections are located on Map I)

FIGURE 14. Surficial deposit test-hole cross-sections P-Q and R-S.

veal the greater than average accumulation of stratified drift (test-hole 52, Sec. I-J, Fig. 12; test-hole 41, Sec. N-O, Fig. 12; test-hole 79, Sec. G-H, Fig. 28 and Sec. L-M, Fig. 13). In some outwash valleys surface drainage does not exist at the present time (e.g., Tremont); in others only underfit streams remain (e.g., Rockland Brook). Outwash probably extends beyond these valleys beneath recent alluvium.

Outwash Deltas. Deltaic fans of outwash were deposited by glacial meltwaters in a few places along the base of South Mountain. The approximate depth of the late glacial submergence is indicated by the flat surface of these

FIGURE 15. Springs emerging at contact between outwash and underlying estuarine deposits, Wilmot (21 A 14 D 71 N).

FIGURE 16. Parallel sand bars over till and estuarine deposits at Brickton (21 A 14 D 31 F).

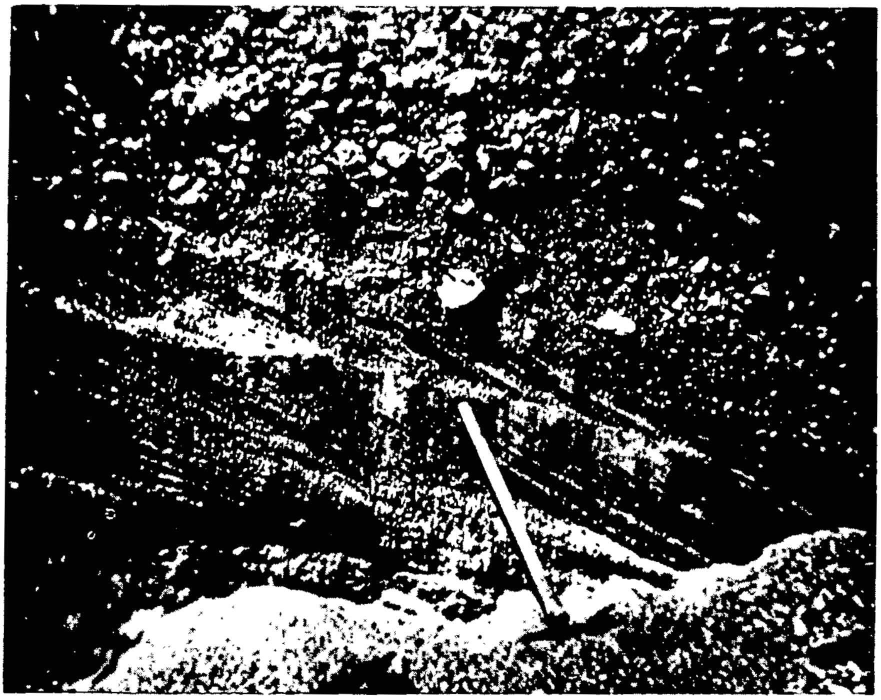


FIGURE 17. Sand and gravel outwash at Nictaux (21 A 14 D 46 K).

FIGURE 18. View eastward of outwash delta at Walbrook (21 H 1 B 74).

deposits. In gravel pits, long foreset bedding is exposed with beds generally extending several tens of feet (Fig. 18). The deltas were deposited rapidly because they include many beds of sand and gravel which are only moderately well sorted. With the disappearance of the body of water, streams which formerly aggraded the deltas became incised. Good examples of outwash deltas can be seen at Walbrook in the Gaspereau Valley, and at Round Hill east of Annapolis Royal.

Till

Till mantles much of the remainder of the Valley and underlies stratified drift in places. It varies in thickness from a few feet to several tens of feet (Sec. N-O, Fig. 12 and Sec. R-S, Fig. 14). Till rarely overlies significant thicknesses of stratified drift, although inclusions of stratified drift are found occasionally. Where till and estuarine deposits are present in the same section, till is always subjacent the bedded silt and clay.

The composition of till depends on the nature of the subjacent bedrock because most till is reworked bedrock with an admixture of material from more distant sources. For example, the till overlying the Blomidon Formation is of a heavier texture than till overlying the Wolfville Formation. The difference in composition is reflected in grain size analyses of the Pelton Clay loam, typical of a till soil mantling the Blomidon Formation, and the Woodville sandy loam, typical of a till soil mantling the Wolfville Formation (Table 3). (These analyses and those for other soils in the Annapolis-Cornwallis Valley are given in Harlow and Whiteside, 1943, p. 75-88.)

Table 3. Grain Size Analyses for Two Till Soils

	PELTON CLAY LOAM (C-Horizon)	WOODVILLE SANDY LOAM (C-Horizon)
%>1.0 mm.	4	10
% sand (1.0 - 0.05 mm.)	34	59
% silt (0.05 - 0.002 mm.)	45	21
% clay (<0.002 mm.)	17	10

Abundant basalt boulders are common in till at the base of North Mountain; abundant granite and quartzite boulders are usually present in till along the flank of South Mountain.

Estuarine Deposits

Estuarine silt and clay are present at the western end of the Valley. Bailey (1896, p. 21) has reported bands of marine shells and star-fishes *(Ophiopholis)* in the clay at Middleton, establishing the estuarine origin of these deposits. These deposits, however, do not uniformly mantle the floor of the Valley west of Wilmot. In fact, they often alternate in a patch work with till deposits.

A considerable thickness of estuarine deposits is present in some places with 64 feet recorded in test-hole 68 at Nictaux and 90 feet in the log of a water well at Tupperville. This large volume of sediment can be accounted for by considering that the estuary was the settling basin for the large volume of fine material carried in suspension by glacial meltwater. This type of sedimentation is recorded also in the Gaspereau Valley in test-holes 224-227 (Appendix A).

Estuarine deposits are almost always red or reddish-brown in colour. A moderately stiff clay is the dominant component in most places. For example, the C-Horizon of the Fash Clay is typically 13 per cent sand, 28 per cent silt, and 59 per cent clay (Harlow and Whiteside, 1943, p. 87). Near the boundaries of the estuarine deposits, silt and very fine sand are often more abundant as thin laminations. A good example of this can be seen at Nictaux West (21 A 14 D 28 G ☐).

Recent

Weathered Sandstone

Weathered sandstone is present as the surficial material in some parts of the Valley where glacial deposits are thin or missing. The weathered sandstone residuum is more poorly sorted than typical glacio-fluvial material (see Table 13), and grades downward within a few feet into unweathered rock.

Weathered sandstone cannot be distinguished from sandy till on aerial photographs. Therefore, these deposits could be mapped only on the basis of a reconnaissance survey on the ground, and some of the area mapped as weathered sandstone undoubtedly contains some sandy till. Places where the presence of sandstone can easily be determined have been marked with an X on map 1.

Peat and Muck

Following deglaciation, many flat or slightly depressional areas with poor drainage began to fill with peat and/or muck. The most extensive areas of peat and muck accumulated in the central part of the Valley, commonly over outwash sand and gravel. They are important for two reasons: commercial quantities of peat may be present, as in the case of the Caribou Bog, and the accumulation of vegetable matter may give a ''boggy'' taste and smell to groundwater in adjacent surficial aquifers.

Aeolian Deposits

Hickox (1962) has mapped several irregular sand hills and several long, sinuous sand ridges in the central Annapolis Valley as sand dunes. However, considering the shape of the sand bodies, their internal structure (which includes pebble lenses), and their textural characteristics (see discussion, Appendix B), they are not likely aeolian in origin. The long sinuous sand ridges are probably eskers and the irregular shaped sand hills are probably kames. Wind action has most likely been confined to places where vegetation has been stripped from sand and gravel recently by man's activities. This has been the cause of dune formation in southwestern Maine (Bloom, 1960), and has resulted in the formation of ventifacts in a sand pit north of Kingston in the Annapolis Valley (Hickox, 1959).

Hickox (1962) has reported that up to 6 feet of loess is present on the southeast side of the Annapolis Valley. The writer was unsuccessful in locating these deposits of loess. Some wind deposited material is undoubtedly present in places, but most likely it has been altered by soil forming processes.

Stream Alluvium, Dykeland, Salt Marsh and Tidal Flat

Recent alluvium occupies the flood plains of major streams and their tributaries in the Valley. The nature of alluvium depends primarily on the composition of the material through which the streams have cut. Alluvium is composed of silt and clay where streams have eroded through till and estuarine deposits. Alluvium includes sand and gravel where stratified drift has been eroded. For example, test-hole 80 (Appendix A) is in point-bar deposits of the Annapolis River flood plain. In the center of the Valley, recent alluvium may overlie coarser and better sorted beds of outwash (test-hole 76, Sec. G-H, Fig. 28, and test-hole 56, Sec. I-J, Fig. 12).

The tidal estuaries of the larger streams draining the Annapolis-Cornwallis Valley have been dyked to form rich pastureland (Map 1). Dykeland consists of clay, silt, and sand deposited under the influence of both stream and tidal currents. Test-holes 38, 136, 138, and 223 (Appendix A) have been drilled in dykeland. Note that in some cases (test-holes 38 and

138), outwash may be present beneath heavy textured dykeland deposits.

Active deposition is still taking place on the present salt marsh and tidal flat beyond the protection of dykes.

Structure

The Acadian orogeny created tight, northeast trending folds and a near vertical cleavage in Lower Devonian and younger rocks (Smitheringale, 1960). Then, mafic sills and dykes intruded these rocks; this event was followed by faulting and intrusion of the granite batholith in the late Lower or Middle Devonian.

Rocks of the Horton Group were deposited on an erosional surface and subsequently folded but not metamorphased.

Following the uplift and erosion of the Palaeozoic rocks, Triassic rocks were deposited and subsequently deformed into a broad structural basin which is faulted in several places. For example, several large faults have displaced North Mountain where wind gaps and water gaps now exist southwest of the map area.

Near Kentville, Klein (1957) has described the New Ross Road fault which has juxtaposed Triassic rocks and Halifax slates along Dodge Brook. The fault plane is not visible, but Crosby (1962) estimates a displacement of 400 feet near Kentville and 1,000 feet at the continuation of the fault at Kingsport (his evidence there is repetition of beds)

An outcrop of Triassic rocks has been discovered (21 H 1 B 61 C ⊡) in an area assumed to be slate by Klein (1960) and Crosby (1962). This reduces but does not erase the stratigraphic displacement. However, the juxtaposition of slate and sandstone does not necessarily mean a fault exists. The pre-Triassic erosional surface most likely had some relief. Perhaps, therefore, Dodge Brook now closely follows a pre-Triassic valley, and the dip of sandstone beds to the east (observed by Klein, 1960) may reflect the original dip. There is not enough evidence, however, to prove either hypothesis.

Geomorphology

Following the formation of the Triassic structural basin, there was a period of erosion which produced a peneplain in the Cretaceous throughout eastern North America (Goldthwait, 1924, p. 40). Since then, a second cycle of erosion, initiated by regional uplift, has produced lowlands in belts of weaker rocks and left the more resistant rocks as uplands. Early in the second cycle of erosion, drainage was established along the present Bay of Fundy (Goldthwait, 1924, p. 44) but some streams probably flowed across the present Annapolis-Cornwallis Valley and through North

Mountain where there are now wind gaps and water gaps. Subsequent streams have since eroded the relatively weak rocks of the Wolfville and Blomidon Formations and have captured the drainage which formerly crossed the Valley. Relative sea level sometime during the second cycle of erosion was more than 100 feet below its present level because the bedrock depressions near the Minas Basin are now more than 100 feet below sea level (Fig. 4).

In New England, the bedrock topography today is essentially the same as it was prior to the Pleistocene epoch (Shafer and Hartshorn, 1965), and the same is probably true in western Nova Scotia. The pre-Pleistocene relief, however, has been decreased by glacio-fluvial and recent estuarine deposits which have aggraded the floors of the valleys in response to the rise in sea level.

A case of stream capture by Dodge Brook south of Kentville and several cases of drainage changes due to glacial deposits in the Annapolis-Cornwallis Valley are cited in Trescott (1967).

HYDROLOGY

Hydrostratigraphic Units

Introduction

A hydrostratigraphic unit is defined as a group of geologic materials which have similar water-bearing properties. In many cases, a formation, such as the Blomidon Formation, is also a hydrostratigraphic unit. In other cases, several formations, such as those including the early Palaeozoic metamorphic rocks, have been grouped together into one hydrostratigraphic unit.

In this section the occurrence of groundwater in each hydrostratigraphic unit will be discussed along with the yields which may be expected from wells constructed in these units.

Hydraulic Properties of Aquifers

Several pump tests were run to determine the hydraulic properties of some surficial and bedrock aquifers. Analyses of three of the pump tests are given in Appendix D. Pump test procedures and various formulas for determining hydraulic properties of aquifers are described elsewhere (see, for example, Walton, 1962, and Jones, 1963).

The hydraulic properties commonly determined from pump tests are the coefficients of transmissibility and storage. The coefficient of transmissibility (often shortened to transmissibility T) of an aquifer is defined as the rate of flow of water in gallons per day through a vertical strip of aquifer 1 foot wide under unit hydraulic gradient (Ferris *et al.* 1962). In this report it has the units of imperial gallons per day per foot (igpd/ft). The transmissibility is equivalent to the saturated thickness of the aquifer in feet times the permeability P. Permeability is defined as the rate of flow of water through a 1 square foot cross-section of aquifer under a gradient of one foot per foot.

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 (Theis, 1935). Under water-table conditions where water is released from storage by partial drainage of the aquifer in the vicinity of the well, the coefficient of storage eventually becomes equal to the specific yield of the aquifer. The specific yield is defined as the ratio of the volume of water that can be obtained by gravity drainage of a material to the total volume of the material. Under artesian conditions, where the aquifer is not actually drained, water released from storage is derived chiefly from compression of the aquifer skeleton and to a lesser degree from expansion of the water itself.

Discussion of the Aquifer Map

The aquifer map (Map 2) was prepared to accompany the discussion of hydrostratigraphic units. The boundaries of the bedrock hydrostratigraphic units are the same as the corresponding geologic boundaries on map 1 except for the Wolfville-Blomidon boundary. This boundary was drawn where the surface elevation is about 200 feet above the uppermost sandstones of the Wolfville Formation. Thus, a well drilled near this line should encounter fairly good sandstone aquifers at a depth of about 200 feet. South of this line, sandstone aquifers will be found increasingly close to the surface. North of this line the depth to good aquifers will increase rapidly as the topography rises along the North Mountain scarp. Elsewhere in the outcrop belt of the Wolfville Formation, bedrock may be found anywhere from the surface to a depth of almost 200 feet, depending on the thickness of surficial deposits. The first bedrock encountered, however, may be siltstone and claystone, but interbedded sandstones and conglomerates should be present at greater depth.

Isopachs of the probable thickness of saturated sand and gravel are given on map 2. The true thickness of saturated sand and gravel is often unknown because all of the control is from limited test-hole information, and interpolations between test-hole values are based on judgment and on the distribution of surficial deposits. The zero isopach is the only one which can be taken as approximately correct since this line generally represents the boundary of the surficial sand and gravel deposits. Some small isolated kames are not shown on the map because they have almost no potential as aquifers. The reader should refer to the Summary, Recommendations and Conclusions for recommendations concerning use of information on the saturated thickness of sand and gravel.

On map 2, the depth to the water-table, in feet, is given for numerous places in the Annapolis-Cornwallis Valley and along the adjacent mountains. Most of the information is from dug wells, irrigation pits, and test-holes which were measured in the middle to late summer during the course of field work. The water-table generally follows the topography and is usually close to the surface in materials of low permeability because steep groundwater gradients are possible. The water-table often does not follow the topography closely in materials of high permeability because groundwater gradients are more gentle. Thus, some general statements can be made concerning the depth of the water-table in various places in the area under study.

The water-table is seldom greater than 15 feet and is commonly less than 10 feet below the surface under the following circumstances: along North and South Mountains where bedrock of low permeability is overlain by till and where there is no extreme local relief; along the Annapolis-Corn-Wallis Valley in areas underlain by till; and in outwash sand and gravel where nearby streams have cut only a few feet below the general land surface. The depth to water may vary considerable, and be as great as 40 or more feet, where the topography is highly dissected by streams along the South and North Mountain scarps. Depths to water from 15 to 30 feet are common beneath low sandstone ridges, and in outwash where streams have cut 20 or more feet below the surface of the outwash plain. The greatest depths to water are encountered in large kames which are usually unsaturated where they extend above the regional land surface.

Bedrock Hydrostratigraphic Units

Slates and Quartzites

All of the early Palaeozoic rocks from the Goldenville Formation through the Torbrook Formation are included in this hydrostratigraphic unit. These formations include a variety of rock types (see Table 1) which have been subjected to varying degrees of metamorphism. They are similar, however, because they are all dense, and as a result, the unfractured rock has a very low permeability and will yield no significant amount of water to wells. Fracture systems, therefore, contribute the only important permeability in these metamorphic rocks. Metamorphic rocks are generally fractured or jointed in at least three different directions with usually one or two joint directions more prominently developed than the others. The openings between joints tend to be small except near the surface where weathering may have enlarged some of them.

In slates, the most numerous joints are parallel to the cleavage which is commonly near vertical along the South Mountain highland. As a result, vertical wells will penetrate relatively few of the cleavage joints and will receive water predominantly from directions parallel to the strike of the cleavage.

In massive quartzites, joints are less numerous but more evenly distributed in various directions. Vertical wells, therefore, will penetrate more of the available water-bearing fractures in massive quartzite than in slate, but the total number of joints cut by a well may be similar in both cases. In quartzite, however, there will be more tendency for water to move from all directions towards a pumping well.

In the nature of their jointing, probably all of the early Palaeozoic metamorphic rocks fall somewhere between the two end members, slate and massive quartzite. Occasionally wells may penetrate exceptional numbers of fractures in fault zones and in the crests of folds. If these fractures have not been filled by secondary minerals, greater than average water yields from wells may be expected.

Yields (based on drillers' tests) of thirty-six wells in the early Palaeozoic metamorphic rocks averaged about 3 1/2 imperial gallons per minute (igpm) and range from less than 1 to 12 igpm. This is typical of yields from wells constructed in slate and quartzite (Meinzer, 1923). It should be emphasized, however, that drillers' tests do not necessarily represent the maximum well yields. Another consideration is that most of these wells are for domestic use, and for economic reasons they are usually not drilled deeper after a domestic supply (at least 1 to 2 igpm) has been assured. Meinzer (1923) stated that the nature of jointing in slates and quartzites may justify drilling to a depth of 400 or 500 feet (depending on local experience) in an attempt to obtain an adequate domestic supply.

Granite

Permeability in granite is found almost entirely in joints except near the present bedrock surface or in an ancient weathered zone where some intergranular permeability may exist. Weathered granite residuum at the present bedrock surface has commonly been reworked by glacial action and is considered in the section on till. The most common joints in granite are nearly parallel to the regional surface. Since these joints have resulted from release of pressure on the granite, they decrease in number with depth.

The yield of seven wells in granite on South Mountain (as reported by drillers) averaged 9 igpm. In general, yields greater than those for slate and quartzite should not be expected, but exceptional yields will be encountered in places. For example a well 86 feet deep in granite (21 A 14 A 89 N ⊡) was tested at 45 igpm (probably not its maximum yield). In contrast, a neighbour's well in granite yields barely enough for a domestic supply. This situation illustrates the fact that a second well drilled several hundred feet from a "dry" well in granite may often be a success. Several workers (summarized in Meinzer, 1923) recommend that a well drilled 200 to 250 feet in granite without success should be abandoned and another drilled a 100 or more feet away with a good chance of obtaining an adequate supply.

Horton Group

The Horton Group was not investigated extensively because it underlies only a small part of the area under study. Consequently, it is considered a hydrostratigraphic unit for this report even though it contains rocks with different water-bearing properties.

Though not metamorphosed, fine-grained strata in the Horton Group (shale and siltstone) yield water to wells through joint systems in a manner similar to slate. The coarser-grained strata (sandstone, grit, and conglomerate) generally transmit water through the original interstices as well as through joints. As a result, wells in these rocks yield greater quantities of water than if the permeability were confined to fractures. In some cases the coarser rocks have been silicified to quartzites (Crosby, 1962, p. 31), considerably reducing their effective porosity and permeability.

The lower beds of the Horton Group underlie the Gaspereau Valley, and consist mainly of coarse-grained water-bearing strata. Water in these aquifers is under enough artesian pressure so that flowing wells are common. Wells in these Horton aquifers can be expected to yield from 10 to 100 igpm (Syd Trask, personal communication). Wells penetrating only fine-grained Horton rocks probably will not yield much more than domestic supplies.

Wolfville Formation

The Wolfville Formation includes the most important bedrock aquifers in the Annapolis-Cornwallis Valley. Although containing many interbedded siltstones and claystones, the Wolfville Formation is considered as one hydrostratigraphic unit because good water-bearing sandstones and/or conglomerates may be penetrated almost anywhere within the boundaries of the formation. The interbedded claystones and siltstones insure that water in the coarser clastics is under artesian pressure in most of the formation.

Movement of water in Wolfville sandstones and conglomerates is primarily through intergranular pore spaces and only secondarily through joints. The transmission of water through the rock, however, is limited because the rocks often consist of poorly sorted sediments, and the grains are commonly cemented by secondary minerals. The large range of particle sizes reduces the overall rock porosity and permeability because pore spaces between large particles are filled in by smaller grains. Of the remaining pore space, an average of 17 per cent is filled in by matrix minerals. Of this 17 per cent, an average of 3 per cent is quartz and muscovite-sericite, and 14 per cent is sparry calcite cement (Klein, 1962, p. 1137). Department of Mines drillers have reported kaolinite, an alteration of feldspar, in the matrix of several Wolfville sandstone samples.

The coefficients of transmissibility (T) and storage (S) for several aquifers in the Wolfville Formation are given in table 4. As an example of the determination of T and S for an aquifer in the Wolfville Formation, a pump test analysis of a well at M.W. Graves Co. Ltd., Berwick is given in Appendix D. Note that the coefficient of storage has nearly the same value for the three tests where an observation well was available (an observation well is necessary for an accurate determination of S). From these three tests at the eastern, central, and western parts of the Valley, it would appear safe to predict that S for Triassic aquifers anywhere in the Annapolis-Cornwallis Valley would be in the same order of magnitude as those given in table 4.

Table 4. Hydraulic Properties of Wolfville Formation aquifers

AREA	OWNER OR TEST-HOLE NO.	COEFFICIENT OF TRANSMISSIBILITY T in(igpd/ft)	COEFFICIENT OF STORAGE S
Canning	M.W. Graves Co. Ltd.	6,400	1.5×10^{-4}
Sheffield Mills	135	5,200	
Berwick	M.W. Graves Co. Ltd.	3,700	2.0×10^{-4}
Bridgetown	Acadian Distillers	2,000	1.8×10^{-4}

The transmissibilities, however, are more variable. This should be expected because the coefficient of transmissibility depends on the saturated thickness of the aquifer penetrated by a well. In some cases open holes were pumped so that all available zones with higher permeability were yielding water to the well. In other cases the holes were cased to prevent caving and only the better producing zones yielded water to the well through screens. The permeabilities of the producing zones, therefore, may be more similar in value than the transmissibilities in table 4 would suggest.

Where large volumes of water are required, wells 200 to 400 feet deep in the Wolfville Formation should produce at least 100 igpm. Under ideal circumstances wells with yields of 500 or more igpm might be constructed.

Blomidon Formation

The Blomidon Formation is a hydrostratigraphic unit composed predominantly of fine-grained rocks (siltstone and claystone) which yield only small amounts of water, primarily through joints. Occasionally, thin, interbedded sandstones are encountered which will yield more water to drilled wells. These interbedded sandstones are also important because groundwater moving down through the Blomidon strata is refracted along them to appear as springs. Springs are not confined to one zone, but may be found at almost any stratigraphic horizon somewhere along the North Mountain scarp.

Near the boundary of the Wolfville and Blomidon Formations, most wells are drilled through the fine-grained rocks to the more productive sandstones of the Wolfville Formation. Most other water supplies from the Blomidon Formation are obtained by gravity feed from springs along the North Mountain scarp. Spring supplies are generally adequate for domestic and some farm needs, but they rarely yield enough water for irrigation.

North Mountain Basalt

Porosity and permeability in the lava flows of the North Mountain Basalt are in joints and the upper vesicular part of each flow. The original openings, however, have been filled in to some extent with zeolite and quartz minerals. In many places, there is apparently poor hydraulic connection between groundwater in different zones in the basalt because natural water levels may change many feet as a well is drilled deeper. For example, during early drilling of test-hole 133 (21 H 3 A 27 M ⊡) near Margaretsville, the natural water level was very close to the surface. After completing the hole at a total depth of 275 feet, the natural water potential was about 90 feet below the surface. Test-hole 134, drilled less than 100 feet away from test-hole 133, is 50 feet deep and has a water potential only 5 feet below the surface. (See also discussion in section on groundwater movement).

Information on water yields from basalt is based on wells for domestic use. Of sixty-seven tests reported in drillers' records, the average yield was 5 1/2 igpm, ranging from less than 1 to 40 igpm. Test-hole 133 proved to be one of the best wells completed in basalt. The transmissibility of the 185 feet of saturated basalt is 680 igpd/ft. The average permeability, therefore, is about 4 imperial gallons per day per square foot (igpd/sq. ft.). The safe pumping rate for this well was calculated to be 40 igpm.

Surficial Hydrostratigraphic Units

Ice-Contact Stratified Drift

Although composed predominantly of sand and gravel, ice-contact stratified drift may not be a good aquifer because of poor sorting and lack of an adequate saturated thickness. The poor sorting, which reduces the overall permeability from that of a uniform sand or gravel, resulted from deposition by glacial meltwater streams which fluctuated rapidly in direction and intensity. The more poorly sorted deposits are found along the flank of South Mountain.

The major limiting factor to using ice-contact stratified drift as an aquifer, however, is the limited saturated thickness. For example, it is common along the flank of South Mountain to find that the water-table is actually in bedrock beneath the kames (see Fig. 19). It is likely, therefore, that no extensive sand and gravel aquifers exist along the flank of South Mountain. Locally, however, sand and gravel may yield moderate supplies to dug wells.

In the Valley proper, it is generally safe to assume that the water-table beneath kames is approximately at the same elevation as nearby marshes and streams. In South Berwick, for example, the water-table may be 50 or more feet beneath the surface, leaving from zero to a few tens of feet saturated sand and gravel above bedrock. In such circumstances, utilization of the sand and gravel for wells is restricted by the small available drawdown.

The only large deposits of saturated sand and gravel are found in bedrock valleys. Comparison of the bedrock topography map (Fig. 4) with the saturated thickness of sand and gravel (Map 2) shows the close relation between the important surficial aquifers and the bedrock valleys. The main bedrock valley between Kentville and Waterville is filled with ice-contact stratified drift. This material is similar to outwash because stream action has produced better sorted and stratified deposits than commonly found along the flank of South Mountain. Aquifer characteristics of this ice-contact stratified drift, therefore, will be treated in the section on outwash.

Outwash

Outwash generally contains the best sorted sand and gravel aquifers. This results in higher permeabilities than commonly found in ice-contact stratified drift. Additionally, since outwash streams were not confined by glacial ice, outwash was spread over the low parts of the Valley where the water-table is now generally within 10 feet of the surface. Therefore, outwash and the ice-contact stratified drift filling bedrock valleys constitute the most important surficial hydrostratigraphic unit.

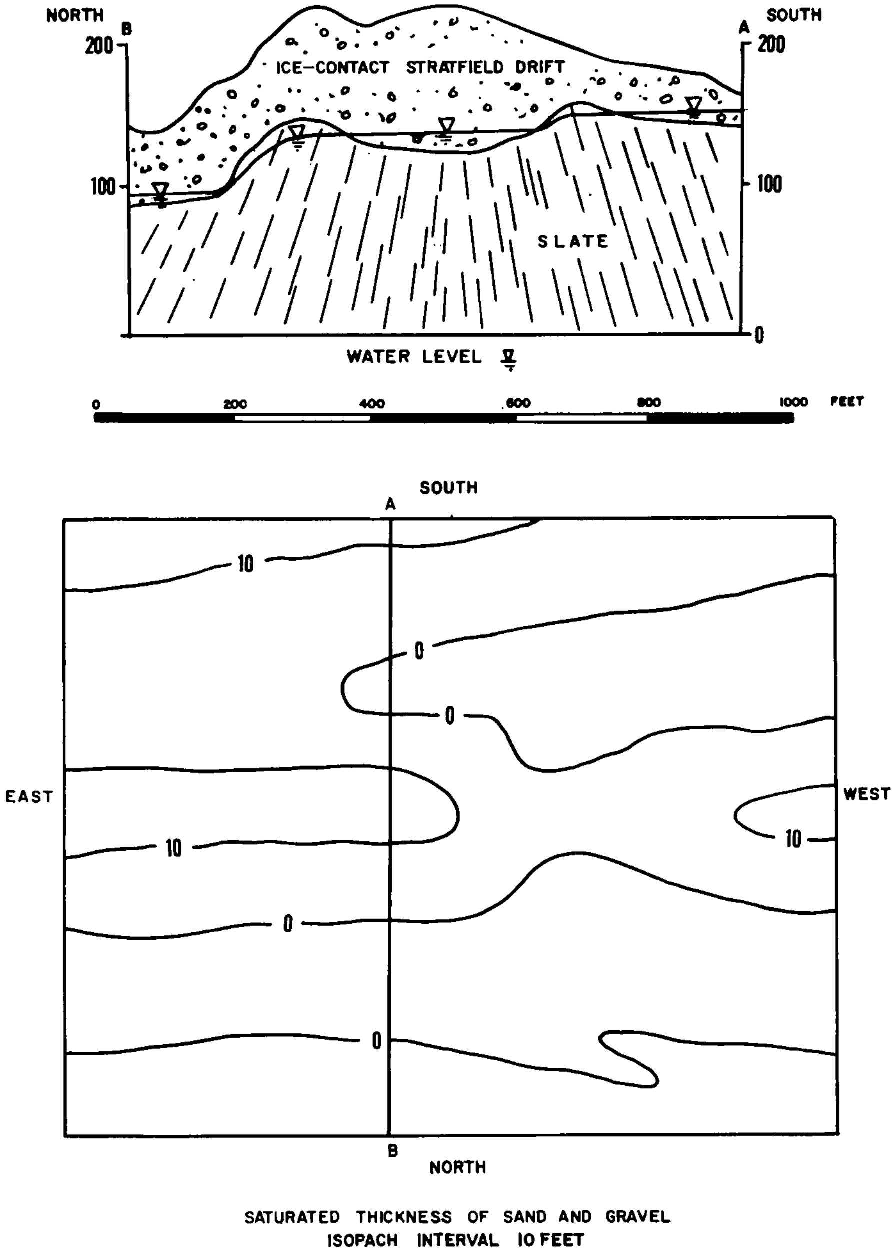


FIGURE 19. Hypothetical example showing why sand and gravel aquifers are limited in thickness and areal extent along the flank of South Mountain.

Aquifer characteristics of several sand and gravel aquifers are given in table 5. The aquifer at Coldbrook is in a kame complex filling a bedrock valley. The coefficient of storage is typical of unconfined aquifers. The high transmissibility indicates that this aquifer contains unusually well sorted gravel. In fact, this aquifer is the best one tested in the Valley to the present time. One well in the aquifer can be pumped safely at about 1,400 igpm or 2,000,000 imperial gallons per day.

The gravel outwash aquifer at Greenwood is also an excellent one, but the saturated thickness is only 18 feet. This rules out the use of large production wells, but a series of individual low yield wells could be spaced fairly close together and their yields combined to produce a large volume of water. For example, it was determined that individual sand points pumped at 30 igpm could be spaced only 50 feet apart at Greenwood with no significant interference. In the future, large scale utilization of groundwater in the outwash plain will probably be confined to this method of production because of the limited saturated thickness of this aquifer (see Map 2).

Table 5. Hydraulic properties of several sand and gravel aquifers

AREA	OWNER OR TEST-HOLE NO.	T (igpd/ft.)	P (igpd/sq. ft.)	S
Coldbrook	Scotian Gold	85,000	1,400	2.7×10^{-2}
Greenwood	Municipality of Kings Co.	35,000	2,000	3.6×10^{-2}
South Berwick	89	12,000	1,200	1.9×10^{-3}
Tremont	91	52,000	1,000	3.1×10^{-4}
Middleton	80	50,000	2,000	1.9×10^{-3}

Pump tests were conducted on aquifers in outwash valleys at South Berwick and Tremont. Note that in both cases the coefficient of storage is smaller than the values for Coldbrook and Greenwood. This is a result of silt and clay beds which create leaky artesian conditions in these two aquifers. The gravel aquifer at South Berwick is better sorted and, therefore, has a higher permeability than the aquifer at Tremont. This is explained by the fact that the outwash at Tremont is very close to the source of meltwater discharge in the heart of a kame field. The main disadvantage of outwash valley aquifers is that barrier boundaries are likely to be encountered within a few hundred feet of a pumping well (see analysis of Tremont pump test, Appendix D).

Stream Alluvium

Where streams cut through glacial sand and gravel, stream alluvium should be considered a potential aquifer. The thickness of stream alluvium depends on the depth to bedrock. Along the Annapolis River, for example, bedrock appears in many places. This bedrock commonly underlies the adjacent flood plain at a shallow depth leaving only a thin alluvial cover. In other places, stream alluvium may be several tens of feet thick (see the analysis of the pump test at Middleton, Appendix D).

Another consideration is that streams may not have cut through the earlier outwash deposits, particularly in the east-central part of the Valley near the divide between the Annapolis and Cornwallis Rivers. For example, in test-hole 56 (21 H 2 B 6 K ☐), about 20 feet of outwash sand and gravel underlie the Annapolis River alluvium. In test-hole 76 (21 H 2 A 39 N☐) near Berwick 10 feet of outwash sand and gravel underlie the Cornwallis River alluvium.

Wells are sometimes constructed in alluvium near a river in order to improve the well yield by induced infiltration. In order for this to occur, the natural groundwater gradient toward the river must be reversed. Although this was attempted during the Middleton pump test (see Appendix D), the pumping rate was not great enough to reverse the gradient. One concern when planning to derive some well water by infiltration from a river is that pollution in the river may be drawn into the well. Alluvium will usually act as an effective filter (Cal. State Water Pollution Control Board, 1954), but it would be desirable to monitor the quality of water during a pump test to see if any undesirable materials pass through the natural filter.

Till, Estuarine Deposits, Dykeland, and Weathered Sandstone

Till, estuarine clay and silt, dykeland, and weathered sandstones are considered as a single hydrostratigraphic unit. Only small quantities of water may be obtained from these deposits. As previously discussed, the composition of till depends primarily on the nature of the underlying bedrock. Over sandstones and granite, till is likely to be sandy, and water will move mostly through intergranular pore spaces. Where till is composed predominantly of silt and clay, water is transmitted primarily through sandy lenses and joints in the till. In any case, water supplies from till are adequate only for domestic use, and generally must be obtained from dug wells which provide a large area for infiltration and adequate storage for peak demands. Some water supplies are obtained from springs which appear where the till-bedrock contact is near the surface.

Except where very fine sand and silt are interbedded, the only permeability in estuarine deposits is in joints, but even the joints yield almost no water to dug wells. Thin outwash sand commonly overlies the almost impermeable estuarine deposits at the western end of the Valley. Some domestic water supplies are obtained from shallow dug wells constructed in the outwash, but it is difficult to keep these supplies sanitary.

Dykeland, like the estuarine deposits, is composed of fine-grained material of low permeability and cannot be considered a potential source of groundwater. At the eastern end of the Valley, however, dykeland materials may overlie glacial sand and gravel deposits (see Map 2). This is more commonly the case where glacio-fluvial material mantles the valley above the dykeland.

There is the possibility, however, that these sand and gravel aquifers contain salt water. Between Port Williams and Kentville there is a good chance that salt water is present in the aquifer because tides still extend to Kentville. The Habitant Creek dykeland has been isolated from the sea for many years so that there is a chance that fresh water is present in sand and gravel beneath this dykeland. Even if fresh water is found, however, there is a possibility that pumping will cause salt water intrusion if the aquifer is close to the present estuary.

Weathered sandstone, though fairly permeable, is generally only a few feet thick. Because of the relatively high permeability of this material the water-table may actually be in the underlying bedrock. Dug wells in weathered sandstone provide a few domestic water supplies, but it is better to drill a well into the sandstone where it is easier to provide a sanitary supply.

General Hydrologic Budget for the *Upper Annapolis River Basin*

Introduction

It is often useful to determine how much annual groundwater recharge there is in an area so that an upper limit can be placed on the ultimate groundwater development in that area. The easiest way to determine groundwater recharge is to calculate the natural groundwater discharge because the two quantities will equal each other over a period of time if there has been no net change in groundwater storage. Groundwater discharge includes groundwater runoff to the streams and evapotranspiration of groundwater from the soil. Groundwater runoff to streams (base flow and underground feeding of rivers are synonymous terms) maintains dry weather flow and enters the streams from the main groundwater reservoir. In this report, interflow is considered to be a part of groundwater runoff. Interflow can be defined as

> "the runoff due to that part of the precipitation which infiltrates the surface soil and moves laterally through the upper soil horizons toward the streams as ephemeral, shallow, perched groundwater above the main groundwater level" (Chow, 1964, p. 14-2).

Bank storage discharge is also included in groundwater runoff. River water introduced to alluvial sediments and groundwater stored in these sediments during floods and other high water stages of a river constitute bank storage. This water is released from storage slowly when the river stage falls below the adjacent flood plain water-table. The volume of water in bank storage can be computed in the following factors are known: the area of alluvial sediments affected by bank storage, the mean change in water levels in the sediments, and the mean gravity yield of the sediments. The gravity yield of a sediment is defined by Rasmussen and Andreasen (1959, p. 83) as "the ratio of (1) the volume of water it will yield by gravity to (2) its own volume, during the period of groundwater recession".

Evapotranspiration is water lost to the atmosphere by evaporation from soil and water surfaces, and by transpiration from plants during the growing season. Potential evapotranspiration is that amount of water that would be evaporated and transpired if continuously available.

Groundwater storage is defined as the volume of groundwater within a drainage basin. Any change in mean groundwater levels in a basin over a period of time reflects a change in groundwater storage.

A quantitative estimate of groundwater discharge from a basin can be made if the hydrologic budget for the basin is computed. A hydrologic budget may be defined as:

> ". . . a quantitative statement of the balance between the total water gains and losses of a basin for a period of time. The budget considers all waters, surface and sub-surface, entering and leaving or stored within a basin. Water entering a basin is equated to water leaving a basin, plus or minus changes in basin storage" (Schicht and Walton, 1961, p. 8).

Certain information, namely precipitation records and records of discharge for the stream draining the basin, must be available before even a general hydrologic budget can be estimated. Long term precipitation records are available for several places in the Annapolis-Cornwallis Valley, but discharge records are available only for the Annapolis River at Wilmot (since October, 1963) and for the South Annapolis River at Millville (since 1965). Therefore, a hydrologic budget can be computed only for the Annapolis River basin above Wilmot. The location of this basin, here named the Upper Annapolis River basin, is shown in figure 6. This basin has an area of 211 square miles and includes the South Annapolis River basin which is located mostly on the South Mountain highland. The Upper Annapolis River basin is similar in many respects to the remainder of the Annapolis-Cornwallis Valley. Thus, the proportional value of items in the hydrologic budget for the Upper Annapolis River basin may be applied to the whole Valley.

The hydrologic budget is calculated on the basis of the water year (October 1 to September 30) because surface water discharge and groundwater storage are generally at a minimum at the beginning and end of this period.

When stated as an equation including all of the items that may be involved, the hydrologic budget is:

$$(1) \qquad P_r + SurI + SubI + Imp = R + ET + U + Exp \pm \Delta Soil \pm \Delta Ss \pm \Delta Sg \qquad (1)$$

where:

P_r = precipitation
SurI = surface inflow
SubI = subsurface inflow
Imp = imported water
R = stream flow (includes surface and groundwater runoff)
ET = evapotranspiration
U = subsurface flow
Exp = exported water
Δ Soil = change in soil moisture storage
Δ Ss = change in surface water storage
ΔSg = change in groundwater storage

Of the many factors that may introduce water to a basin, only precipitation contributes water to the Upper Annapolis River basin. Natural surface water inflow is prevented by the surface water divides which bound the basin; and natural groundwater inflow is insignificant because groundwater divides within the basin are essentially coincident with surface water divides. Finally, no water is imported to operate hydroelectric plants, for municipal and industrial use, or for irrigation.

Of the items on the right side of equation 1, runoff, evapotranspiration, and change in groundwater storage are by far the most important. These items will be discussed at length in later paragraphs. Subsurface outflow is present only in the vicinity of the gauging station in the flood plain of the Annapolis River. Elsewhere, groundwater moves toward the Annapolis River or toward tributaries to the river. The amount of subsurface outflow in the flood plain can be estimated with Darcy's law, commonly used in the following form:

$$Q = T I L \qquad (2)$$

where Q is the outflow in imperial gallons per day (igpd), T is the transmissibility of the materials through which underflow takes place, I is the hydraulic gradient of the water-table in feet per mile, and L is the width of the cross-section through which flow takes place in miles. By using available information and making several assumptions, Trescott (1967) estimated Q to be 19,000 igpd or about 0.03 cubic feet per second (cfs). This flow is insignificant when compared to the total discharge and can be ignored in calculation of the hydrologic budget.

Exported water is not a factor in the Upper Annapolis River basin. Change in soil moisture storage, however, may be an important factor in the water budget, particularly if the budget is calculated on a monthly or seasonal basis. The soil is generally near or above field capacity (the amount of water retained in the soil after gravity drainage of a saturated soil) in the late winter and early spring months, and has the greatest soil moisture deficiency (difference in the amount of water actually in the soil and field capacity) in the late summer. On an annual basis, however, the change in soil moisture storage should be small except between wet and dry years. The last two water years considered in this section (1964-1966) were unusually dry, and there may be a significant error in the budget due to the lack of soil moisture data.

About 1.2 per cent of the Upper Annapolis River basin is covered by surface water, almost all in the form of lakes on the South Mountain highland. Records of uncontrolled lake levels are not kept, but this does not introduce serious errors in the water budget because a relative change in lake levels of 2 feet from one year to the next would amount to less than 1 per cent of the total volume of water accounted for on the right side of equation 1.

By eliminating those items of the hydrologic budget which do not apply to the Upper Annapolis River basin or which are generally insignificant in the calculations, the equation for the hydrologic budget reduces to the following form:

$$P_r = R + ET \pm \Delta Sg \qquad (3)$$

where the terms are as defined previously. The hydrologic budget for the Upper Annapolis River basin for the water years 1963-1966 is given in table 6. Each of the items in the budget is discussed in detail below.

Precipitation

Variation in Distribution

Climatic information for Kentville was presented in the Introduction. In this section some detailed comparisons are made, particularly with regard to precipitation. Mean monthly and mean annual temperature and precipitation for those climatic stations with the longest records in the Valley are given in table 7. Locations of these stations and those with shorter records are shown in figure 20. As might be expected, the mean annual temperature decreases in the Valley a degree and a half between Annapolis Royal and Kentville. The largest contrasts in temperature, however, would be expected between the adjacent mountains and the Valley. Little information is available on mean temperatures on North and South Mountains, but for 1965 and 1966, Garland on North Mountain had a mean temperature 3 degrees less than Sheffield Mills and Kentville.

In figure 20 precipitation data are given only for climatic stations with long term records because information for stations with short term re-

Table 6. Hydrologic Budget for the Upper Annapolis River Basin

	PRECIPITATION		STREAM FLOW						EVAPOTRANSPIRATION		
			SURFACE WATER AND SNOWMELT			GROUNDWATER RUNOFF INCLUDING INTERFLOW					
	inches*	acre-feet**	inches	acre-feet	% of precip.	inches	acre-feet	% of precip.	inches	acre-feet	% of precip.
1963 - 1964	42	470,000	22	250,000	53	7	80,000	17	13	140,000	30
1964 - 1965	32	360,000	20	230,000	64	4	40,000	11	8	90,000	25
1965 - 1966	31	340,000	14	160,000	47	3	30,000	9	14	150,000	44

*inches of water over the entire basin

**1 acre-foot is the volume of water 1 foot deep over an area of one acre cords has not been adjusted to the long term normals. It appears from the data given that a fairly uniform decrease in annual precipitation takes place from southwest to northeast in the Valley, but study of available records for all stations indicates that precipitation patterns are much more complicated. For example, for the months of May to September, 1963 to 1965, Clarence on the north side of the Valley received an average of an inch and a half more rain than Lawrencetown on the south side of the Valley. In contrast, during 1964, Greenwood in the center of the Valley received 3 more inches of precipitation than Aylesford in the north-central part of the Valley. The largest disparity is between the climatic stations at Sheffield Mills in the north-central part of the Valley and Kentville on the south side of the Valley. For the years 1962 through 1966, Sheffield Mills averaged 7 inches less precipitation than Kentville.

Another indication of the variability of precipitation is shown in comparisons of daily precipitation records for several climatic stations in the Valley. Such a comparison is presented in table 8 where the daily precipitation records for the months of January and July, 1965 are given for five stations. It can be seen at a glance that fairly uniform precipitation, such as January 17, 1965, is the exception rather than the rule both in the winter and in the summer. Heavy precipitation in particular (such as January 24 and July 24, 1965) is likely to be irregularly distributed.

It is apparent from the above discussion that precipitation distribution is irregular. Consequently, in the computation of the hydrologic budget of a watershed, it is desirable to have a fairly high density of precipitation gauges in order to get a good picture of the amount and distribution of precipitation. Rasmussen and Andreasen (1961, p. 99) stated that a precipitation gauge density of 0.62 per square mile was adequate for their hydrologic budget study. Using this figure for the Upper Annapolis River basin, adequate coverage would mean about one hundred thirty precipitation gauges. In fact, precipitation records are available only for Greenwood and Aylesford, and only the records for Greenwood have been used because the records for Aylesford are discontinuous between 1963 and 1966. Greenwood is located near the center of the Valley part of the basin, and consequently, is probably as representative of climatic conditions in the Valley as one station can be. Records at Greenwood, however, probably do not accurately depict climatic conditions on the South Mountain highland where about half of the Upper Annapolis River basin is located. For example, snowfall averages 20 per cent of precipitation in the Valley, but it probably averages more than 20 per cent of precipitation on highland areas. Further, the snow cover would last longer than it does in the Valley because of the greater accumulation, higher density of vegetation, and slightly lower temperatures.

Precipitation for 1963-1966

Precipitation for the 3 water years in inches and acre-feet of water over the basin is summarized in table 6. Prior to the first water year, precipitation during the water year 1962-1963 was near normal at Annapolis

Table 7. Temperature and Precipitation Normals for Climatic Stations in the Annapolis-Cornwallis Valley *

MONTHLY AND ANNUAL AVERAGES OF TEMPERATURE (°F)

Station	Type of Normal	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Element
Annapolis Royal	1	25.5	25.1	32.0	41.6	51.4	59.4	65.3	64.8	58.3	49.6	40.6	29.8	45.3	MT
	1	33.0	32.7	39.6	50.5	61.7	69.6	75.9	74.8	67.5	58.1	47.7	36.3	54.0	MX
	1	18.0	17.5	24.3	32.7	41.0	49.1	54.6	54.8	49.1	41.0	33.5	23.3	36.6	MN
Greenwood A	2	23.0	23.0	30.3	41.4	52.0	60.8	67.4	65.9	58.3	48.2	39.1	27.5	44.8	MT
	2	30.1	30.4	37.1	50.1	62.4	71.5	78.7	76.3	68.6	57.1	46.0	34.3	53.6	MX
	2	15.8	15.5	23.5	32.6	41.6	50.1	56.1	55.4	47.9	39.3	32.2	20.6	35.9	MN
Kentville CDA	1	22.5	22.2	29.6	40.4	50.9	59.7	66.6	65.3	58.3	48.1	39.0	27.0	44.1	MT
	1	29.7	29.8	37.2	49.4	61.8	70.6	78.0	76.4	68.3	57.2	46.0	33.3	53.1	MX
	1	15.3	14.5	21.9	31.4	40.0	48.8	55.2	54.1	48.2	39.0	31.9	20.6	35.1	MN

MONTHLY AND ANNUAL PRECIPITATION IN INCHES

Station	Type of Normal	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Element
Annapolis Royal	1	2.87	2.19	2.30	2.66	3.04	3.44	2.98	3.75	3.81	3.77	4.49	2.73	38.03	R
	1	23.2	18.6	11.4	2.4	T	0.0	0.0	0.0	0.0	T	3.2	17.0	75.8	S
	1	5.19	4.05	3.44	2.90	3.04	3.44	2.98	3.75	3.81	3.77	4.81	4.43	45.61	P
Paradise	3	3.79	2.64	1.92	3.19	3.17	2.87	2.48	4.13	3.38	3.71	4.34	3.06	38.68	R
	3	24.2	19.3	16.4	2.1	0.0	0.0	0.0	0.0	0.0	T	4.4	15.7	82.1	S
	3	6.21	4.57	3.56	3.40	3.17	2.87	2.48	4.13	3.38	3.71	4.78	4.63	46.89	P
Middleton	4	1.93	1.63	2.10	2.35	3.17	3.19	2.82	3.21	3.87	3.87	4.25	2.83	35.22	R
	4	23.5	20.3	14.5	7.3	T	0.0	0.0	0.0	0.0	0.2	6.9	20.3	93.0	S
	4	4.28	3.66	3.55	3.08	3.17	3.19	2.82	3.21	3.87	3.89	4.94	4.86	44.52	P

Greenwood A	4	2.41	1.85	1.66	2.63	3.03	2.96	2.36	3.83	2.87	3.01	3.99	2.85	33.45	R
	4	27.8	23.5	15.7	4.7	0.1	0.0	0.0	0.0	T	0.5	5.7	20.5	98.5	S
	4	5.19	4.20	3.23	3.10	3.04	2.96	2.36	3.83	2.87	3.06	4.56	4.90	43.30	P
Kentville CDA	1	2.39	1.64	1.89	2.36	2.87	2.87	2.54	3.52	3.78	3.59	3.96	2.37	33.78	R
	1	23.0	20.2	17.3	4.2	0.1	0.0	0.0	0.0	0.0	0.3	4.5	17.7	87.3	S
	1	4.69	3.66	3.62	2.78	2.88	2.87	2.54	3.52	3.78	3.62	4.41	4.14	42.51	P
Wolfville	4	2.00	1.60	1.99	2.37	3.03	3.04	2.64	3.15	4.17	3.69	3.94	2.27	33.89	R
	4	0.9	16.9	14.5	6.5	0.1	0.0	0.0	0.0	0.0	0.1	5.2	18.6	82.8	S
	4	4.09	3.29	3.44	3.02	3.04	3.04	2.64	3.15	4.17	3.70	4.46	4.13	42.17	P

TYPE OF NORMAL

Code	Description
1	Normals were computed directly from a period of record of 25 to 30 years within the period 1931 - 1960. In most cases the record existed over the full 30 years.
2	The data for these normals were from the full ten-year period 1951 - 1960 adjusted to the standard normal period 1931 - 1960.
3	These averages are based on the complete ten years of record from 1951 to 1960. No adjustment factor was used.
4	These averages are based on the period of record of 10 to 24 years during the period 1931 to 1960. No adjustment factor has been used.

T = less than 0.1 inch of snow

* Adopted from Canada Department of Transport, Climatology Division, Meteorological Branch, 1965, Temperature and precipitation normals, preliminary listing.

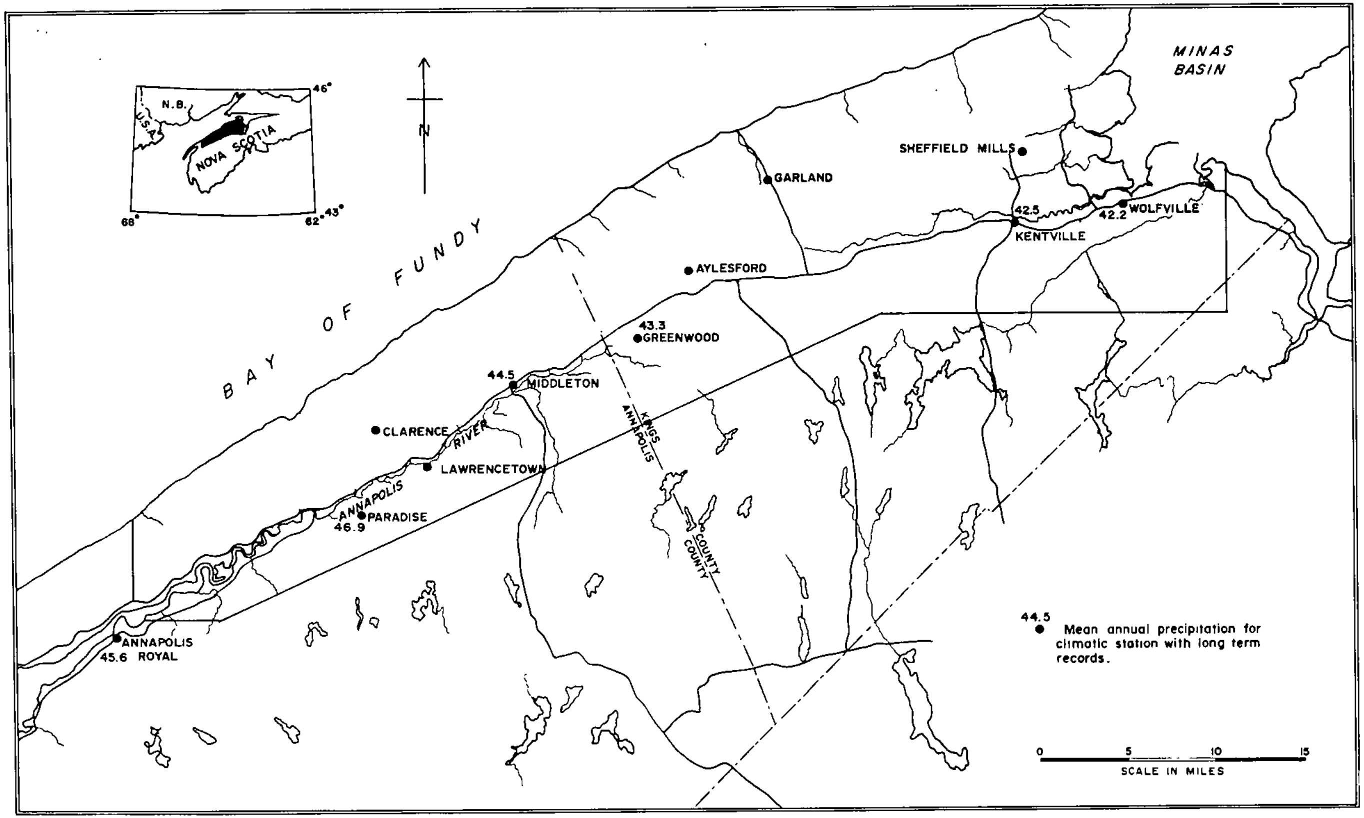


FIGURE 20. Climatic stations in the Annapolis-Cornwallis Valley.

Table 8. Daily precipitation records for Five Annapolis-Cornwallis Valley climatic Stations for January and July, 1965

	Annapolis Royal	Paradise	Greenwood	Sheffield Mills	Kentville	Annapolis Royal	Paradise	Greenwood	Sheffield Mills	Kentville
	January					July				
1		0.05	0.31	T*						
2			T							
3		0.05	0.02		0.08	0.04	0.05	0.04	0.05	0.01
4			0.03							
5						T				
6	0.10	0.05	0.03	0.11	0.02	0.01				
7		0.02	0.01	0.02	0.02					
8	0.20	0.14	T	0.08	0.02	0.50	0.72	0.73	0.38	0.22
9	0.39	0.35	0.49	0.23	0.26					
10	0.10	0.07	0.01	0.09	0.07	0.23	0.06	0.03		
11	0.10		0.07		0.01					
12			T							
13	0.03	0.01					T			
14	0.10	0.16	0.16	0.09	0.12	0.65	0.09	T	0.03	0.03
15	0.10		0.13				0.28	0.03		
16	0.40	0.55	0.38	0.46	0.59					
17	0.10	0.06	0.07	0.07	0.09					
18	0.40	0.50	0.03	0.55	0.30	T	T	T		
19	0.40	0.40	0.57	0.34	0.26	0.01	0.13	0.02	0.35	0.21
20	0.40	0.16	0.13	0.08	0.10			0.11	0.03	0.05
21			T							
22			T							
23								T	0.02	0.17
24	0.40	0.40	0.10	0.55	0.41	0.82	0.40	T	0.16	0.24
25	0.20	0.30	0.65	0.14	0.41			0.36		
26	0.50	0.50	0.04	0.41	0.56			T		
27		0.05	0.41	0.14	0.14					T
28	0.05	0.10	0.17	0.44	0.14	0.12	0.08	T	0.11	0.19
29	0.35	0.10	0.14	0.11	0.09	0.31	0.53	0.57	0.18	0.50
30	0.25	0.10	T	0.02	T					
31			0.05							
Totals	4.57	4.12	4.00	3.93	5.67	2.69	2.34	1.89	1.31	1.62

* Less than 0.01 inch

Royal and Greenwood, but considerably above normal at Kentville. Consequently, groundwater storage and stream runoff were probably normal or slightly above normal at the beginning of water year 1963-1964. Precipitation during 1963-1964 was near normal at Greenwood, but precipitation during the 2 water years 1964-1966 was far below normal. It is apparent from table 6 that the deficiency of precipitation during the last 2 water years considerably altered the value of many other items in the hydrologic budget.

Runoff

Daily discharge of the Annapolis River at Wilmot and pertinent climatic data from Greenwood are shown in figure 21 for the 3 water years 1963-1966. In order to compare annual river discharge for these 3 years with the estimated ''normal'' discharge, use was made of long term records for the La Have River at West Northfield, 42 miles south-southeast of Wilmot (information is from "Runoff Conditions in Canada", published monthly by the Dept. of Energy, Mines and Resources). It was assumed that the per cent of normal discharge at Wilmot for each water year was the same as the per cent of normal discharge at West Northfield for those years. Using this method, normal annual discharge for the Annapolis River at Wilmot was estimated to be about 334,000 acre-feet. Therefore, the water year 1963-1964 discharge of 332,000 acre-feet was near normal, but the discharge for the water year 1964-1965 was below normal (270,000 acre-feet) and discharge for the water year 1965-1966 was considerably below normal (191,000 acre-feet). It can be seen from table 6 that river discharge responds closely to changes in annual precipitation.

Snowmelt and Storm Runoff

In addition to various forms of groundwater runoff, stream discharge includes surface runoff due to rain and melted snow. The greatest discharges during the year occur between November and April and often include a great deal of snowmelt. To help correlate discharge with snowmelt, mean daily temperatures for the period including mean daily temperatures below freezing have been plotted above discharge in figure 21. It can be seen that peak discharges from November to April correlate well with rises in temperature. Included in these discharges, however, in rain runoff since increases in temperature are usually associated with a frontal system and storms. In some cases, however, very little rain is associated with snowmelt (March, 1964, and April, 1965, Fig. 21). Because of losses to evaporation, sublimation, and to groundwater and soil moisture storage, only part of the snow cover is discharged through the streams. As a rough estimate, probably 10 to 20 per cent of annual stream discharge can be attributed to snowmelt. After groundwater runoff is subtracted, the remaining stream discharge may be attributed to storm runoff.

Base Flow or Groundwater Runoff

Backwater and Descending Types of Groundwater Discharge. The most important component of stream discharge with respect to this report

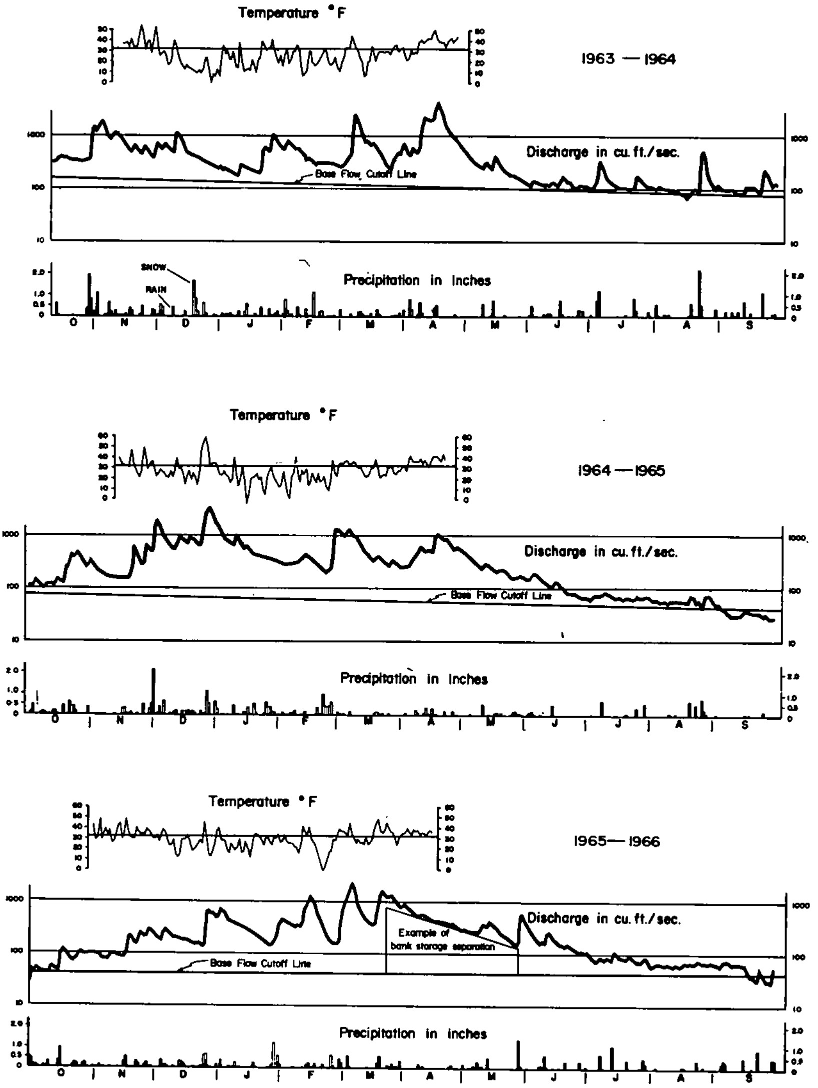


FIGURE 21. Mean daily discharge for the Annapolis River at Wilmot, and pertinent climatic data, including mean daily temperature and daily precipitation, for CFB Greenwood.

is base flow. Before discussing the method used for determining the quantity of base flow in the Annapolis River, it is important to emphasize that the section of the Annapolis River in the Valley is hydraulically connected to the aquifers which discharge water into it. This is the "back water type" of underground feeding of rivers where the fluid potential of water in bank storage during periods of high flow decreases or eliminates groundwater discharge into the stream (Chernaya, 1964, p. 455). The fluid potential is the height of the water surface above sea level. Zektser (1963) states that the artesian component of groundwater discharge may not cease but only decrease during periods of flood. Whether this is actually the case depends on whether the artesian head is above the river flood stage. In any case, groundwater discharge is at least reduced during floods when the river is hydraulically connected to the groundwater source. Groundwater runoff is at a maximum following the return of the river to low water conditions because bank storage discharge is added to groundwater discharge from the regional flow system.

In contrast, the "descending type" of groundwater discharge occurs primarily in mountainous areas where much of the groundwater discharge is from springs above the stream water line (Chernaya, 1964, p. 455). Instead of decreasing during periods of flood, the descending type of groundwater discharge follows a smoothed form of the river hydrograph and is at a peak during the flood peak. (Interflow as defined by Chow (1964, p. 14-2) is a type of descending groundwater discharge but it occurs only during and immediately after storms). Some of the groundwater discharge into streams on the South Mountain highland is probably of the descending type. This would make groundwater discharge in the Upper Annapolis River basin a combination of the backwater and descending types.

Methods for Determining the Quantity of Base Flow. The most accurate method of determining groundwater runoff is to have extensive knowledge of groundwater levels, hydraulic gradients, and permeabilities so that actual groundwater drainage can be computed by equation 2. As in most groundwater studies, adequate information is not available for direct computation of groundwater runoff, and indirect methods must be employed.

One method includes correlating groundwater levels in several wells with base flow in stream discharge records (Rasmussen and Andreasen, 1959, and Schicht and Walton, 1961), or correlating water levels from one well in the principal aquifer supplying the stream with river stage (Dement'yev, 1963). Such methods cannot be used at present in the Upper Annapolis River basin because of the lack of water level records for the sand and gravel aquifers which make the major groundwater contribution to the river.

Other methods employ graphical means of separating base flow from stream flow hydrographs.

> "The principal difficulties in the application of all graphical methods of separation of hydrographs lie in the separation of the values of underground flow during periods of

> high water and floods, since in the majority of cases direct determination of volumes of stream flow during the period of stable low water, when it is not distorted in any way and when there are no rain floods, gives the value of underground feeding of rivers'' (Chernaya, 1964, p. 455).

Methods for separating groundwater discharge from surface water runoff under individual storms are cited, for example, in Walton (1965, p. 36) and in Kudelin (1949, 1960). On an annual basis, however, the separation of discharge components under each storm is not as important as a fairly precise estimation of the total annual base flow discharge.

Low Flow Cutoff Method. Because of insufficient information, the type of hydrograph separation used in this report must be more schematic than those considering the dynamics of groundwater flow into a river Chernaya (1964) has compared several schematic methods with those considered to be the most accurate to see which of the general methods most neatly predicts the actual groundwater runoff. He concludes:

> ''The cutoff method on stable low-water discharges in which the high water and floods are cut off on the hydrograph by straight lines, can be applied as a schematic, simplified method of approximate determination of the total volume of annual underground flow without taking into account its distribution within periods of high water and floods. The application of this method is possible and it gives relatively correct results for rivers with the backwater type of feeding for generalized and smallscale solutions of feeding and also on river reaches with mixed types of feeding of underground water'' (Chernaya, 1964, p. 464).

It seems logical, therefore, to apply this method to the Annapolis River hydrographs. The resulting straight line separations are shown in figure 21. Kunkle (1962) also separates basin storage (water that falls as precipitation and moves in some path through the ground to the river) from other stream discharge components by the straight line cutoff method.

It is apparent from figure 21 that the cutoff method, though simple enough in principle, is not necessarily easy to apply. The line for the water year 1963-1964 was drawn from the estimated low flows of the summer of 1963 to the low flows of the summer of 1964. The low flows for 1963 were estimated by assuming that they occured in September and that they were about 20 per cent less than the low flows in October (as was the case in 1964). By assuming that low flow in October, 1963 was 200 cfs, the cutoff line was drawn from 160 cfs on October 1, 1963.

Total base flow (Table 6) in the water year 1963-1964 was greater in amount (80,000 acre-feet, 17 per cent of precipitation) than for the next 2 water years. Precipitation was near normal during 1963-1964, but there was an apparent decrease in general groundwater levels over the water year as indicated by the downward sloping cutoff line. Thus, groundwater storage was apparently greater at the beginning of this water year, but the reasons for this cannot be determined with available information.

Discharges during the summers of 1965 and 1966 were greatly influenced by the control of the South Annapolis River. Several lakes on the South Mountain highland are used to store water during the spring for use during the dry parts of the summer. Thus, the mean daily discharge from the South Annapolis River is relatively constant during dry summers (thereby keeping the discharge at Wilmot fairly constant) as the storage in the lakes is depleted. The contribution from lake storage can be illustrated by comparing the discharge at Millville with that at Wilmot. The discharge at Millville was 26 per cent of the discharge at Wilmot for the water year 1965-1966 but for the months of June through September, 1966, discharge at Millville increased to 44 per cent of the discharge at Wilmot. In 1965 all of the storage had been used by August 29, and in 1966 by September 16, causing sharp drops in discharge after those dates. This made it particularly difficult to draw meaningful cutoff lines for base flow discharge in water years 1964-1966. With the separation that was made, base flow discharge for 1964-1966 was 40,000 acre-feet (11 per cent of precipitation) and base flow discharge for 1965-1966 was 30,000 acre-feet (9 per cent of precipitation).

The most convenient cutoff line for 1965-1966 has no slope, suggesting no change in groundwater discharge over the water year. Perhaps it only took a year for groundwater levels and gradients to adjust to the abnormally low precipitation during the two water years 1964-1966.

Groundwater Runoff for the Annapolis-Cornwallis Valley. Part of the groundwater runoff given in table 6 has been derived from the South Mountain highland. An attempt was made to separate this contribution by considering discharges in August, 1966, a month of low precipitation (0.8 inch) and essentially no storm runoff (refer to Fig. 21). From the total August discharge at Wilmot were subtracted the total discharge of the South Annapolis River at Millville and the estimated total discharge of the Fales River and an unnamed stream which together drain almost all of the South Mountain highland in the Upper Annapolis River basin. The estimates for the Fales River and the unnamed stream were based on measurements of discharge on August 17 and 19, 1965 during a similar dry period. The remaining discharge, 1,300 acre-feet, can be attributed to base flow discharge in the Valley part of the Upper Annapolis River basin.

Assuming that 1,300 acre-feet was the base flow contribution every month of water year 1965-1966 (the cutoff line has no slope,) 16,000 acre-feet was the base flow discharge for the water year. Based on the fact that the Valley part of the Upper Annapolis River basin is about one-quarter of the Annapolis-Cornwallis Valley, an estimate of the total base flow discharge of the Annapolis-Cornwallis Valley from Annapolis Royal to the Minas Basin would be 64,000 acre-feet. Assuming further that the near normal year 1963-1964 groundwater runoff for the entire Annapolis-Cornwallis Valley was greater than that for 1965-1966 by the same percentage as in the Upper Annapolis

River Basin, a "normal" base flow discharge for the entire Valley would be 170,000 acre-feet. This is only a rough estimate of groundwater runoff because of the many assumptions involved, and should be less than groundwater recharge because groundwater evapotranspiration losses have not been considered.

As a comparison, it is estimated that about 6,400 acre-feet of groundwater are being used in the Valley per year. This figure was calculated from town water well consumption records (700 acre-feet); by assuming that the remaining population of the Valley on wells are using 100 igpd/person (4,100 acre-feet); and by adding an estimated industrial consumption of 1,600 acre-feet outside of town water supplies.

Bank Storage. A short term record of bank storage is available for the Cornwallis River flood plain near Berwick (Fig. 22). There, water levels in two piezometers (narrow diameter wells) about 10 feet from the river have been measured daily since June, 1966. One piezometer (76-a) is set at a depth of 8 feet and is used to measure fluctuations in the water-table; the other (76-b) is used to measure the water potential fluctuations at a depth of 26 feet, 6 feet below the surface of the bedrock. A record of river stage was kept starting in November, 1966. Note that the daily readings were all instantaneous and do not represent daily averages or extremes. In addition, river stage and groundwater levels in figure 22 do not always show a consistent relationship because of ice conditions.

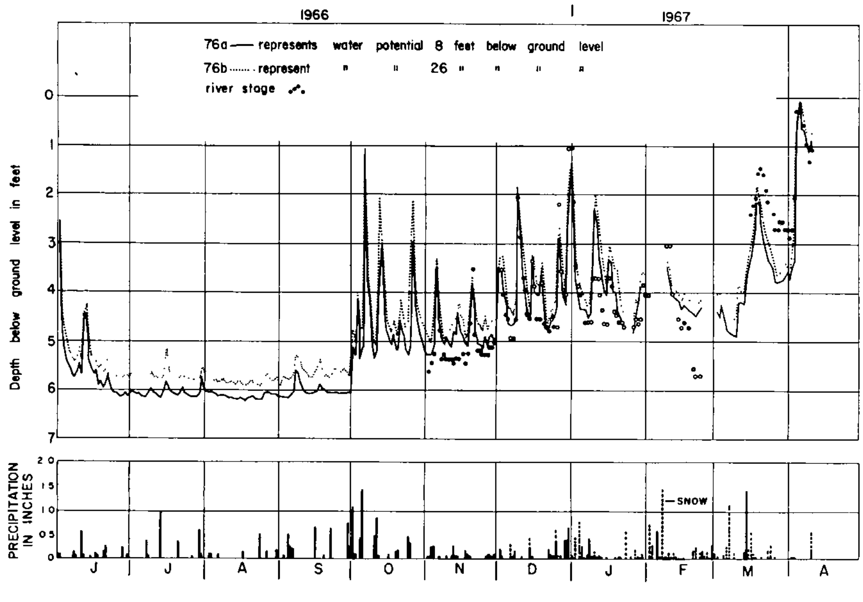


FIGURE 22. Water level records for two piezometers 10 feet from the Cornwallis River.

Creation and discharge of bank storage can be observed in the hydrographs in figure 22. The bank storage effect, however, is obscured to some extent by the response of groundwater potentials near the river to the variable load created by the changing river stage. The same effect was observed in alluvial sediments of the Annapolis River flood plain during the Middleton pump test (Appendix D). Nevertheless, it can be observed that the river was effluent during low river stages because the vertical component of the groundwater gradient was upward and the flood plain water-table was above the river stage.

During some intermediate and high water stages the river was influent because the river stage was above the flood plain water-table, but at the same time, the vertical component of the groundwater gradient remained upward due to the loading effect. The vertical gradient reversed, however, on the three occasions when the river almost spilled over its banks (October 6 and December 9 and 31, 1966). Although the decrease in groundwater potentials with river stage was due partly to the decreased load on the aquifer, some of the groundwater discharge during falling river stage was bank storage discharge.

Kunkle (1962) uses the straight line cutoff method to separate basin storage, but he separates bank storage as a distinct runoff component on river hydrographs. As an example, one period of bank storage recession (March 24 to May 28, 1966, Fig. 21) is separated according to Kunkle's method. The volume of water released from bank storage during this recession of river stage (35,000 acre-feet) is given by the area under the recession line and above basin storage discharge. In order to determine whether this volume of water could conceivably come from bank storage, a calculation was made of the probable volume of water that could be stored in sediments adjacent to the river during a flood. It was assumed that bank storage is confined to flood plain sediments because the river flood plain is generally depressed several to ten or more feet below the adjacent Valley lowland, and because the water-table in adjacent sediments does not usually descend below the altitude of the flood plain. The length of the flood plain is 19.5 miles from Wilmot to Rockland Brook (south of Berwick) and includes the South Annapolis River flood plain. The average width of the flood plain is 0.2 mile. Throughout the length of the flood plain, probably no more than an average of 5 feet of flood plain sediments are available to be saturated by flood waters. Assuming a gravity yield of 0.10, 1,300 acre-feet of water could be stored during a flood and released as bank storage. Even if the actual amount of bank storage were double this figure, the volume is an order of magnitude smaller than 35,000 acre-feet. Indeed, it would seem that the cutoff method would allow for some bank storage since the straight line is an average of decrease in groundwater discharge during a flood and the increase in groundwater discharge following the lowering of river stage. Perhaps the recessions in the Annapolis River hydrographs, such as the one discussed above, are more related to snowmelt on the South Mountain highland than bank storage. This is one subject that certainly needs more investigation.

Base Flow Between Auburn and Wilmot. One way to determine base flow contribution to a river is to gauge the river at several different places when there is no storm runoff. It was easy to find extended periods without precipitation, but the control of the South Annapolis River proved to be too much of a problem. Water was stored overnight and released during the day to meet power demands. This resulted in daily slugs of water moving down the river at a rate of slightly under 1 mile per hour. Without keeping a continous record of river stage at the gauging sections, it was not possible to know whether a high, low, rising, or falling stage was being gauged.

It was thought that the problem could be solved by using mean daily discharges for the reach of the Annapolis River between Auburn and Wilmot. Each uncontrolled tributary to the river was gauged in the middle of August, 1965 assuming that the instantaneous discharge would represent the mean for the day. This effort was of no avail because records for the gauging station on the South Annapolis River at Millville were unreliable for that period. If this project is attempted again in the future, provision should be made to measure evaporation from the river because evaporation loss during low flow in the summer may be considerable (Dement'yev, 1963).

Basin Groundwater Storage

Changes in Storage During the Water Years 1963-1966

To determine the change in groundwater storage from one year to the next, it is necessary to have records of groundwater levels. Water level records are available only for two bedrock wells outside the Upper Annapolis River basin for 1965-1966. The well at Canning is influenced by a nearby pumping well, but there does not seem to have been a significant change in the water level from October 1, 1965 to September 30, 1966. At Berwick, the water level in a bedrock well 700 feet deep was 2.6 feet lower on September 30, 1966 than it was on October 1, 1965. Assuming a coefficient of storage of 2×10^{-4}, this represents a drop in groundwater storage in the bedrock in this area of less than one one-hundredth inch. All that can be said from available information, therefore, is that there does not appear to have been a significant change in groundwater storage in bedrock aquifers.

The surficial sand and gravel aquifers, however, probably contribute most of the base flow to the Annapolis River. Records of water levels in sand and gravel aquifers were not available until 1966, and it can only be speculated that some decrease in groundwater storage took place from 1963 to 1966 because of the abnormally low precipitation during the last two years and because base flow contribution to the river decreased during that time.

Seasonal Changes in Groundwater Storage - Piezometer Records

Records of piezometers east of Berwick and of water levels in a well near Auburn are good examples of changes in groundwater storage since June, 1966. Water levels in surficial deposits and a few feet below the bedrock surface (**piezometers** 77-a and -b, Fig. 24; piezometers 79-a, -b, and -c, Fig. 26; and well 88, Fig. 23) receded almost uninteruptedly from June to October during the growing season when evaporation and transpiration were greatest. The recession followed a parabolic curve that decreased in slope with time. The total amount of groundwater recession varies considerably from place to place depending primarily on soil permeability and groundwater gradients (compare well 88, Fig. 23, in a flat outwash plain with piezometers 77-a and -b, Fig. 24, along a gentle slope).

In contrast to groundwater recession under water-table conditions, water under artesian pressure in the bedrock (well 78-b, Fig. 25, and well 79-d, Fig. 26) followed a nearly straight line recession during the summer. Very little fluctuation is observed in the recession of well 79-d until late September when there seems to have been some response to precipitation. The occasional sharp rises in water potential in well 78-b, however, are not clearly related to precipitation and an explanation is needed. Test-hole 78 is in a sand and gravel kame to a depth of 51 feet and in red Triassic siltstone and claystone from 51 to 75 feet. Piezometer 78-a extends to a depth of 48 feet, but unfortunately the water-table is generally below that level just above bedrock. Piezometer 78-b is used to measure water potentials about 15 feet into the bedrock. The hole in the bedrock was back filled with sand and gravel, much more permeable than the bedrock. Therefore, when slugs of water from rains moved down through the kame and temporarily raised the water-table, the pressure was easily transmitted through the permeable backfill to raise the potential in well 78-b. The actual artesian potential in the bedrock was not affected, however, and the potential of each slug of water was rapidly dissipated. This phenomenon was much more common after October when the true water level fluctuations in the bedrock were probably similar to those in well 79-d.

Groundwater recovery in the surficial deposits and a few feet below the bedrock surface was more immediate than the recovery of artesian water potentials in the bedrock. The summer rain on June 10, 1966 brought the soil moisture up to field capacity and recharged the water-table. This recharge is reflected in the recession curves (Figs. 24 and 26) which were offset by this rain. The recession curves were not again affected significantly until October 6, 1966 when, after a total of 4 inches of rain from September 29 to October 5, the water levels in the outwash valley rose about 2 feet in 2 days. Assuming a specific yield of 0.10, 2 inches of water would raise the water-table about 2 feet. The other 2 inches of precipitation were used in overcoming soil moisture deficiency. A soil moisture deficiency of 2 inches explains why the 1 inch rains of July 13 and September 22, 1966 did not raise water levels. Perhaps even 2 inch rains, such as those in July and August, 1964 (Fig. 21) would not have caused any significant groundwater recharge. Consequently, it can be concluded that, except for summers with heavy rains, the summer groundwater recession probably follows a similar pattern every year.

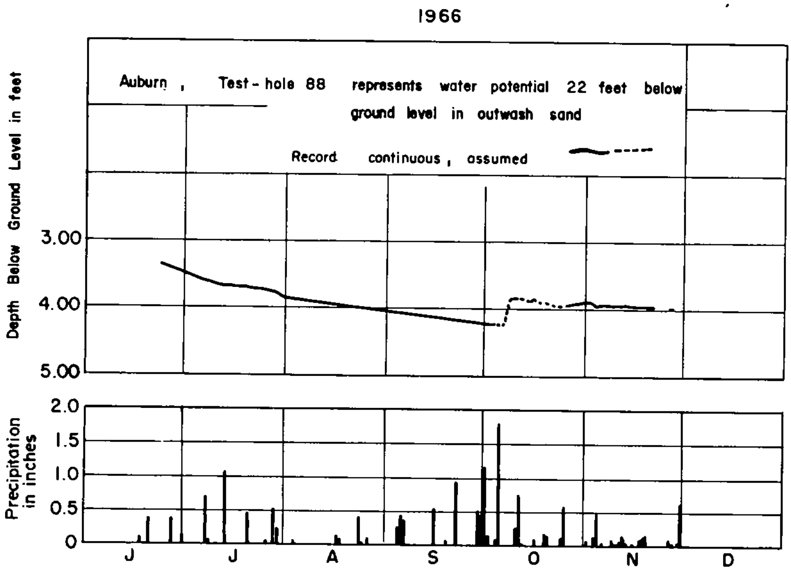


FIGURE 23. Groundwater levels in outwash at Auburn.

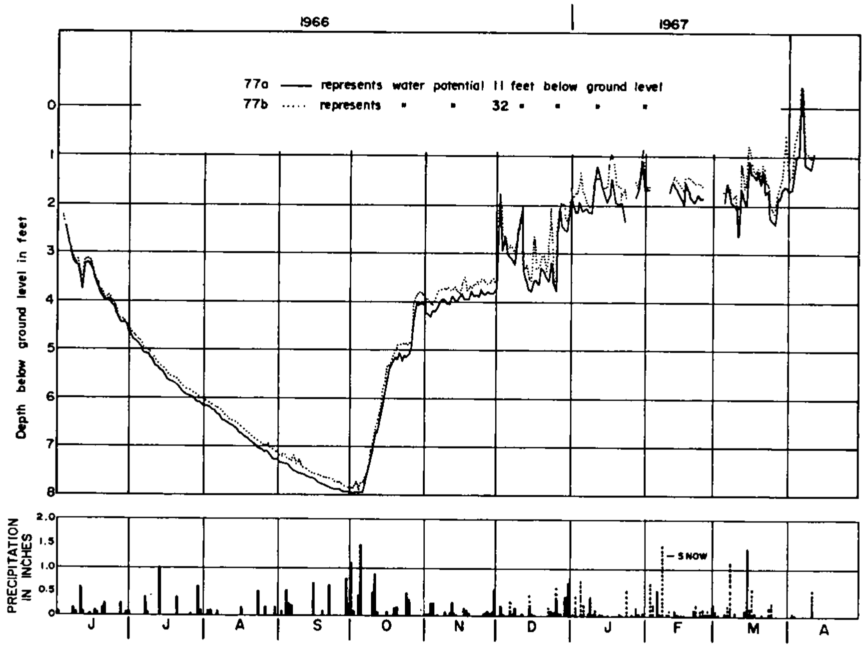


FIGURE 24. Water level records for two piezometers along a gentle slope.

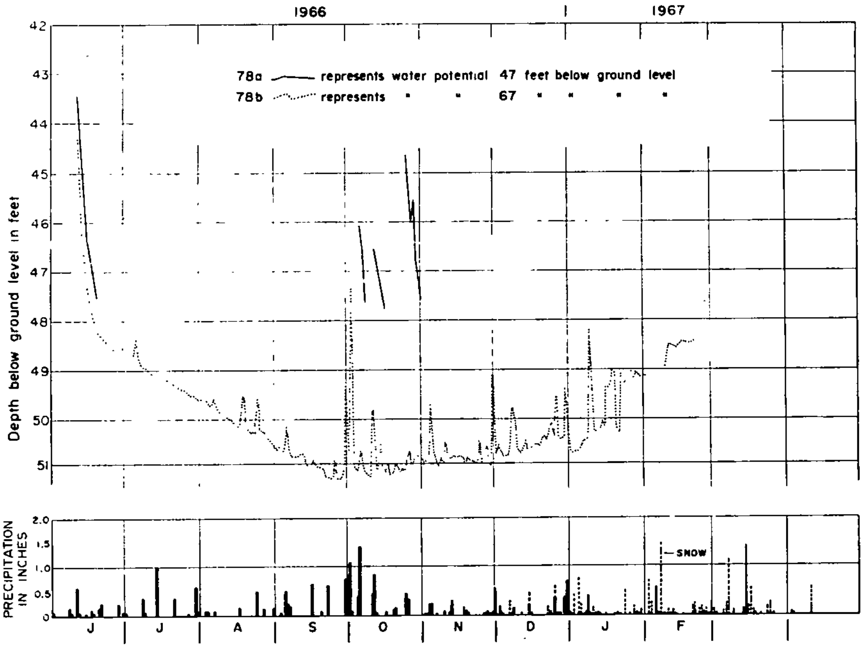


FIGURE 25. Water level records for a piezometer in a kame (78-a), and a piezometer in the underlying bedrock (78-b).

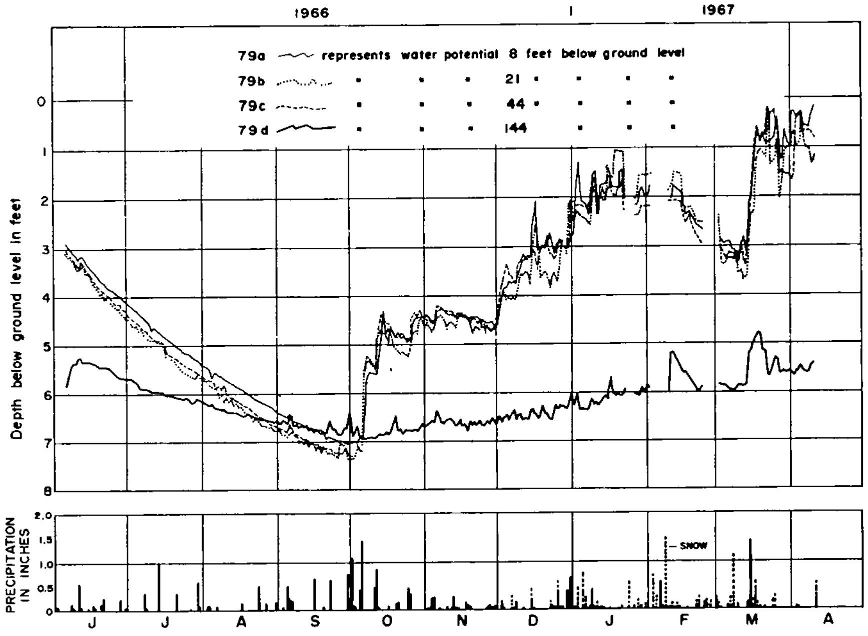


FIGURE 26. Water level records for two piezometers in outwash sand and gravel (79-a and -b) and for two piezometers in the underlying bedrock (79-c and -d).

Water levels in well 77-a and -b rose more slowly than those in 79-a, -b, and -c with the advent of fall rains. It is interesting to note that water levels continued to rise during December and January when the mean daily temperature was generally below freezing. Evidently the frozen ground during these months was not deep enough nor the ice continuous enough to prevent groundwater recharge from rain and melting snow. As the water-table rose within a few feet of the ground surface from December through March, the magnitude of water level fluctuations increased. Water level declines were probably related to the formation of ice in the soil with water being drawn by capillary forces into ice lenses. Melting snow and possibly partial melting of ice lenses during thaws released water to raise groundwater levels.

In the two bedrock piezometers which represent artesian conditions, it can be seen that there was no sudden rise in water potential with the advent of fall rains. In well 79-d, the gradual rise in water potential was almost a mirror image of the recession in potential during the summer months. The gradual rise in artesian potential in well 78-b was masked by the introduction of slugs of water, but the rise appears to have been gradual through December, increasing more in January and February.

It is clear from comparison of water level changes that artesian water potential changes in bedrock correspond only in a general way to the fluctuations of the water-table in surficial deposits. This supports the contention that it is unwise to use water level data from bedrock wells as an indication of mean groundwater stage.

Evapotranspiration

Evaporation directly attributable to man's activities is very small in the Upper Annapolis River basin. Irrigation is not widely practiced and there is no important industrial consumption of water. The largest population center, CFB Greenwood, apparently consumed 120,000 igpd during the water year 1964-1965 (calculated from records of water pumpage and treated sewage discharge). This apparent loss to evaporation, however, amounted to less than 0.05 per cent of the water accounted for on the right side of equation 1.

Evapotranspiration can be computed on an annual basis by solving equation 3 for ET, if the change in groundwater storage (ΔSg) is known. Although groundwater level data are not available, it is suspected that reduction in groundwater storage occurred in the water years 1963-1966. Consequently, the values for ET given in table 6 for 1963-1966 are too small by the value of Δ Sg.

An estimation of the distribution of ET during the year can be made by solving equation 3 on a monthly basis (Fig. 27). Values of ET for the months of October and November are too high because increases in storage have not been considered. The quantity (Precipitation - Runoff) for December through April has been averaged because snow accumulation and snowmelt during these months caused large fluctuations in runoff which were not indicative of actual ET. Note that the average value for this five month period is negative. The negative values indicate that precipitation records at Greenwood do not reflect the larger amounts of rain and snow that fall on the South Mountain highland.

Direct calculations of potential evapotranspiration (PE) have been made for the months of June, July, and August at Kentville and Sheffield Mills based on measurements made with a black Bellani plate atmometer by the Canada Dept. of Agriculture, Kentville. This instrument, as described by Robertson (1953), consists of a

> "thin porous black ceramic disc, 7.5 cm in diameter, fused to the large end of a glazed ceramic funnel. Water is conducted through the lower open end of the funnel from a burette which acts as a reservoir and measuring device."

The Bellani plate is mounted horizontally in the open 4 feet above the ground.

Information obtained with the Bellani plate is useful, but the calculations do not necessarily indicate true PE. Mukammal and Bruce (1960, p. 13) have shown that, whereas the dominant factor in ET is insolation, "the energy for observed evaporation from the Bellani instrument must come

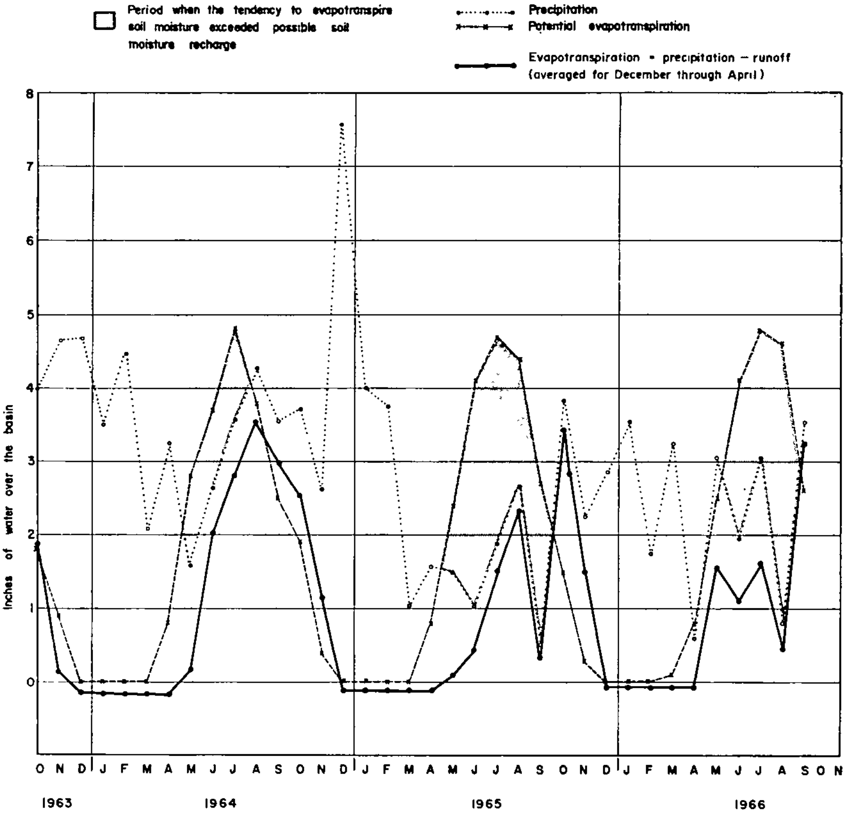


FIGURE 27. Evapotranspiration, Upper Annapolis River basin, 1963-1966.

in large part from sources other than insolation." Therefore, because Bellani plate data are available for only three months of the year and because this information may not indicate true PE, the PE given in figure 27 has been computed from Thornthwaite's formulas. These formulas are based on mean monthly temperature and have been solved by use of a simplified scheme (Turner, 1958). As a comparison, PE for the months of June, July, and August by Thornthwaite's formulas totaled 12.3 inches in 1964 and 13.2 inches in 1965. Evaporation from the Bellani plate totaled 6.7 inches and 11.7 inches for those months in 1964 and 1965, respectively.

For the water years 1963-1966, PE averaged 21.3 inches annually whereas ET averaged 12.1 inches annually. The difference is explained by the fact that PE for the months of May through September commonly exceeds precipitation. This explains why there is a moisture deficiency and why the average rain during those months does not recharge the water-table.

It is not apparent from table 6 why ET for 1965-1966 was more than 5 inches greater than ET for 1964-1965 even though total precipitation was nearly the same. The distribution of precipitation during the two years, however, was different. Almost 5 inches more rain fell from May through September in 1966 than in 1965. Most of the additional rain in 1966 was evapotranspired because, as already noted, no groundwater recharge took place from June 10 to October 6, 1966.

The total ET discussed above consists of ET from the groundwater reservoir and ET of moisture that has reached the water-table. For the lack of information, the relative importance of these two components has not been determined in this report. In other areas, groundwater ET has been calculated to be from 5 per cent (Schicht and Walton, 1961) to 39 per cent (Rasmussen and Andreasen, 1959) of the total ET. Relatively, groundwater ET is less important during dry years when the water-table is farther beneath the ground surface.

Conclusions

The objective of determining annual groundwater recharge has not been realized because the values for base flow discharge are only an approximation, and groundwater evapotranspiration could not be determined at all. Even if the values for these items were known precisely, however, their sum would be merely a theoretical limit for groundwater development because only a fraction of natural groundwater discharge can be diverted to well fields. In practice, the effects of existing and future groundwater development can be predicted only by using pump test information and pumping records (Bredehoeft, personal communication). Nevertheless, the hydrologic budget presented in this chapter is useful because it provides some insight into various aspects of the hydrology of the Upper Annapolis River basin and the Annapolis-Cornwallis Valley.

Movement of Groundwater in the Annapolis-Cornwallis Valley

Introduction

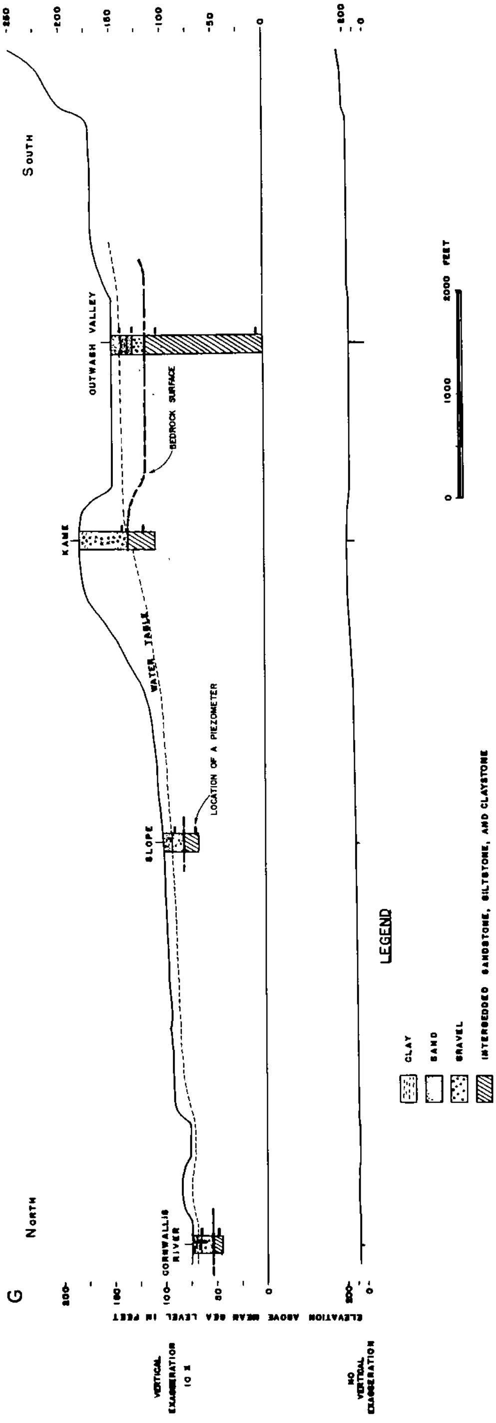
Groundwater moves regionally from the North and South Mountains towards the Annapolis-Cornwallis Valley as indicated by the fact that the water-table and artesian water potentials follow the regional topography. Superposed on the regional flow are local flow systems which are most prominently developed in the more highly dissected eastern end of the Valley.

Groundwater does not move in an isotropic and homogeneous medium because geologic materials vary considerably in average permeability and in directional permeability due to joints, stratification, etc. In order to obtain detailed information on the movement of groundwater and the effects of geologic materials of different permeabilities, it was necessary to measure the water potential at various depths in the same location. This was done with a piezometer nest, which is made of several tubes of different lengths with perforated ends installed in one hole or in several nearby holes. Four piezometer nests were installed in a line east of Berwick between the base of South Mountain and the Cornwallis River (see Map 1, and Sec. G-H, Fig. 28). The section east of Berwick was chosen for several reasons: firstly, it was thought that there would be a local flow system in the outwash valley at the base of South Mountain superposed on the regional flow system from South Mountain to the Cornwallis River; secondly, a piezometer nest could be installed on a long gentle slope from the kame on the north side of the outwash valley to the Cornwallis River to test some hypotheses concerning groundwater flow beneath a regional slope; and thirdly, something could be learned about groundwater discharge near the Cornwallis River.

Installation of Piezometers and Data Collection

The piezometers in a given nest were installed in separate holes spaced 2 or 3 feet apart, except for piezometers 78-a and -b, which were installed in the same hole because of the difficulty in drilling through the cobble gravel in the kame. The piezometers were made of continuous, one inch diameter, flexible, plastic tubing with one-eighth inch holes drilled in the bottom 3 feet. After a four and three-quarter inch hole was drilled with a rotary rig to the desired depth, a piezometer was installed by pumping water through it as it was pushed down the hole. If water was not pumped down the piezometer, the perforations tended to clog up before the tube was in place. After the tube was in place, the bottom 3 feet of the hole was back-filled with gravel and the remainder of the hole with material removed during drilling. The tops of the tubes were protected with short lengths of iron pipe and pipe caps (Fig. 29). The tops of the iron pipes were leveled within one one-hundredth of a foot so that comparisons of water levels between piezometers in the same nest could be made easily.

In general, readings of water levels in the piezometers were made daily with a chalked steel tape. Readings were usually made during the early



(Section is located on Map I)

FIGURE 28. *Test-hole cross-section G-H.*

morning except in the winter when the readings were made (weather permitting) later in the day to take advantage of higher temperatures. Although wa-level fluctuations during the day could not be measured this way, it was felt that the once daily readings were adequate for the purpose of this study.

FIGURE 29. Piezometer nest 79 in the outwash valley.

The measurements made with the chalked steel tape represent the difference in feet between the water level in the piezometers and the tops of the iron pipe. (The depths to water shown on the hydrographs of the piezometers are from ground level). Measurements were made to the nearest hundredth of a foot so that small differences in water potential could be defined accurately. The depth at which the water potential was measured is the depth below ground to the mid-point of the perforations in the plastic tube.

Vertical Potential Differences in the Piezometer Nests

Piezometers 76-a and -b, (Fig. 22)

The differences in water potential represented by the piezometers 10 feet from the Cornwallis River have been discussed at length in the chapter on the hydrologic budget. To summarize briefly, the vertical component of groundwater movement was upward during most low and intermediate river stages. During the highest river stages, groundwater movement was temporarily reversed as water from the river moved into the flood plain sediments. This is commonly the case for perennial streams where the low flow is maintained by groundwater discharge.

Piezometers 77-a and -b (Fig. 24)

Piezometers 77-a and -b were installed along a gentle regional slope; well 77-a represents the potential 8 feet below ground level in surficial sand and gravel deposits, and well 77-b represents the potential 32 feet below ground level, 14 feet below the surface of the bedrock. The water potential in the deeper piezometer (77-b) was consistently higher than the potential in well 77-a, particularly during the period of summer groundwater recession. During the winter, the difference in potential was not as consistent in magnitude, and on occasion reversed in direction with the potential in well 77-a exceeding that in well 77-b. In spite of the variations during the winter, the dominant vertical component of groundwater movement was upward during the period of record. This is due to the fact that groundwater recession and recovery are taking place throughout the flow system and not just at the site of the piezometer nest. Occasional reversal of the groundwater potential during the winter may have been related to the formation of ice in the soil and to the periods when the soil was completely saturated.

Piezometers 78-a and -b (Fig. 25)

The problems with piezometers 78-a and -b have been discussed to some extent in the section on the hydrologic budget. Firstly, well 78-a was installed in kame material just above the general water-table so that this piezometer is dry most of the time. Secondly, piezometer 78-b was installed in fine-grained bedrock and back-filled with kame material so that on occasion slugs of water were introduced which did not represent actual water potential increases in the formation. To have properly completed this piezometer in claystone and siltstone, the hole should have been cement grouted above the bottom 3 feet of the piezometer. Even though this was not done, some useful information on water potentials in bedrock has been obtained.

From those times when there was water in piezometer 78-a, it appears that a downward gradient was present between the water-table in the kame and the water potential 16 feet into bedrock. This is logical because the kame is not in a situation typical of a discharge area (see Sec. G-H, Fig. 28). Firm conclusions concerning the direction of groundwater movement, however, should not be drawn from these piezometer hydrographs because groundwater in surficial sand and gravel deposits may be nearly independent of the artesian system in the Wolfville Formation (see discussion of piezometers 79-a, -b, -c and -d).

Piezometers 79-a, -b, -c and -d (Fig. 26)

Piezometers 79-a and -b were installed at two different depths in outwash sand and gravel, and piezometers 79-c and -d were installed 12 feet and 112 feet, respectively, below the surface of the underlying interbedded sandstones and shales of the Wolfville Formation (see Fig. 28). As discussed earlier, it is apparent from the hydrographs that the water potential 112 feet into the bedrock was nearly independent of water level fluctuations in the overlying surficial deposits for the period of these records.

The vertical components of groundwater movement in piezometers 79-a, -b and -c proved to be interesting. Throughout the summer groundwater recession, the vertical component between 8 and 21 feet was consistently downward. The vertical component of the gradient between 21 and 44 feet, however, was almost always upward. From the first of October to the fifteenth of January, the vertical components of the groundwater gradient were generally the same as during the summer recession although greater fluctuations in the magnitude of these components occurred during the fall and winter months. From January 15 to March 2, 1967 the potential at 21 feet was higher than at 8 and 44 feet, indicating that there was a tendency for groundwater to move away from the central part of the outwash. After March 2, 1967 the vertical components of groundwater movement generally reverted to the former situation in which movement was towards the central part of the outwash.

Flow System in the Vicinity of the Piezometer Nests

It is evident from the observed potentials that the outwash valley is not a discharge area for a local flow system in the vicinity of piezometer nest No. 79. Further evidence for this is the fact that no surface stream exists in this section of the outwash valley (permanent surface streams appear in the valley about 4,000 feet to the east and 1,000 feet to the west of this section), and the fact that the water-table does not rise beneath the kame on the north side of the valley. A similar situation exists at the Tremont pump test site where no surface stream is present in the valley and downward vertical gradients were noted in observation wells in the outwash. Outwash valleys are discharge areas, however, where the water-table rises on both sides of the valley and perennial streams are present in them.

The movement of groundwater (during most of the year) both downward from the water-table and upward from the bedrock towards the center of the outwash has a logical explanation. The log of test-hole 79-d shows that the outwash is not homogeneous but consists of coarse sand to 9 feet, interbedded red clay and gravel from 9 to 15 feet, coarse sand from 16 to 21 feet, and fine to coarse gravel from 21 to 32 feet. Beneath the outwash, the bedrock is interbedded sandstone, siltstone and claystone. There is a zone of higher permeability, therefore, between 15 and 32 feet with zones of lower permeability both above and below. Toth (1962) has indicated that groundwater flow may be refracted from materials of lower permeability toward an enclosed geologic unit of higher permeability as in this outwash valley (see Fig. 30).

The reversal of the vertical component of groundwater movement from the middle of January to the first of March indicates that this section of the outwash valley was temporarily a discharge area during that time. The

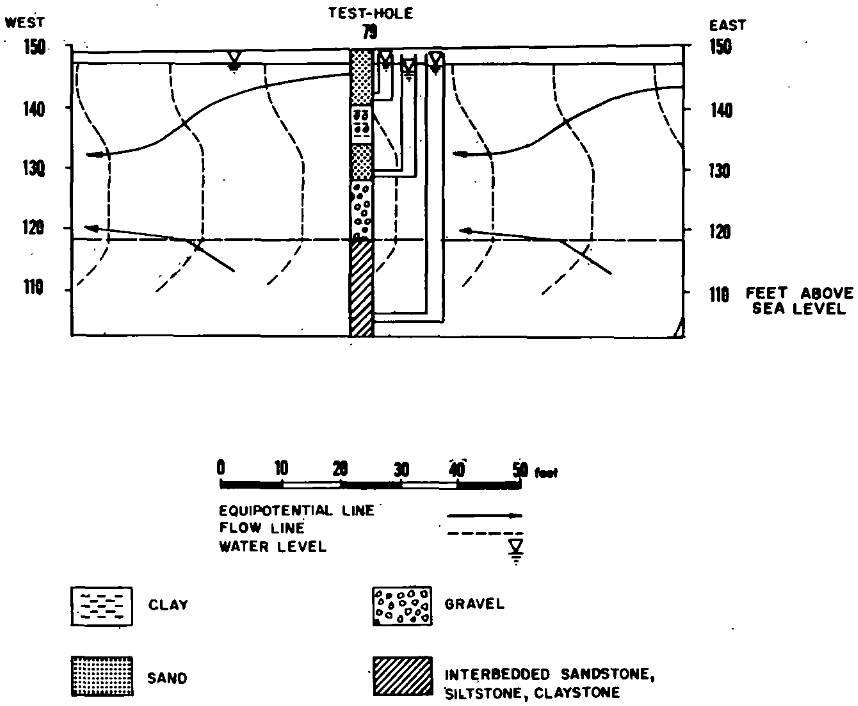


FIGURE 30. An explanation for the water potentials observed in test-hole 79.

upward movement may have represented the transfer of groundwater to form ice lenses in the soil. During the same time, there is a recession in groundwater levels which reflects a lack of recharge as water was incorporated into ice. This hypothesis is supported by the fact that the mean daily temperature was almost always below freezing and almost all precipitation was in the form of snow during this period. An equilibrium between the ice and groundwater seems to have been reached in the early part of March as the potentials reverted to the "normal" situation. Groundwater levels rose over 2 feet in 5 days after nearly 2 inches of rain fell on March 13 and 14. Evidently the rain and melted snow easily penetrated the frozen soil to recharge the water-table.

The direction of lateral movement of groundwater in this outwash valley is probably dominantly westward toward Rockland Brook and not north to the Cornwallis River. The outwash is situated in a bedrock trough as shown by Section G-H, figure 28, and much of the bedrock consists of fine-grained materials of low permeability. Because of the pronounced difference in permeability between the bedrock and the outwash, the bedrock ridge acts as a barrier to any significant movement of groundwater northward toward the Cornwallis River.

On the other hand, there is a gradient of about 18 feet per mile westward along the outwash valley between test-holes 79 and 90. Groundwater, therefore, is very likely moving westward along the outwash valley because of the gradient and the relatively high permeability of the outwash materials. This hypothesis of the movement of groundwater in the outwash valley is shown schematically in figure 30.

From the kame northward to the Cornwallis River there is a shallow flow system in the surficial deposits which are only a few feet to a few tens of feet thick. The piezometers at test-hole 77 were placed along the slope to see if flow is actually parallel to the surface. The vertical component of the groundwater gradient, however, was consistently upward at this point along the regional slope. At first it was thought that this demonstrated Toth's (1962) conclusion that groundwater discharge takes place along the lower half of a basin and not just in the vicinity of the stream. Further study, however, turned up another explanation. An earlier test-hole (No. 34) was drilled about 100 feet to the north and down slope from the piezometers at test-hole 77. Bedrock in test-hole 34 is only 11 feet below the surface, but in test-hole 77, bedrock is 18 feet below the surface. Groundwater in the surficial deposits, therefore, is moving toward a low bedrock ridge. In order to continue moving predominantly in the more permeable surficial deposits, the deeper groundwater must be refracted upwards as it approaches this ridge (Fig. 31). Freeze and Witherspoon (1967) have shown that the anisotropic and nonhomogeneous nature of a porous medium can easily cause apparently anomalous potential differences such as this one.

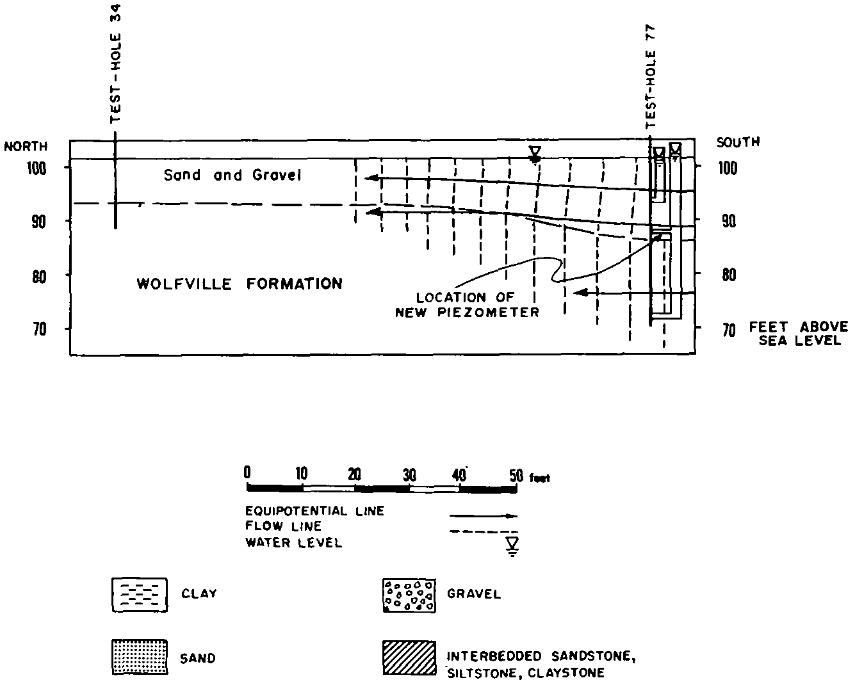


FIGURE 31. Suggested cause for upward vertical component of groundwater movement in test-hole 77.

Generalizations Concerning Groundwater Flow in the Annapolis-Cornwallis Valley

Water potentials follow different patterns of recession and recovery in the surficial sand and gravel deposits than they do under artesian conditions in the bedrock. These different water level patterns are possible because of the confining siltstones and claystones in the Triassic rocks which restrict vertical groundwater movement between sand and gravel deposits and the bedrock. As a consequence, much of the precipitation that enters sand and gravel aquifers appears in streams as base flow without having passed through the bedrock. This fact, however, does not necessarily limit the development of bedrock aquifers because a bedrock well field would change the natural groundwater gradients and considerably increase leakage from surficial deposits. The amount of leakage which might be induced through confining beds could be determined from pump tests and records of pumpage.

Where the permeability of the finer-grained surficial deposits (such as till and estuarine deposits) is more nearly the same as that of the bedrock siltstones and claystones, a more uniform flow system probably dominates groundwater movement. This idea, however, cannot be demonstrated from the piezometer records because none of the piezometer nests are completed in fine-grained surficial materials.

Under natural conditions water enters the Wolfville Formation mostly through rock outcrops and through surficial deposits where the water potential is downward. Some water enters the formation from the underlying Palaeozoic rocks although the rate of movement is probably very slow. Most of the water in the Blomidon Formation has probably come through the basalt because there is little opportunity for infiltration along the steep scarp slope of North Mountain. Movement of water downward in the basalt was demonstrated in test-hole 133 south of Margaretsville. However, little other information concerning gradients in the North Mountain basalt is available at the present time.

Groundwater movement within the Wolfville and Blomidon Formations is concentrated in the sandstones and conglomerates for the same reason that water in the outwash valley south of Berwick tends to move towards the beds of higher permeability. In areas where there must be vertical circulation (such as the upward movement beneath the major streams) the rate of movement across the siltstones and claystones is probably very slow.

CHEMICAL QUALITY OF GROUNDWATER

Introduction

Water is relatively free of mineral matter when it falls as precipitation. As it moves slowly through the ground it dissolves mineral matter from the surficial deposits and rocks through which it passes. The composition of the geologic materials through which groundwater moves, therefore, is important in determining the chemistry of the water. This factor is emphasized in this report. Other factors influencing the water chemistry are the length of time the water has been in the ground and the distance it has gone since entering the ground. Thus, water which has travelled only a short distance in a shallow groundwater flow system may have considerably different chemistry from water found deep within a regional groundwater flow system. These factors will be examined in detail in another paper.

Expression of Water Analyses

Chemical analyses of water are commonly reported in parts per million by weight (ppm). One part per million represents 1 milligram of solute in 1 kilogram of solution. Water quality standards are generally cited in ppm, and therefore, the analyses tabulated at the end of this section are presented in ppm.

To facilitate comparison of ions in the analyses (such as in table 9 or on the trilinear diagrams), it is best to report the ions in terms which consider not only the weight but the chemical equivalence. If the concentration of an ion in parts per million is divided by the combining weight of that ion (combining weight = atomic or molecular weight of the ion divided by the ionic charge), the concentration is converted to milligram equivalents per kilogram (epm).

Discussion of Chemical Constituents Determined in the Water Analyses

Before discussing the influence which the various hydrostratigraphic units of the Annapolis-Cornwallis Valley have on the groundwater chemistry, a brief discussion of the constituents determined in the chemical analyses is given below. Most of the discussion is a summary of material from Hem(1959).

Calcium

Calcium is commonly present in groundwater because it is a cation in many soluble minerals (e.g. calcite, dolomite, gypsum, and anhydrite), and may be dissolved during the weathering of other common minerals such as many of the silicates. Where it is present in the form of calcium bicarbonate, it is in equilibrium with the dissolved carbon dioxide in the water. Thus, if carbon dioxide is driven off when the water is boiled or when it enters a zone of reduced pressure around a pumping well, calcium carbonate may be precipitated as an encrustation.

Magnesium

Magnesium is common in groundwater because it is a component in many silicate minerals, and, along with calcium and carbonate, forms the soluble mineral dolomite. Although the amount of magnesium carbonate in solution depends on the partial pressure of carbon dioxide, magnesium carbonate does not precipitate from solution as readily as does calcium carbonate. Variation in the ratio of calcium to magnesium ions (in epm) may indicate that two groundwaters are from different hydrostratigraphic units. The calcium/magnesium ratio ranges between 2 and 6 for groundwaters discussed in this report.

Sodium

Groundwater obtains sodium mostly from weathered feldspars, from some evaporite sediments, and from recirculation of sodium in the ocean by precipitation and by salt water intrusion. In the laboratory, sodium was calculated from the value for chloride in most of the samples analyzed. This assumption - that all chloride is combined with sodium - is justifiable for waters with low salt concentrations (Gerry Byers, personal communication). In some of the earlier water analyses, however, particularly from the metamorphic and Horton units, sodium was determined with a flame photometer. In these cases the ratio of sodium to chloride is not 1.00 but 0.78 in the metamorphic rocks and 0.71 in the Horton Group. Thus, some chloride is combined with other cations and the reported value for sodium is greater than the actual value. The Piper trilinear plots misrepresent the value of sodium plus potassium because of this error and because potassium was not determined in the analyses. Potassium is often present in concentrations equal to or less than that of sodium in waters of low dissolved solids (Hem, 1959).

Iron

Iron is a common constituent of rocks and soils, but it is normally present in the groundwater only in small amounts (usually less than 0.3 ppm in groundwaters of the Annapolis-Cornwallis Valley). The reliability of iron determinations in chemical analyses depends on the care taken in sampling because rust from well casings and plumbing fixtures may contaminate the the sample if the water which has been standing in the well has not been flushed out first. It was found, however, that the time lapse between sampling and laboratory analysis does not affect the accuracy of the laboratory determination (see appendix C).

The chemistry of iron in water is complex, but the precipitation of iron in the form of ferric hydroxide often occurs when groundwater comes in contact with the oxygen in air. Micro-organisms may also precipitate iron and cause problems, one of which is the encrustation of well screens.

Manganese

Manganese behaves chemically like iron, but it is much less abundant in rocks than iron, and most of it in groundwater has probably been dissolved from soil and sediments. A precipitation reaction yielding manganese hydroxide occurs when water containing manganous bicarbonate under reducing conditions comes in contact with oxygen. Micro-organisms may also precipitate manganese. The concentration of manganese in solution may be nearly as great as iron in acid water but it is normally present in quantities much less than iron in alkaline waters. In the Annapolis-Cornwallis Valley, manganese usually is present in groundwater in concentrations of 0.01 ppm or less, and is seldom present in amounts greater than 0.03 ppm.

Sulfate

Sulfates are commonly produced by the weathering of heavy mineral sulfides. Shales may contain pyrite, for example, which can be oxidized to sulfates by circulation of groundwater. Few of the cations in groundwater form insoluble precipitates with sulfate, and therefore, sulfate may occur in high concentrations in groundwater. In the Annapolis-Cornwallis Valley, high concentrations of sulfates most often result from dissolution of gypsum and/or anhydrite lenses in shale.

Chloride

Chlorides in groundwater may come from a variety of sources including precipitation near the ocean, decomposition of organic material in the soil, weathering of some igneous rock minerals, incomplete flushing of sea water from aquifers recently covered by the sea, and concentration of salt in confined aquifers by the clay membrane effect (Bredehoeft, *et. at.*, 1963). In the last case, the clay content of shales retards the passage of ions as groundwater moves upward through the confining beds in discharge areas. This mechanism may be partly responsible for the increase in sodium chloride with depth in the Wolfville Formation. Chlorides, like sulfates, tend to stay in solution. Consequently, it is possible for groundwater to contain large concentrations of chlorides.

Alkalinity

The alkalinity of water is its property to neutralize acid. Alkalinity may be due to a number of constituents in groundwater, but in most groundwaters, alkalinity is due to carbonate and bicarbonate ions. The alkalinity of groundwaters considered in this report can be assumed to be due to bicarbonate ions because the pH of the waters is commonly less than 8.2. Alkalinity, reported as calcium carbonate (ppm) in the analyses has been converted to an equivalent amount of bicarbonate in epm for the Piper trilinear diagrams.

Hardness

The minerals causing hardness in water form insoluble residues with soap and contribute to encrustations. Temporary hardness or hardness that can be removed by boiling water is due to the carbonates of magnesium and calcium. Permanent hardness, due to calcium and magnesium sulfates, cannot be removed by boiling water. Since the hardness of water for domestic purposes does not become particularly objectionable until it exceeds 100 parts per million (Hem, 1959), waters with a hardness of less than 100 ppm arbitrarily can be considered "soft" and those above 100 ppm "hard".

Specific Conductance

The specific conductance of water is its property to conduct an electrical current. Although the specific conductance of water increases with increasing total dissolved solids, there is no simple relationship between the two. Considering the range of concentration of total dissolved solids and the ions typically found in groundwaters of the Annapolis-Cornwallis Valley, specific conductance is approximately related to total dissolved in organic solids in the following manner:

$$\text{Specific conductance } (\mu \text{ mhos}) \times 0.55 = \text{total dissolves solids (ppm)} \quad ,$$

where a μ mho is one millionth of a mho which is the reciprocal of the unit of electrical resistance, the ohm (Gerry Byers, personal communication).

Nitrate

Nitrate in groundwater may come from several sources including plants which fix nitrogen in the soil, fertilizers, and organic pollution. Local occurrences of nitrate in groundwater may indicate organic pollution and an unsanitary condition existing in the water supply.

pH

"The pH value of a water represents the overall balance of a series of equilibria existing in solution" (Hem, 1959, p. 46). The pH depends to a large extent on the alkalinity and ranges in most groundwaters from about 5.5 to slightly over 8. The pH of a water sample should be determined in the field as soon after sampling as possible because there is a significant tendency for the sample to become more neutral with time (see appendix C). This happens because loss of gases and changing temperatures can alter chemical equilibria, particularly the alkalinity, and thus change the pH.

Chemical Quality of Groundwater in the Hydrostratigraphic Units

Numerous samples of groundwater were taken for chemical analysis from all of the hydrostratigraphic units in and adjacent to the Annapolis-

Cornwallis Valley (the complete analyses are given in Appendix E). The following discussion of the chemical quality of groundwater in each hydrostratigraphic unit is based on mean values for each chemical constituent in each unit given in table 9 and on trilinear plots of the major cations and anions in the analyses. It is apparent from an examination of table 9 that mean values for some of the constituents in several of the units are nearly the same; mean values for other items differ considerably among some of the units. In order to show where there are similarities in water chemistry and where there are significant differences, statistical analyses were made (see Appendix C). Many of the statements in this section are based on the results of these analyses.

The trilinear plots (after Piper, 1944) of the water analyses are given in figures 32 to 35. In these diagrams, the major cations in groundwater (calcium, magnesium and sodium plus potassium) are given as per cents of total equivalents per million in one triangular field; in the other, the major anions (carbonate plus bicarbonate, chloride, and sulfate) are given as per cents of total equivalents per million; and the combined chemistry is plotted in the diamond-shaped field. The second trilinear diagram of figure 35 is a plot of the mean per cent of total equivalents per million for the major ions in each unit. It can be seen in figure 35 that there are no large differences in the relative composition of the major ions among the various units and that they all can be considered predominantly calcium bicarbonate waters. Further, the mean value of total dissolved solids in groundwaters of all units except the Blomidon Formation and the Horton Group is less than 200 ppm (see Table 11).

In general, waters in the units forming the North and South Mountain highlands are lower in hardness and contain fewer dissolved solids than do the waters in the lowland units. This is due to the fact that the lowlands are predominantly discharge areas where groundwaters have been in contact with soluble minerals longer than they have in the highland recharge areas.

It should be noted that some of the samples from the Blomidon Formation, granite, till overlying the North Mountain Basalt (and also possibly some samples from the sand and gravel deposits and Wolfville Formation) may have been contaminated by rusty casing and/or plumbing fixtures. As a result, the mean values for iron given for these units in table 9 could be misleading. For more representative values, scan the analyses given in Appendix E.

North Mountain Basalt

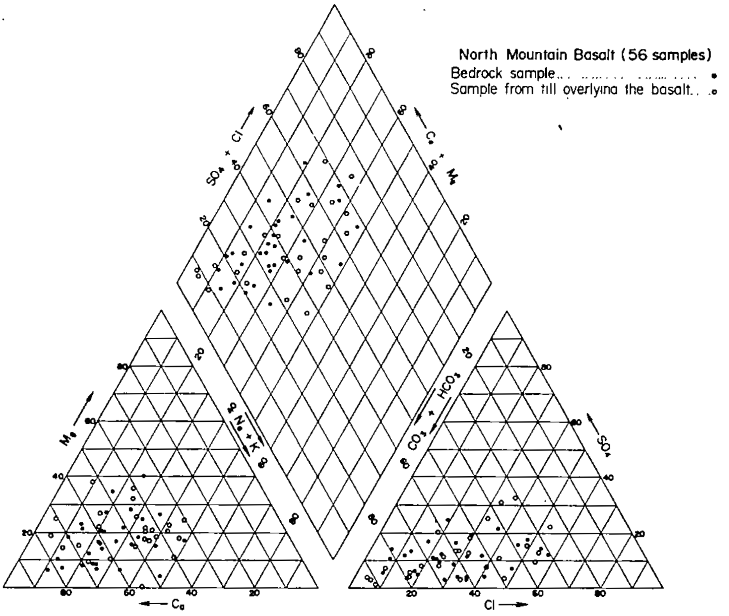
The North Mountain Basalt is an upland unit containing waters of excellent chemical quality (i.e. low in total dissolved solids, hardness and iron). Note in figure 32 that the waters are predominantly calcium bicarbonate in composition.

Blomidon Formation

The Blomidon Formation is a lowland unit along the base of the North Mountain scarp where most of the samples from drilled wells were ob-

Table 9. Mean Values for the Chemical Constituents in the Hydrostratigraphic Units

	Ca (epm)	Mg (epm)	Na (epm)	Fe (epm)	Mn (epm)	SO (epm)	Cl (epm)	NO (epm)	Alkalinity (ppm)	Hardness (ppm)	Spec. Cond. (µmhos)	pH
Bedrock Units												
North Mountain Basalt	1.01	0.30	0.42	0.003	0.0010	0.17	0.44	0.17	52	66	20	7.1
Blomidon Formation	5.19	0.74	0.78	0.021	0.0050	2.86	0.79	0.18	105	268	56	7.4
Wolfville Formation	2.07	0.33	0.95	0.012	0.0016	0,42	0.95	0.16	79	117	35	7.4
Metamorphic Rocks	0.78	0.30	0.36	0.018	0.0068	0.13	0.50	0.09	41	57	19	6.6
Granite	1.88	0.30	0.21	0.050	0.0000	0.33	0.21	0.05	79	109	28	6.9
Horton Group	1.99	0.97	0.88	0.003	0.0011	0.28	1.24	0.05	93	149	38	7.6
Surficial Units												
Sand and Gravel Deposits	0.93	0.30	0.53	0.016	0.0027	0.24	0.54	0.12	41	62	21	6.8
All till deposits	0.89	0.33	0.47	0.019	0.0022	0.22	0.53	0.10	47	62	21	6.8
Basalt till	0.85	0.32	0.45	0.044	0.0012	0.17	0.46	0.09	53	59	20	6.8
Blomidon till	1.59	0.46	0.54	0.003	0.0005	0.67	0.56	0.31	53	103	29	6.4
Wolfville till	1.42	0.45	1.85	0.002	0.0012	0.81	1.86	0.24	91	94	40	7.3
Metamorphic till	0.71	0.28	0.29	0.017	0.0030	0.16	0.36	0.06	45	52	17	6.6
Horton till	1.16	0.53	0.42	0.003	0.0013	0.06	0.74	0.09	50	92	25	6.9



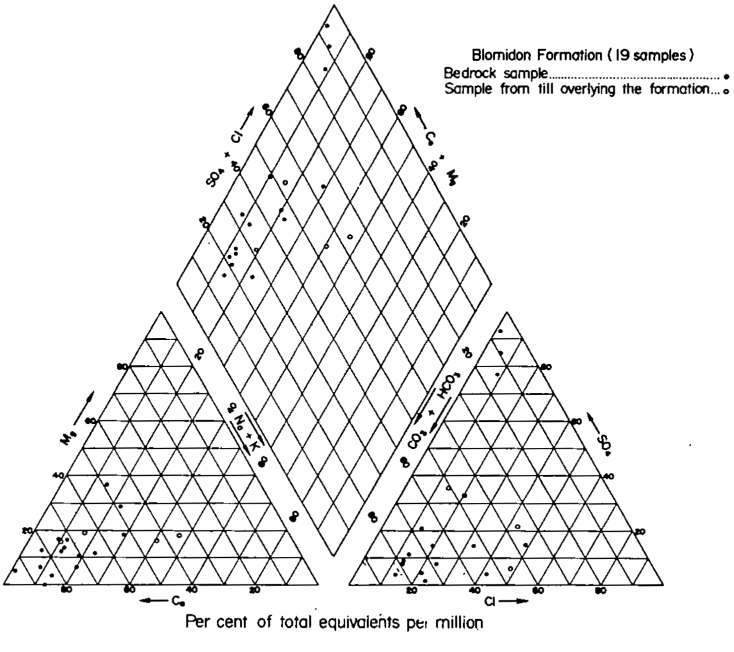


FIGURE 32. Trilinear plots of water analyses for the North Mountain Basalt, and for the Blomidon Formation.

tained. These waters contain more dissolved solids and hardness than are commonly found in waters from any other unit considered in this report. In a few cases this is due to large amounts of calcium sulfate dissolved from gypsum lenses in the formation (note the high sulfate waters plotted in Fig. 32). Of the other dissolved constituents which affect the quality of Blomidon Formation waters, calcium bicarbonate is the most important because it increases the value for alkalinity, hardness, total dissolved solids and the buffering action tends to keep the pH above 7 (calcium carbonate is probably one of the cementing materials in the formation).

The relatively high mean values for iron and manganese given in tables 9 and 11 are due to the inclusion of one sample containing 5 ppm iron and 1 ppm manganese. The mean concentration for manganese in the other fourteen samples is less than 0.01 ppm and for iron only 0.07 ppm.

Waters from most of the springs along the North Mountain scarp contain fewer dissolved solids than waters from the drilled wells and often approximate the composition of water from the till overlying the Blomidon Formation (see Table 9).

Wolfville Formation

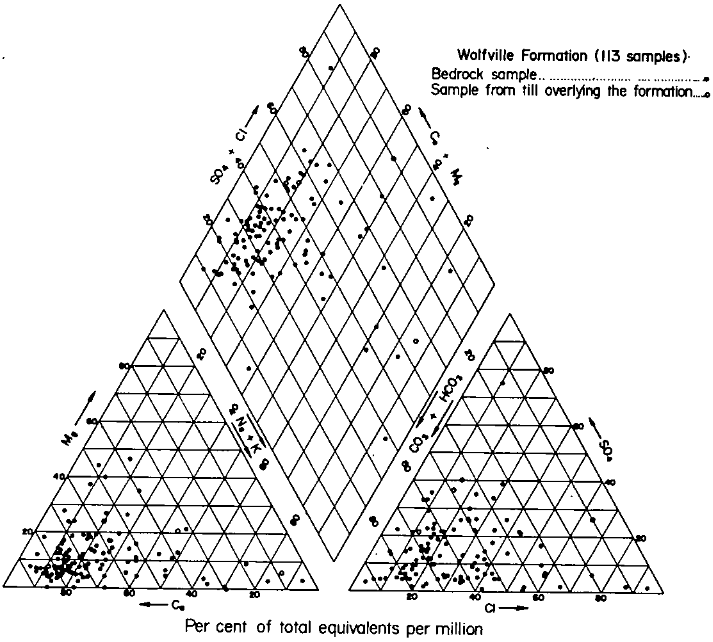
The Wolfville Formation is a lowland unit which usually contains good quality waters even though these waters have more dissolved solids than do waters in the upland units. The most important dissolved ions in this unit are calcium and bicarbonate (calcium carbonate is a common cementing agent in this formation). The bicarbonate is an important contributor to the total dissolved solids, and constitutes most of the hardness and alkalinity (which tends to keep the waters slightly basic). A few Wolfville Formation waters from deeper wells near estuaries are predominantly sodium chloride in composition (note the high chloride waters in Fig. 33). It is apparent, therefore, that the proximity of the sea may adversely affect groundwater quality particularly where wells are drilled in low-lying areas. Salty water, however, should not be a problem near the coast where the land and the water-table rise rapidly away from the shore (unless high production wells are contemplated).

Metamorphic Rocks

The metamorphic rocks are an upland unit containing waters low in hardness and dissolved solids similar in composition to waters in the North Mountain Basalt (see Table 9 and Fig. 34). Waters in the metamorphic rocks, however, are more acid than waters in the basalt. As a result, iron and manganese are often present in objectionable amounts (see Tables 9 and 11).

Granite

Only four water supplies were sampled in granite areas because there are so few people living in these areas. Note in table 9 and in figures 34 and 35 that these samples contain more calcium bicarbonate than do waters in the metamorphic rocks and basalt. This gives the granite waters



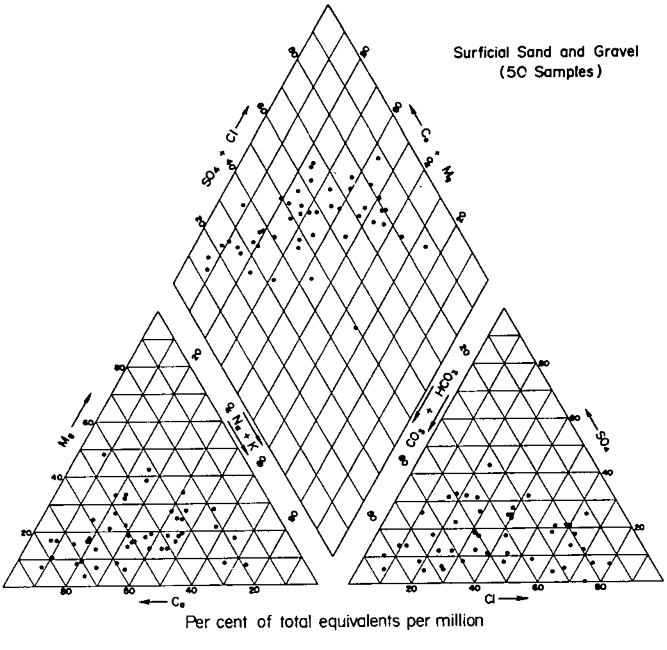


FIGURE 33. Trilinear plots of water analyses for the Wolfville Formation, and for the surficial sand and gravel deposits.

higher alkalinity, hardness and dissolved solids than is common for waters in other upland units.

Horton Group

The Horton Group is a lowland unit in the Gaspereau Valley where most of the samples from drilled wells were obtained. As a lowland unit, note the similarity between the composition of waters in this unit and waters in the Wolfville Formation (Table 9 and Fig. 35). Comments made about the quality of waters in the Wolfville Formation also apply to waters in the Horton rocks except that some waters in the Horton rocks contain significantly more magnesium than does the average groundwater in the Wolfville Formation.

Glacial Till Deposits

Waters from dug wells in till overlying the basalt and metamorphic rocks have essentially the same composition as waters in the underlying bedrock. This is due partly to the influence that the underlying bedrock has on the composition of the till and partly to the fact that these are upland areas. Waters in the lowland till deposits have more dissolved solids than do the waters in the upland till deposits, but waters in the lowland till deposits are often of better quality than waters in the underlying bedrock. This is true of waters in till overlying the Blomidon and Horton units, but most of the differences do not show up in the statistical analyses because of the lack of an adequate number of samples. For the five samples of water available from till overlying the Wolfville Formation, the chemical composition does not seem to differ significantly from the composition of waters in the underlying bedrock.

In figure 35, note that all of the surficial deposits plot within a small area in the diamond-shaped field and that there is a tendency for the surficial deposit waters to contain a higher percentage of sodium chloride than is commonly found in the bedrock waters. The larger relative concentrations of sodium chloride in the surficial deposit waters may come partly from precipitation because salt introduced to the air by breakers along the coast may act as nuclei in rain drops.

Surficial Sand and Gravel Deposits

Surficial sand and gravel deposits generally contain waters of excellent quality similar in composition to waters in the upland units (Table 9 and Fig. 33). Although these deposits mantle the lowland areas and overly the Wolfville Formation, they are often recharge areas for shallow local flow systems because of their relatively high permeability. In relation to waters in the Wolfville Formation, waters in the sand and gravel deposits contain less calcium bicarbonate. Thus, these waters have lower alkalinity, pH, hardness and fewer dissolved solids than do waters in the Wolfville Formation.

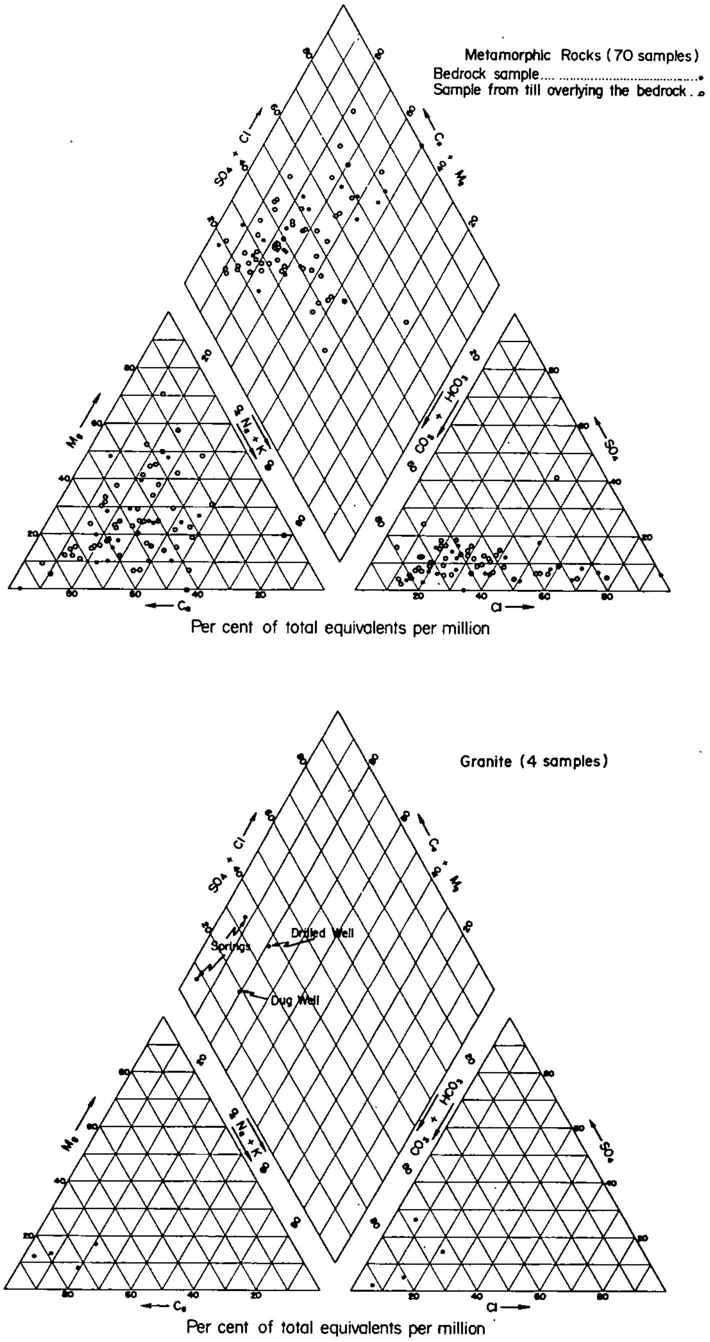


FIGURE 34. Trilinear plots of water analyses for granite, and for metamorphic rocks.

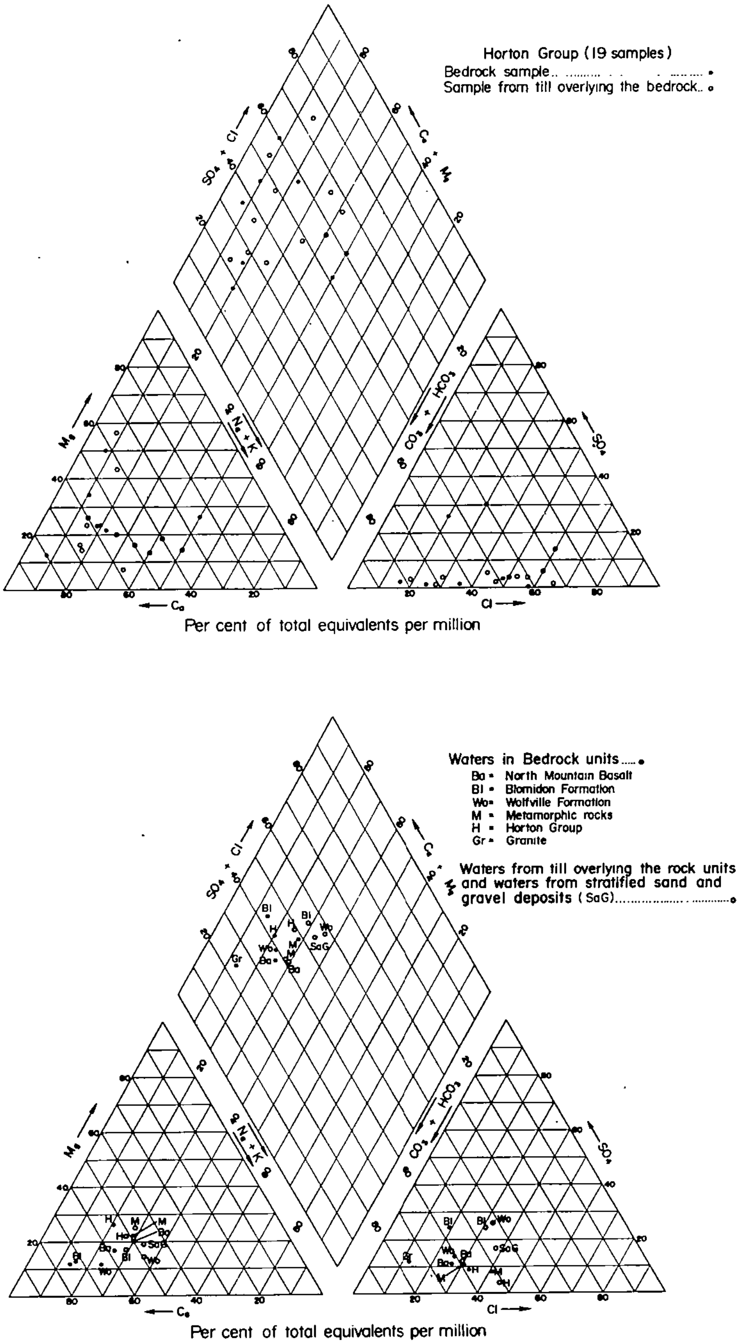


FIGURE 35. Trilinear plots of water analyses for the Horton Group, and trilinear plot of the mean per cent of total equivalents per million for each hydro-stratigraphic unit.

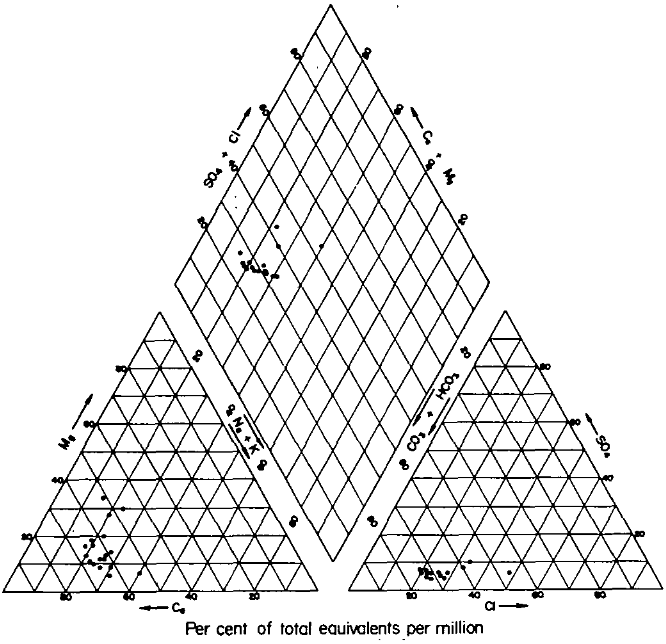


FIGURE 36. Trilinear plot of water analyses for United Elastic Ltd., Bridgetown, N.S.

Variations in Groundwater Quality with Time

Groundwater does not vary in quality nearly as much as surface water, but it should not be assumed that there is no variation in groundwater quality with time. For example, the water supply of the Bridgetown plant of United Elastic Limited has been analyzed periodically since 1960. Some of these analyses are presented in table 10. It can be seen that most of the major ions, except sulfate, have varied over 100 per cent in value over the seven year period represented.

The observed variations are probably due to some combination of factors. One factor may be that water is pumped alternately from two wells about 1,000 feet apart in the Wolfville Formation, but there is no indication in the trilinear plot (Fig. 36) that two distinctly different groundwaters are present. Other factors may be the sampling procedure (e.g. contamination from iron in the casing), the time lag between sampling and analysis (this probably affects the pH), and normal analytical error although the same laboratory analyzed all samples. In addition to the combined effect of the factors mentioned above, some of the variation may be due to natural fluctuations in water quality even though seasonal fluctuations are not apparent and there does not seem to be a long term trend. Although the quantitative importance of the various possible factors affecting quality is not known, this example shows that one chemical analysis does not define the groundwater chemistry at a particular location.

Table 10. Chemical Analyses of Well Water, United Elastic Limited, Bridgetown, Nova Scotia

		Ca (epm)	Mg (epm)	Na* (epm)	SO_4 (epm)	Cl (epm)	HCO_3 (epm)	Fe (ppm)	Hardness (ppm)	pH
Sept.	22/60	0.96	0.14	0.38	0.08	0.38	1.00	0.02	55	7.1
April	12/61	1.10	0.17	0.54	0.09	0.54	1.27	0.05	63	6.9
June	26/61	1.06	0.58	0.40	0.07	0.40	1.20	0.00	82	7.6
Nov.	21/61	1.30	0.86	0.39	0.10	0.39	1.33	0.05	58	7.4
April	2/62	0.79	0.51	0.39	0.10	0.39	1.27	0.05	65	7.9
July	21/62	1.13	0.31	0.34	0.10	0.34	1.27	0.02	72	8.2
Oct.	8/62	1.10	0.17	0.39	0.10	0.39	1.20	0.03	63	8.2
July	23/63			0.37	0.10	0.37	1.60	0.02	56	8.1
Oct.	29/63	1.00	0.10	0.48	0.10	0.48	1.16		55	8.1
Jan.	20/64	0.96	0.34	0.37	0.10	0.37	1.20	0.03	65	8.2
April	24/64	1.06	0.21	0.31	0.10	0.31	1.10	0.04	62	8.1
July	17/64	1.06	0.14	0.79	0.10	0.79	0.80	0.08	60	7.3
Jan.	25/65	1.03	0.20	0.42	0.10	0.42	0.80	0.01	62	6.7
April	20/65	1.06	0.21	0.42	0.10	0.42	1.07	0.03	63	7.4
Aug.	10/65	1.03	0.24	0.28	0.10	0.28	1.13	0.02	63	8.0
Nov.	2/65	1.10	0.30	0.34	0.10	0.34	1.23	0.01	70	8.0
Jan.	26/66	0.96	0.20	0.42	0.10	0.42	1.13	0.02	58	8.0
April	18/66	1.03	0.17	0.34	0.10	0.34	0.60	0.02	60	8.0
Oct.	25/66	0.89	0.21	0.42	0.10	0.42	1.07	0.02	55	8.1

* calculated from chloride

The water quality of sand and gravel aquifers in the Annapolis-Cornwallis Valley has not yet been monitored in this manner. When this is done, some significant changes in quality with time will probably show up. The lack of recharge during the summer and the proximity of the water-table to the surface in many places during the winter probably cause seasonal fluctuations in water quality in surficial aquifers.

Relationship of Groundwater Quality to Use

Domestic Use

The principal domestic use of water is for drinking purposes. In table 11 the chemical constituents important in drinking water are tabulated along with the recommended limits of the U.S. Public Health Service Drinking Water Standards (1962). Iron and manganese are limited because, even in small amounts, they can impair the taste of water and beverages and they may precipitate to stain clothes and plumbing fixtures. Objectionable amounts of iron and manganese are commonly present only in metamorphic rock groundwaters. Other water supplies with excessive amounts of iron often have been contaminated by rusty casing and/or plumbing fixtures.

Sulfates are limited in drinking water because they may have a laxative effect in high concentrations. Chlorides contribute to total dissolved solids which, in high concentrations, give bad taste to water and may be harmful to plants and animals. The mean values for sulfate and chloride are far below the United States Public Health Service recommended limits. Gypsum lenses in the Blomidon Formation, however, make a few groundwaters in this unit unpalatable. In addition, deep well waters in the Wolfville Formation and the Horton Group, particularly near estuaries, may contain objectionable quantities of chlorides. Total dissolved solids will not exceed the recommended limits except in the unusual cases mentioned above where large amounts of sulfates and/or chlorides are present.

There is a recommended limit on the amount of nitrate in water supplies because high nitrate waters are poisonous to children. Although mean values for nitrate reported in table 11 are far below the recommended limit, waters from some wells have excessive concentrations of nitrate that may be due to pollution. Particular care should be taken to provide sanitary protection for shallow wells in surficial deposits and to properly case drilled wells in the bedrock.

In relation to the chemical constituents given in table 11, most groundwaters in the Annapolis-Cornwallis Valley are acceptable as drinking water. Many other ions, however, particularly those which may be present in small amounts, have not been determined in the routine chemical analysis. Some of these ions, such as arsenic, lead, hexavalent chromium, etc., may make a water supply unsatisfactory for drinking purposes when present in small amounts. If the presence of these other ions is suspected in a particular case, they should be determined in the water analysis. In addition, all drinking water supplies should also be tested for bacteriological contamination.

Table 11. Mean Values of Chemical Constituents Related to Drinking Water Standards

	Fe (ppm)	Mn (ppm)	SO_4 (ppm)	Cl (ppm)	TDS (μmhos x 0.55= ppm)	NO_3 (ppm)	Hard-ness (ppm)
North Mountain Basalt	0.06	0.01	8.4	15.7	110	10.8	66
Blomidon Formation	0.39	0.07	137.	27.9	310	10.8	268
Wolfville Formation	0.22	0.02	20.0	33.7	190	9.6	117
Metamorphic rocks	0.34	0.09	6.3	23.8	100	5.6	57
Granite	0.93	<0.01	15.7	7.5	160	3.1	109
Horton Group	0.06	0.02	13.4	59.7	210	3.3	149
Sand and Gravel Deposits	0.30	0.04	11.7	19.2	120	7.7	62
All till deposits together	0.36	0.03	10.5	18.6	110	6.5	62
Drinking water limits*	0.3	0.05	250.	250.	500	45.	

*Recommended limits, U.S. Public Health Service Drinking Water Standards (1962).

Groundwater seldom contains impurities in amounts which are offensive to taste, sight and smell (i.e. aesthetically offensive), but there are occasional reports of turbid groundwater due to pollution from surface water or to formation collapse in a drilled well. Some groundwaters in surficial aquifers may be coloured and have "boggy" odors (often due to hydrogen sulfide) if the aquifers are connected to swampy areas, but better quality water is often found in deeper zones.

Though water hardness is not restricted in drinking water, it is included in table 11 because hard waters are objectionable for laundry, cooking, and heating purposes. The mean values for hardness in the Wolfville Formation, Blomidon Formation, Horton Group, and Granite are above 100 ppm. Some groundwaters in these units, therefore, are "hard", and water softeners may be necessary to make the water satisfactory for use.

Agricultural Use

The major agricultural uses of water are for watering livestock and for irrigation. There are limits to the tolerance of livestock to dissolved minerals, but generally these limits are much higher than those for human consumption. Thus, only a very few groundwaters in the Annapolis-Cornwallis Valley (such as the high sulfate Spa Spring waters) should not be used for watering livestock if better quality water is available.

For irrigation water the most important factors to be considered are the total dissolved solids, the concentration of some individual constituents, and the relative concentration of sodium.

> "Salts may harm plant growth physically by limiting the uptake of water through modification of osmotic processes, or chemically by metabolic reactions such as caused by toxic constituents. Effects of salts on soils, causing changes in soil structure, permeability, and aeration, indirectly affect plant growth" (Todd, 1959, p. 190).

There are two common methods of classifying irrigation waters, and both use specific conductance as an indication of total dissolved solids. One method (Wilcox, 1948) uses per cent sodium (or soluble sodium percentage) as an indication of the sodium or alkali hazard. Soluble sodium percentage (SSP) is defined by

$$\mathrm{SSP} = 100\,(\mathrm{Na} + \mathrm{K}) \,/\, (\mathrm{Ca} + \mathrm{Mg} + \mathrm{Na} + \mathrm{K}).$$

The other method, recommended by the Salinity Laboratory of the U.S. Department of Agriculture (Richards, 1954), uses the sodium adsorption ratio (SAR) as an indication of the sodium hazard. The SAR is defined by

$$\mathrm{SAR} = \mathrm{Na} \,/ \sqrt{(\mathrm{Ca} + \mathrm{Mg})\,/2}.$$

All ions are expressed in epm both in the calculation of the SSP and the SAR. In table 12, waters from the various hydrostratigraphic units have been classified as to their suitability for use as irrigation water.

It is apparent that the average groundwater in every unit can be classified as excellent to good for irrigation. Since mean values have been

Table 12. Groundwaters in Relation to Irrigation Water Quality Classifications

	Mean values for			Wilcox (1948)		Richards (1954)		
				Water Class		Sodium (Alkali) Hazard Low (SAR< 10)	Salinity Hazard	
	SSP	SAR	Specific Conductance (μmhos)	Excellent (SSP< 20, < 250 μmhos)	Good (SSP 20-40, 250-750 μmhos)		Low (< 250 μmhos)	Medium (250-750 μmhos)
North Mountain Basalt	24	0.52	20	X to	X	X	X	
Blomidon Formation	12	0.45	56	X		X	X	
Wolfville Formation	28	0.86	35	X to	X	X	X	
Metamorphic Rocks	25	0.49	19	X to	X	X	X	
Granite	9	0.20	28	X		X	X	
Horton Group	23	0.73	38	X to	X	X	X	
Sand and Gravel	30	0.67	21	X to	X	X	X	
All till deposits together	28	0.60	21	X to	X	X	X	

used in the calculations, however, there will be some groundwaters, particularly in the Blomidon and Wolfville Formations and in the Horton Group, which may be of poorer quality for irrigation.

Boron was not determined in the chemical analyses, but it is important in determining the quality of irrigation waters. Boron in very small quantities is essential for normal plant growth, but when it exceeds certain limits, depending on the particular crop, it becomes toxic. The major crops grown in the Annapolis-Cornwallis Valley are sensitive to semitolerant to Boron, which means that Boron should not exceed about 1.3 ppm and should ideally be less than 0.3 ppm for these crops (Wilcox, 1948).

In some areas of the Annapolis-Cornwallis Valley, the major problem with groundwater irrigation will not be the initial water quality, but the lack of proper drainage in the fields being irrigated. Plants utilize only a small proportion of the dissolved minerals in irrigation water (Hem, 1959). The remaining salts are either precipitated in the soil or dissolved in the residual water. If poor drainage conditions do not permit these residual salts to be removed, the accumulation of salts may gradually deteriorate the soil.

Industrial Use

Industrial water quality standards vary widely depending on the use. For many uses, particularly in food processing plants, groundwater must meet drinking water standards. For many other purposes, such as cooling water, water quality specifications are not as rigid, requiring only that the waters not be excessively corrosive or encrusting.

In some cases, such as the manufacture of high grade paper or for use as boiler feed water, almost no natural groundwater is satisfactory without treatment because quality approaching or exceeding that of commercial distilled water is required.

No attempt will be made here to list water quality criteria for various industries because there are so many varying requirements (see McKee and Wolf, 1963, for a comprehensive discussion of industrial water quality criteria). Any groundwater can be treated for a particular case, but the cost of the treatment of a particular water in relation to treatment of other possible water supplies should be studied thoroughly. Fortunately, most groundwaters in the major surficial aquifers and in the Wolfville Formation require little, if any, treatment for many industrial purposes.

GROUNDWATER POLLUTION

Introduction

One aspect of groundwater quality, the natural water chemistry, was examined in the preceding section. In this section, another important aspect of groundwater quality - undesirable materials introduced by man's activities - will be discussed. Because of varying usage, pollution and contamination will be defined. The following definitions have been modified from those given in McKee and Wolf (1963, p. 5 and 6). "Pollution" is defined as an impairment of water quality by sewage, industrial wastes, and other sources which adversely affects any beneficial use of the water even though a health hazard may not be involved. "Contamination" is defined as an impairment of of water quality by sewage, industrial wastes, and other sources which creates an actual hazard to public health through poisoning or through spread of disease.

Pollution of unconfined surficial aquifers is more likely to be a problem than pollution of aquifers in the bedrock because potential pollutants have only a short distance to travel before reaching the saturated zone in the surficial aquifers. After reaching the saturated zone, many pollutants are easily transported in the relatively large interstitial openings of the sand and gravel. In contrast, many of the aquifers in the Wolfville Formation are protected by confining beds of claystone and siltstone.

No attempt will be made in this chapter to present a comprehensive discussion of groundwater pollution hazards in the Annapolis-Cornwallis Valley. Instead, some of the more important potential pollution problems are examined along with some actual cases of groundwater pollution.

Sources of Pollutants

Municipal and Domestic Sewage

Most of the larger towns in the Annapolis-Cornwallis Valley are located near the Annapolis and Cornwallis Rivers. Many of these towns have sewerage systems but few towns treat their sewage in any way. With the exception of CFB Greenwood, which has complete sewage treatment facilities, all towns are now discharging raw or only partly treated sewage into the rivers. Because of this situation, 1961 water quality surveys concluded that both rivers are grossly contaminated by sewage wastes (Dept. of National Health and Welfare, 1962a, and 1962b).

Normally the condition of these rivers poses little threat to groundwater because the rivers are natural groundwater discharge areas. During floods, however, there is a chance that some pollutants may not be filtered out as river waters enter the flood plain sediments. Also during floods, polluted water might enter poorly completed wells constructed in flood plain sediments.

Municipal sewage may endanger groundwater more in the future if oxidation and settling ponds are bulldozed in sand and gravel deposits outside natural groundwater discharge areas. Provision should be made to seal such pits to prevent seepage into groundwater reservoirs, or to locate them where it can be demonstrated that the possibility of polluting existing and future groundwater supplies is low.

Aside from the town sewer systems, there are numerous individual septic tanks scattered around the Valley. Many of these are not adequate for the job or are not properly maintained, and thus represent potential sources of pollution. Pollution from septic tanks or from barn yards and manure piles is often indicated when high concentrations of nitrate are found in water analyses. Other objectionable substances may be present in a polluted water supply along with nitrate. For example, it is not uncommon to dispose of unwanted poisons by dumping them down the drain. Also, detergents, which are not filtered out by the soil, may appear in water supplies. Although not harmful to health, detergents are aesthetically objectionable when foam comes out of a water tap.

In some cases, particularly if surface runoff can penetrate improperly completed wells, there will also be bacterial contamination of the water supply. However, if the drainage from septic tanks and manure piles can filter even a short distance through the soil before entering a well, there is commonly no bacterial contamination. A comprehensive study in California (Cal. State Water Pollution Control Board, 1954) demonstrated that bacteria are confined to a zone within a few feet of the source of pollution in sand and gravel.

In the future, new housing developments should be connected to a common sewer and sewage treatment system to protect the surficial aquifers. In addition, all existing septic tanks located close to or up-hill from water supplies should be relocated at least 100 feet down-hill from water supplies to minimize the chance of local pollution. It should be obvious that shallow sand points and dug wells should not be located close to barn yards and paths followed by farm animals, but this situation was noted in many places during the course of field work in the Annapolis-Cornwallis Valley.

Industrial Waste Disposal Pits

At the time of the 1961 water quality surveys of the Annapolis and Cornwallis Rivers, most industries in the Valley discharged their liquid and solid wastes into the rivers. Since that time many industries have taken measures to reduce their pollution of the rivers. In some cases the solid wastes were found to be useful as feed for livestock. Liquid wastes have usually been pumped to settling and oxidation ponds before being discharged into streams.

The major potential pollution hazard arises when unlined disposal pits are located in sand and gravel away from discharge areas or where the groundwater gradient is toward pumping wells. When these pits are filled, they act, although sometimes inefficiently, as groundwater recharge pits. If there are any objectionable substances in the waste which are not filtered out by the soil, they will enter the groundwater reservoir and pollute water supplies.

There is a case of groundwater pollution of this nature at an apple processing plant at Coldbrook, Kings County. Initially the groundwater pumped from an unconfined sand and gravel aquifer contained iron in concentrations of 0.2 ppm or less. No hydrogen sulphide gas was reported.

Apple processing wastes were pumped to a leaching pond bulldozed in sand and gravel only 300 feet from the well. Because it was feared that the leaching pond might pollute the aquifer, organic and inorganic chemical analysis were made of a groundwater sample taken 15 feet from the leaching pond in the summer of 1965. Apple waste products, waste degradation products, and bacteria were found in this sample. At that time the water quality in the production well had not been affected. Possibly clay lenses had retarded movement of polluted water to the well.

Later in 1965 during production and in 1966, the well water deteriorated in quality. Iron was present in concentrations of 3 to 4 ppm and hydrogen sulphide gas was reported. Reaction of the apple wastes with the groundwater could easily account for this change in water quality. Hydrogen sulphide would result from the anaerobic decomposition of the organic wastes, and the solubility of iron would be increased by the decrease in dissolved oxygen and by the decrease in pH (due to malic, butyric, and other organic acids).

Although not demonstrated in this case, butyric acid increases the solubility of minerals such as the carbonates, and the bacteria producing butyric acid also attack carbonates (Pauli, 1966). Thus, the danger from an organic waste comes not only from the substances in the waste itself, but also from the effects these substances may have on the inorganic water chemistry of the aquifer.

Garbage Dumps

The disposal of garbage is a problem anywhere there is civilization. Aside from municipal dumps, there are numerous private and illegal dumps marring the landscape of the Annapolis-Cornwallis Valley. Most of the official municipal dumps are in abandoned gravel pits or in relatively unproductive sandy areas. These are often groundwater recharge areas and consequently there is a potential danger of groundwater pollution. At the Kentville dump, for example, it was noted that pits, excavated to receive garbage, extended to the water-table.

Several unsuccessful attempts were made to obtain groundwater samples in sand and gravel near garbage dumps. In a few cases the concentration of garbage was not large enough in any one place to warrant taking a water sample. In other cases the geology was unsatisfactory for obtaining water samples from sand points. It is not known what would have been found if water samples had been obtained, but certainly there is the opportunity for numerous organic and inorganic substances to move into the groundwater reservoir with infiltrating precipitation.

The population of the Annapolis-Cornwallis Valley is not large enough at the present time to make the disposal of garbage a major problem. It is recommended, however, that garbage dumps be located in or near groundwater discharge areas (but not on river flood plains) so that the potential pollution of aquifers is minimized. It is also recommended that a campaign be conducted to eliminate the private and illegal dumps scattered about the Valley.

Pesticides

Since 1945 when DDT became available for general use, there has been widespread use of synthetic pesticides in agricultural and other areas. The use of pesticides will continue to increase because

> "our affluent Canadian society has established social and economic attitudes that have reduced our tolerance to pests and the damage they do to our environment" (Hurtig and Harris, 1966, p. 2).

The general group of pesticides most widely used in agriculture to the present time have been the synthetic organic chlorinated hydrocarbons (e.g. DDT, dieldrin, aldrin, heptachlor). Commonly such pesticides are applied to orchards and crops such as tobacco and potatoes several times a year. There is ample opportunity for these pesticides to be carried into the soil by precipitation, by the use of large volumes of water-pesticide solution in orchards, and by direct application to the soil (in fertilizers) to attack soil insects.

Most of the synthetic organic chlorinated hydrocarbons persist for long periods of time in soil. Biodegradation is often slow and conversion products may or may not be toxic. For example,

> "small amounts of aldrin are converted to dieldrin and heptachlor to heptachlor epoxide. Both of these metabodies are toxic and considerably more persistent than the parent materials" (Hurtig and Harris, 1966, p. 9).

In British Columbia, aldrin/dieldrin and heptachlor/heptachlor epoxide residues have persisted in the soil at least 9 years after initial treatment (Wilkenson, *et al.*, 1964). In Nova Scotia, chlorinated hydrocarbons have been known to persist at least 6 years in soils (Stewart, *et al.*, 1965).

Because of their persistence and their continued application year after year, the possibility exists that some of the chlorinated hydrocarbons may be leached from the soil to pollute groundwater. If these pesticides get into the groundwater, the concentrations may not be toxic because available data indicate

> "that there is no evidence of risk to human populations from the levels of pesticide residues currently being detected in water or in commercial supplies of fish consumed by man" (Hurtig, 1966, p. 5).

Nevertheless, there is a possibility of greatly increased toxicity (synergistic effects) where several pesticides are used in combination (McKee and Wolf, 1963, p. 356). The toxic effects, however, are not the only pollution hazard because some synthetic organic pesticides cause objectionable tastes and odors in water supplies (McKee and Wolf, 1963, p. 356).

In an attempt to determine if any significant amounts of chlorinated hydrocarbons are present in groundwater beneath orchards and crops commonly sprayed with pesticides, groundwater samples were taken from two different orchards (21 H 2 B 28 B ⊡, and 21 H 2 B 26 H ⊡) and a potato field (21 H 2 B 8 E ⊡). These locations were chosen because the water-table was close to the surface (between 5 and 13 feet) and the sandy soil made the collection of water samples from sand points fairly easy.

Briefly, the procedure followed was to shovel away the top foot of soil (where most of the pesticide residues are found) to minimize the possibility of contamination of the water sample. A power auger was used to drill a 4 inch hole to a depth several feet below the water-table. After a 1¼ inch sand point was inserted in the hole, the point was developed and pumped for 15 minutes with a small gasoline powered centrifugal pump (Fig. 37). Then, a 5 gallon sample of water was taken for analysis at the Agricultural Research Station, Kentville.

Analysis for the presence of chlorinated hydrocarbons was made by gas chromatography, a particularly good method for separating complex organic mixtures (Morley, 1966). Preliminary indications are that no chlorinated hydrocarbons are present in any of the samples, (D.K.R. Stewart, personal communication). These three samples, however, should be considered as only a start in the investigation of this problem. More work should be done, particularly in areas where there is intensive application of pesticides.

It can be tentatively concluded, however, that the soil acts as a good filter preventing significant amounts of pesticide (as normally applied in agriculture) from reaching the water-table. Thus, it appears that the major danger from pesticide residues in the soil is that they may be incorporated in surface runoff and in agricultural products.

FIGURE 37. Power auger and pump used to obtain water samples for pesticide analysis.

Miscellaneous Sources

Water Wells

Numerous actual or potential sources of groundwater pollution are the many dug wells in the Annapolis-Cornwallis Valley area. The trend is away from using dug wells as water supplies because it is more difficult to keep them sanitary and many of them are not dependable during dry summers. It is certainly possible to construct sanitary dug wells, but in many cases little effort has been made to keep surface runoff out of the wells.

Few of the abandoned dug wells have been filled in. Some of them have become a physical hazard as they were left covered with rotten boards. Others are now used as receptacles for garbage or have been converted to septic tanks. Needless to say, this is an undesirable situation because, even in areas where the surficial deposit is a clay till, it may be possible for pollutants to penetrate bedrock aquifers. The hazard is greater in sand and gravel because many water supplies come from shallow sand points.

The Well Drilling Act, which applies to wells drilled or dug since January 1, 1965, has regulations prescribing among other things 1. That abandoned wells be cement grouted back to the surface, 2. that wells should not be used for waste disposal without special permission, and 3. that wells should be located certain minimum distances from various sources of pollution. A campaign should be conducted to enforce these regulations, and measures should be taken to apply such regulations to wells drilled or dug prior to 1965.

Drilled wells may also be sources of pollution where they penetrate several water-bearing zones including one which has water of poor quality. If such a zone is not sealed off, the poor quality water in it may pollute other aquifers with better quality water. The Well Drilling Act requires that aquifers with relatively poor quality water be sealed off, but if there is any appreciable time lag before this is done, the resulting deterioration in water quality in good aquifers may last for years.

Gasoline Pollution

Leaking gasoline tanks can seriously pollute surficial aquifers. A small amount of gasoline may spread as a thin film over a large area and persist for years if the natural groundwater movement is slow. Gasoline tanks in use are always a potential source of pollution, but abandoned tanks are a more serious hazard because they will eventually corrode and release any remaining gasoline.

There have been two reported cases of gasoline pollution in the Valley. At Greenwood Village, gasoline tanks in use sprung leaks and polluted the surficial aquifer. At least one water supply was affected, and there is the possibility that many more will be as the zone of pollution spreads with the natural groundwater movement. In a case such as this where a localized source of pollution threatens many water supplies, a well might be completed near the source of pollution and pumped to offset natural groundwater movement away from the source. This case emphasizes the need for regular inspection of gasoline tanks (by pressurizing them) so that leaks can be caught and corrected before the gasoline turns up in a water supply.

In the second case, at Nictaux Falls, the sale of gasoline from a small gas station-general store was discontinued in 1956 (?). The gasoline tanks (located underground) were pumped as nearly dry as possible and then abandoned. In the winter of 1965, the first odor of gasoline was noted in water coming from two dug wells and a spring within about 200 feet of the tanks. The gasoline taste and odor had persisted for six months by the time this case was noted in September, 1966. Fortunately, in this case, the area polluted is small. However, this is only one of many abandoned gas stations in the Annapolis-Cornwallis Valley and the problem of corroding tanks may become much more serious in the future.

Accidental and Indiscriminate Dumping of Harmful Materials

Although no cases were noted during the course of field work, there is always the possibility of accidental or deliberate spillage of poisons, pesticides, etc. In the case of pesticides, the soil may filter normal applications, but will probably not filter out a spilled tank of water-pesticide solution. When such spillage occurs, care should be taken to monitor the quality of groundwater supplies which may be affected.

SUMMARY, RECOMMENDATIONS AND CONCLUSIONS*

The Annapolis-Cornwallis Valley is one of the most ideally suited areas in the province for further groundwater development. The Wolfville Formation underlies most of the Valley and contains many good sandstone and conglomerate aquifers. Within the practical limits of this formation shown on map 2, wells yielding from 100 to 500 or more igpm may be completed, depending on the depth of the well and on the number of productive zones penetrated. Within about one-half mile of the southern boundary of the Wolfville Formation the producing zones may be inadequate for high yield wells because the formation wedges out over the underlying Palaeozoic rocks. Along the scarp of North Mountain, a few hundred feet of the Blomidon Formation may have to be penetrated before good aquifers in the Wolfville Formation are encountered.

In addition to bedrock aquifers, there are good surficial sand and gravel aquifers located mostly in the eastern half of the Valley. The thickness of saturated sand and gravel is shown on map 2. Only limited water supplies may be found where the saturated thickness is between zero and 20 feet. This is especially true at the western end of the Valley because the outwash is usually only a few feet thick over estuarine clay, and along the flank of South Mountain because of a combination of deep water-table, poor size sorting, and possible existence of nearby barrier-boundary conditions. Where these areas overlie the Wolfville Formation, large water supplies will probably be limited to the bedrock. Nevertheless, careful samples of surficial deposits should be taken in case this material proves to be thick enough for a sand point well system. The optimum spacing of sand points will have to be determined from pump tests.

Where saturated sand and gravel is shown as greater than 20 feet thick, the possibility of using surficial aquifers should definitely be explored. If local surficial aquifers prove to be unsatisfactory, wells in bedrock will be necessary. Along bedrock depressions where the saturated thickness of sand and gravel is shown as greater than 40 feet, the best and most economical water supplies will probably be in the surficial deposits. In these deposits, it should be possible to obtain yields from 100 to 1,000 or more igpm from one well. If one or two test-holes give poor results, it would pay to explore further because the character of surficial deposits can change rapidly. The safe production rate of a well, however, may be decreased by nearby reductions in permeability in surficial deposits and/or the proximity of bedrock ridges. To estimate the amount of additional drawdown in a production well due to such permeability reductions (barrier-boundaries), a carefully controlled pump test of several days duration should be made.

Outside the Valley proper, the geology is not as suitable for groundwater development. For example, the permeability in rocks forming North and South Mountain is primarily in joints. Wells in these rocks can seldom be

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* Summaries and conclusions on the hydrologic budget and groundwater movement are made at the end of those sections.

counted on to meet more than domestic needs, although in places, there are wells in granite and basalt which will yield 40 to 50 igpm. (Rocks in the lower Horton Group underlying the Gaspereau Valley, however, contain moderately good aquifers that may yield up to 100 or more igpm to wells).

Though good aquifers underlie most of the Annapolis-Cornwallis Valley, the demand for groundwater will vary considerably from place to place. At the present stage of development there are no areas of serious groundwater depletion. However, the consequences of any planned new development should be studied thoroughly. Predictions of future groundwater levels due to an assumed development are most accurately made with an analog model which incorporates all available information on the hydraulic properties of the aquifers and all available records of well pumpage in the area. An analog model is useful not only for planning the most economical well field, but also for predicting how this new well field would interfere with existing wells. It is easier to anticipate the effects of a new cone of depression and take remedial measures than it is to handle the practical and legal problems after the damage is done.

Groundwater quality in the surficial sand and gravel aquifers and in the Wolfville Formation is usually good enough so that little or no treatment is required for agricultural, domestic, and many industrial uses. Waters in the Wolfville Formation, however, have larger amounts of calcium carbonate than waters in surficial sand and gravel. This causes higher alkalinity, hardness, and pH in waters from Wolfville aquifers. In places, dissolved iron in the waters of both units may be present in objectionable quantities.

One restriction to increasing the capacity of wells in the Wolfville Formation by drilling them deeper is that the quality of water may decrease with depth, particularly near estuaries. This problem and the companion one of salt water intrusion near estuaries may limit some of the future development of groundwater in this hydrostratigraphic unit. Further investigation of these two problems needs to be made.

Several pollution hazards and cases of groundwater pollution are cited and recommendations for minimizing pollution were made in the last section. Although the problem is not serious at the present time, care must be taken to protect this valuable resource. Much is to be lost and nothing to be gained by using groundwater as a waste disposal medium with utter disregard for other beneficial uses as has happened with the surface waters of the Annapolis and Cornwallis Rivers.

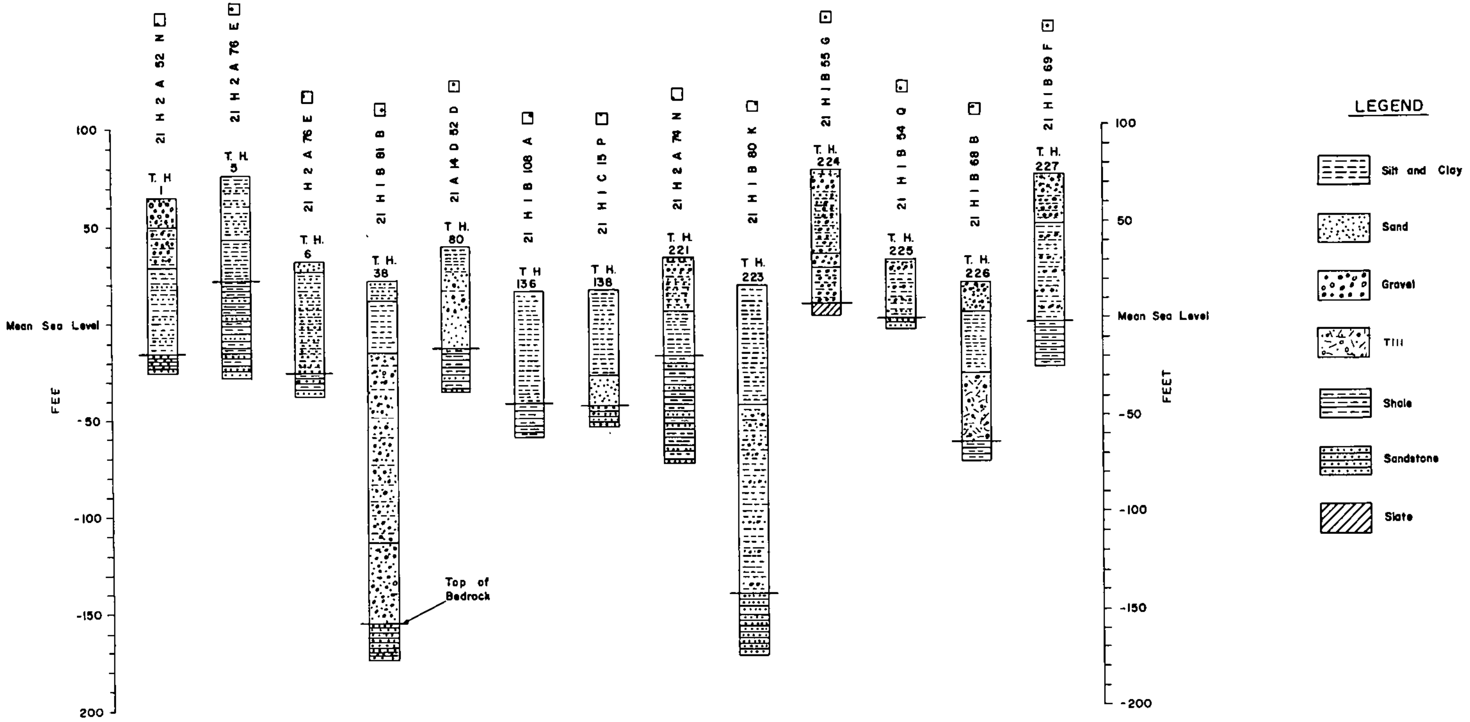
Most of the towns in the Valley now use surface water supplies from the adjacent mountains. In many cases these supplies are barely adequate for present needs, and the quality of the water may fluctuate from season to season. Commonly there is little prospect of adding other lakes to the system. Thus, these towns must turn to groundwater if they wish to grow and attract more business and industry.

Where good aquifers are available, there are many advantages to using groundwater: no long transmission lines need to be installed and maintained; the water quality and temperature are relatively constant, and, as demand grows, the well field can be expanded to meet any forseeable needs.

The possibilities of groundwater for each town will not be listed because essentially all towns in the Valley are situated above aquifers in the Wolfville Formation. The possibilities for sand and gravel aquifers are shown on map 2. In any case where there is not adequate test-hole information in this report, towns should initiate their own test-drilling program so that knowledge of potential aquifers will be available when needed.

The variability of precipitation during the growing season is apparent from the records for 1963-1966 given in figure 21. As a result, supplemental irrigation is becoming more widespread in the Valley. The benefits in increased crop yields are often well worth the expense of installing an irrigation system.

APPENDIX A. *(FIGURE 38.)* GRAPHIC LOGS OF SURFICIAL DEPOSIT TEST-HOLES NOT ILLUSTRATED IN THE CROSS-SECTIONS.



Note: the logs of all test-holes located on map 1 are on file at the N.S. Dept. of Mines. Some of these logs are not shown graphically in this report.

Table 13. Statistical Measures for 14 Samples

Location	Type of deposit Hickox (1962)	Type of deposit This Report	X	s	Sk1	Kg
21 H 2 A 61 Q ⊡		wt. sst.*	1.61Ø	1.76Ø	0.18	1.00
21 H 2 A 62 G ⊡		wt. sst.	1.87Ø	1.17Ø	-0.11	1.20
21 H 2 B 50 B ⊡		wt. sst.	1.23Ø	2.52Ø	0.10	1.03
21 H 1 C 36 G ⊡		I-CSD **	2.68Ø	0.76Ø	-0.19	1.02
21 H 2 B 3 C ⊡	dune	I-CSD	2.26Ø	0.61Ø	0.17	1.05
21 H 2 B 4 N ⊡	dune	I-CSD	2.01Ø	0.72Ø	-0.14	1.20
21 H 2 B 6 A ⊡	outwash	I-CSD	1.92Ø	0.65Ø	0.07	1.11
21 H 2 B 7 M ⊡	dune	esker	1.42Ø	0.85Ø	-0.01	0.99
21 A 15 C 82 Q ⊡	dune	I-CSD	1.88Ø	0.83Ø	-0.03	1.00
21 A 15 C 102 O ⊡	dune	esker	1.85Ø	0.82Ø	0.03	1.13
21 A 15 C 102 M ⊡	dune	I-CSD	1.92Ø	0.66Ø	0.06	1.11
21 A 15 C 102 M ⊡	dune	I-CSD	1.83Ø	0.95Ø	-0.06	1.10
21 A 15 C 107 G ⊡	dune	I-CSD	2.41Ø	0.70Ø	0.14	1.23
21 A 15 C 107 K ⊡	I-CSD	I-CSD	2.02Ø	0.50Ø	0.25	1.16

* Weathered Sandstone

**Ice-Contact Stratified Drift

APPENDIX B.

TEXTURAL CHARACTERISTICS OF SOME SURFICIAL DEPOSITS

Textural characteristics are sometimes helpful in identifying depositional environments of sand bodies. Samples of several questionable deposits were taken for sieve analysis. The locations from which these samples were taken are shown on map 1 and described in table 13. Cumulative weight percentages were plotted against phi diameter on arithmetic probability paper as recommended by Folk and Ward (1957). The following statistical measures were then computed: skewness, which describes the symmetry of the grain-size distribution curve; kurtosis, which measures the peakedness of the grain-size distribution curve; standard deviation, a measure of sorting, and mean size. Formulas from Folk and Ward (1957) were used (Table 14). These formulas are easier to use, but less precise than the method of moments employed by Friedman (1961).

Of all the statistical parameters, the standard deviation is the best for distinguishing between fluvial and dune environments (Friedman, 1961). He states that standard deviation values for inland dunes are commonly less than 0.50 Ø; the standard deviation of fluvial sands is commonly greater than 0.50 Ø . A more definite indentification can be made by plotting the mean grain-size ratio of a heavy mineral to a light one against the standard deviation ratio of the heavy to light material (Friedman, 1961). Although this was not done, the fact that all of the samples in table 13 have standard deviations equal to or greater than 0.50 Ø would suggest that they were deposited in a fluvial environment.

Table 14. Formulas Used in Textural Analysis

Statistical Measure		Formulas from Folk and Ward (1957)
mean size	$\overline{X}$	= (Ø16* + Ø50 + Ø84) / 3
standard deviation	s	= (Ø84 - Ø16) / 4 + (Ø95 - Ø5) / 6.6
skewness	Sk1	= [(Ø16 + Ø84 - 2Ø50) / 2 (Ø84 - Ø16)] + Ø5 + Ø95 - 2Ø50 / 2 (Ø95 - Ø5)
kurtosis	Kg	= (Ø95 - Ø5) / 2.44 (Ø75 - Ø25)

* Ø16 stands for the phi diameter at the 16th percentile of the distribution, etc.

APPENDIX C.

GROUNDWATER CHEMISTRY-STATISTICAL ANALYSES

Introduction

Commonly several days and sometimes a few weeks lapse before a water sample is analyzed in a laboratory. During this time the water sample is subjected to a different physical environment than that of the aquifer from which the sample was taken. The new physical environment may alter the value of some of the chemical properties of the water (e.g. the amount of dissolved gas and the pH). Consequently, it may be desirable to do a partial chemical analysis in the field immediately after the water sample is taken. During the summer of 1966 all water samples were analyzed for pH and total iron in the field with a portable Hach kit* and again in the laboratory along with the remainder of the analysis. In the first part of this appendix, the hypothesis that there is no significant difference in the field and laboratory values for pH and total iron is tested statistically.

The second part of this appendix is a brief description of Stein's two-stage method for determining the minimum number of water samples which need to be collected in a regional water sampling program.

The third part of this appendix is an analysis of the variance of each chemical constituent among the various hydrostratigraphic units. This analysis is used to show where there are similarities and where there are significant differences in the water chemistry among the various hydrostratigraphic units.

Field and Laboratory pH Determinations

In this analysis it has been assumed that the field determinations of pH represent the formation water pH (although the field procedure permits determination at best to the nearest 0.1 pH). The initially acid waters were analyzed separately from those which were initially basic because there appeared to be a tendency for both types of water to become more neutral before analysis in the laboratory.

For initially acid waters, is there reason to believe at the 1 per cent level of significance that the laboratory determinations are different from the field determinations for which the mean value = 6.0? The following procedure was used (see Appendix F for definitions of the symbols):

1. Hypothesis: $\mu = 6.0$
2. $\alpha = 0.01$
3. $$t = \frac{\bar{X} - 6.0}{s/\sqrt{N}}$$

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* portable field kit DR-EL, Hach Chemical Co., Ames, Iowa.

where:

$$s^2 = \frac{\sum_{i=1}^{N} Xi^2 - \frac{\left(\sum_{i=1}^{N} Xi\right)^2}{N}}{N-1} = \frac{1{,}916 - \frac{(296.2)^2}{46}}{45} = 0.2$$

and: $s = 0.4$

4. Assume this statistic has a t distribution with 45 degrees of freedom.
5. Reject if $t < -2.69$ or if $t > 2.69$.
6. $t = \frac{\overline{X} - 6.0}{s / \sqrt{N}} = \frac{6.4 - 6.0}{0.4 / \sqrt{46}} = 7$ which is >2.69.

and so the hypothesis is rejected.

For initially basic waters, is there any reason to believe at the 1 per cent level of significance that the laboratory determinations are different from the field determinations for which the mean value = 8.0? The following procedure was used:

1. Hypothesis: $\mu = 8.0$
2. $\alpha = 0.01$
3. $t = \frac{\overline{X} - 8.0}{s / \sqrt{N}}$

where:

$$s^2 = \frac{\sum_{i=1}^{N} Xi^2 - \frac{\left(\sum_{i=1}^{N} Xi\right)^2}{N}}{N-1} = \frac{2{,}998 - \frac{(393.6)^2}{52}}{51} = 0.2$$

and: $s = 0.4$

4. Assume this statistic has a t distribution with 51 degrees of freedom.
5. Reject if $t < -2.68$ or if $t > 2.68$.
6. $t = \frac{\overline{X} - 8.0}{s / \sqrt{N}} = \frac{7.6 - 8.0}{0.4 / \sqrt{52}} = -7$ which is < -2.68

and so the hypothesis is rejected. Thus, it is important to determine the pH of a water sample as soon after sampling as possible because there is a significant tendency (at $\alpha = 0.01$) for the sample to become more neutral with time.

Field and Laboratory Total Iron Determinations

The total amount of iron in a water sample may change with time only in that some of the iron may precipitate in the container. There was concern that the procedure for redissolving the precipitated iron in the laboratory is not adequate for accurate determination of total iron. Is there any reason to believe at the 1 per cent level of significance that the laboratory total iron determinations are different from the field determinations for which the mean value = 0.47 ppm (assuming the field determinations are correct)? The following procedure was used:

1. Hypothesis: $\mu = 0.47$
2. $\alpha = 0.01$
3. $$t = \frac{\overline{X} - 0.47}{s / \sqrt{N}}$$

   where:

   $$s^2 = \frac{\sum_{i=1}^{N} Xi^2 - \frac{\left(\sum_{i=1}^{N} Xi\right)^2}{N}}{N - 1} = \frac{112 - \frac{(41.2)^2}{83}}{82} = 1.1$$

   and: $s = 1.0$

4. Assume this statistic has a t distribution with 82 degrees of freedom.
5. Reject if $t < -2.64$ or if $t > 2.64$
6. $$t = \frac{\overline{X} - 0.47}{s / \sqrt{N}} = \frac{0.50 - 0.47}{1.0 / \sqrt{82}} = 0.3$$ which is not greater than

2.64 and so the hypothesis is accepted. It can be argued, however, that only the samples with high concentrations of iron would be affected by the precipitation problem. To check this contention, only the samples with initial total iron values of 1.0 ppm or greater were analyzed according to the above procedure. The calculated $t = 1$ which is not significant at either $\alpha = 0.01$ or 0.05. Further, it can be argued that the field method of determining total iron is not as accurate (disregarding the precipitation problem) as the laboratory method and that an analysis of variance would be the appropriate statistical procedure. This was done according to the procedure described on page 116. The calculated $F = 0.1$ which is not significant when compared to the tabulated $F_{.99}(1,164) = 6.7$. Thus, it is not necessary to determine the value for total iron in the field.

Stein's Two-Stage Method

The number of water samples taken in each hydrostratigraphic unit originally was based on the area of each unit. In the populated regions under study, one water sample was taken per mining tract. For economic reasons (the time involved in sampling and analysis, and the cost of chemical analyses), another method of choosing the number of samples, based on the known variations in water chemistry, was employed during the summer of 1966.

The method used, Stein's two-stage method (Stein, 1945), required that some water analyses were already available from each hydrostratigraphic unit. These samples were used to estimate the variance, s^2, for each item in the analysis for each unit. Then a confidence interval, 2d, within which it was desired to have an estimate of the mean value of a particular item in the analysis, was chosen. The confidence interval was the same for a particular constituent in every hydrostratigraphic unit. The number of samples, n_1, required to estimate the mean within this confidence interval is given as

$$n_1 = (t_1^2 \; s_1^2) \;/\; d^2$$

where t_1 is the tabulated t value for the desired confidence level and the degrees of freedom of the initial sample. The chemical constituent with the largest n_1 in each hydrostratigraphic unit determined the number of samples to be collected in that unit. If the number of samples already collected in a particular unit equalled or exceeded n_1, then no more samples had to be collected. If more samples had been needed, they would have been collected at random and a new mean would have been calculated using all of the samples. This mean would have fallen within d of the population mean (at the stated confidence level) unless the procedure had resulted in an unusual sample. In this case s_2^2 would have exceeded s_1^2 and it would have been necessary to collect more samples.

For the Annapolis-Cornwallis Valley, the number of samples collected considerably exceeded n_1 in every hydrostratigraphic unit. All of these samples, however, were in the eastern two-thirds of the Valley, and it was considered desirable to get some samples at the western end of the Valley. Therefore, the n_1 values were used to determine the number of samples collected at the western end of the Valley. The ninety-two samples collected, however, were only one-third of those which would have been collected under the system of one per mining tract.

In future groundwater sampling programs, it is recommended that only a few random samples be collected first, and that Stein's two-stage method be used to determine the number of samples needed so that the desired information can be obtained with a minimum of time and expense.

Variance of Each Chemical Constituent Among the Various Hydrostratigraphic Units

In order to discuss the water chemistry of each hydrostratigraphic unit in relation to that of other units, an analysis of variance was made of each item in the chemical analysis: 1. by considering the bedrock hydrostratigraphic units as a group of treatments, 2. by considering the till deposits overlying each bedrock unit and the sand and gravel deposits as a group of treatments, and 3. by considering each bedrock unit and its overlying surficial deposit as a group of treatments. In addition, the general treatment comparisons were subdivided into single-degree of freedom comparisons. The following procedure was used:

1. Hypothesis: $\mu_1 = \mu_2 = \ldots = \mu_k$. The means of the k treatments in each group are all equal.
2. $\alpha = 0.05$. The confidence level of 95 per cent is valid for the general treatment comparisons and would be valid for the single-degree of freedom comparisons if they were independent or orthogonal (Steel and Torrie, 1960). Orthogonal comparisons, however, are not necessarily meaningful comparisons. If this is the case (as it is here), it is better to have meaningful comparisons with a confidence level less than 95 per cent.
3. The statistic used is F, the ratio of the treatment mean square to the error mean square.
4. Assuming the observations are randomly selected from normal populations with homogeneous variance and that the hypothesis is true, this statistic has an $F\,(k-1,\ \Sigma n_i - k)$ distribution.
5. The critical region is $F > F_{1-\alpha}(k-1,\ \Sigma n_i - k)$.
6. The calculation of F was done on a computer. An analysis of variance for calcium considering the bedrock units as a group of treatments is given in table 15. Eleven more such analysis of variance tables may be prepared for the remaining items in the chemical analysis (for this group of treatments). These tables, however, have been shortened by combining them into one table for each group of treatments where only the calculated F values are given (Tables 16 to 18). Those comparisons for which the hypothesis of no difference in treatment means has been rejected (at $\alpha = 0.05$) are underlined.

Many of the results given in tables 16 to 18 have been used in the section on the chemical quality of groundwater in the hydrostratigraphic units. In this appendix, therefore, the F values will not be discussed further except to point out that in a given comparison where a significant difference is indicated (e.g. sulfate concentration, Blomidon Formation versus Wolfville Formation, Table 16) the unit with the significantly larger values can be determined by comparing the mean values in table 9.

Table 15. Analysis of Variance for Calcium in Bedrock Groundwaters

	Sum of Squares	df	Mean Square	*F* Ratio
Treatment	212.40	5	42.48	9.34*
Basalt versus Metamorphic rocks	0.62	1	0.62	0.14
Blomidon Formation versus Wolfville Formation	128.25	1	128.25	28.19*
Wolfville Formation versus Horton rocks	0.05	1	0.05	0.01
Basalt + Metamorphic versus Blomidon + Wolfville + Horton	82.08	1	82.08	18.04*
Error	823.54	181	4.55	
Total	1,035.94	186		

*Significant *F* values (see Table 16 for critical *F* values)

Table 16. Values for F for the Analysis of Variance of Groundwater Chemical Constituents (Bedrock Units)

		Ca	Mg	Na	Fe	SO_4	Cl	NO_3	Alkalinity	Hardness	Spec. Cond.	pH
General Treatment Comparisons	$F_{.95}$ (5,181) = 2.26	9.34*	7.52	0.83	1.49	4.73	0.78	1.09	5.78	12.09	4.41	4.95
$F_{.95}$ (1,181) = 3.89	Basalt versus Metamorphic rocks	0.14	<1.0	0.02	2.14	0.01	0.01	2.25	0.73	0.10	0.06	7.09
	Blomidon Formation versus Wolfville Formation	28.19	16.21	0.14	<1.0	20.60	0.13	0.14	4.66	36.18	7.54	0.00
	Wolfville Formation versus Horton rocks	0.01	20.40	0.01	<1.0	0.03	0.20	1.87	0.67	0.79	0.11	0.67
	Basalt + Metamorphic versus Blomidon + Wolfville + Horton	18.04	3.51	3.54	<1.0	2.69	3.06	0.08	23.01	23.96	14.32	15.53

*Significant F values are underlined

Table 17. Values for F for the Analysis of Variance of Groundwater Chemical Constituents (Surficial Units)

		Ca	Mg	Na	Fe	SO_4	Cl	NO_3	Alkalinity	Hardness	Spec. Cond.	pH
General Treatment Comparisons												
	$F_{.95}$ (5,145) = 2.28	1.98	2.74*	7.82	1.74	19.69	6.81	3.34	1.56	2.67	4.83	1.64
$F_{.95}$ (1,145) = 3.90	All till deposits versus Sand and Gravel deposits	0.17	0.68	0.99	<1.0	1.56	0.06	1.54	1.86	0.01	0.05	0.43
	Basalt till versus Metamorphic till + Horton till	0.11	<1.0	1.11	6.3	0.59	0.03	0.46	0.50	0.00	0.19	1.42
	Basalt till + Metamorphic till + Horton till versus Blomidon till + Wolfville till	6.20	2.48	23.47	1.2	92.09	18.07	1.41	3.36	5.74	17.31	0.97
	Blomidon till versus Wolfville till	0.10	<1.0	13.01	<1.0	1.44	11.62	0.54	1.91	0.08	1.95	4.01
	Metamorphic till versus Horton till	3.30	10.52	0.51	0.8	3.03	4.39	0.27	0.18	7.52	4.70	1.36

*Significant F values are underlined

Table 18. Values for *F* for the Analysis of Variance of Groundwater Chemical Constituents (Bedrock versus Surficial Units)

	Ca	Mg	Na	Fe	SO_4	Cl	NO_3	Alkalinity	Hardness	Spec. Cond.	pH
Basalt versus Basalt till $F_{.95}$ (1,55) = 4.01	1.06	0.12	0.10	6.15*	0.00	0.03	1.49	0.01	0.55	0.10	5.41
Blomidon versus Blomidon till $F_{.95}$ (1,17) = 4.45	1.21	0.74	0.36	0.28	0.40	0.33	1.45	3.69	1.93	1.15	8.86
Wolfville versus Wolfville till $F_{.95}$ (1,113) = 3.93	0.98	0.50	0.82	0.37	1.81	0.84	1.11	0.27	0.44	0.12	0.02
Metamorphic versus Metamorphic till $F_{.95}$ (1,69) = 3.98	0.18	0.11	1.61	0.01	0.47	3.60	0.90	0.12	0.35	0.39	0.02
Horton versus Horton till $F_{.95}$ (1,17) = 4.45	2.74	3.26	2.68	0.03	4.08	2.59	0.35	6.02	2.99	3.78	4.52
Wolfville versus Sand and Gravel deposits $F_{.95}$ (1,161) = 3.90	28.73	0.29	1.99	0.46	3.68	1.93	1.15	25.63	22.93	9.85	24.30

*Significant *F* values are underlined

APPENDIX D. PUMP TEST ANALYSES

Introduction

Several pump tests were run to determine the hydraulic characteristics of various aquifers. The coefficients of transmissibility and storage are given in tables 4 and 5. As examples of the determination of T and S and other hydraulic properties, three of the pump tests are discussed in this Appendix. The various formulas and procedures have been taken almost entirely from Walton (1962). Only the formulas and variables used in this Appendix are given below. The reader is referred to Walton (1962) for a complete discussion.

Adjustment of Drawdown Data

During a pump test, water levels in the pumping well and observation wells are measured periodically according to a prescribed schedule (see, for example, Jones, 1963). Drawdowns are obtained by subtracting the water levels obtained during the pumping test from water levels that would have been observed if the well had not been pumped. Drawdowns are not measured from the "static" level measured just before the start of the test but from water level trends extrapolated from measurements made for at least 24 hours prior to the test, and preferably for a longer period. These measurements are made most conveniently with an automatic water level recorder installed on one of the wells a few days prior to the test.

In the case of the Middleton pump test, drawdown data were adjusted for the diurnal fluctuation of the nearby Annapolis River. This fluctuation caused a loading effect on the aquifer with water levels in the wells close to the river fluctuating in response to this loading. The ratio of the water level change in the well to the change in river stage is called the tidal efficiency (T.E.) and is given as:

$$T.E. = (\Delta W / \Delta R)\,100$$

where ΔW is the change in water level resulting from a change in river stage, in feet, and ΔR is the change in river stage, in feet.

Wells, particularly those in surficial aquifers, often do not penetrate the full thickness of an aquifer. In such cases, drawdowns in the pumping well and in nearby observation wells are greater than they would have been if the well were fully penetrating. Drawdowns, therefore, must be adjusted for the effects of partial penetration. This can be done for observation wells by using the following equation from Butler (1957):

$$s_{fp} = C_{po}\, s_{pp} \qquad (4)$$

where:

s_{fp} = drawdown in observation well for fully penetrating conditions, in feet

C_{po} = partial penetration constant for observation well, fraction

s_{pp} = observed drawdown for partial penetrating conditions, in feet.

For a pumping well, Butler's (1957) formula is:

$$s_{fp} = C_{pp} \; s_{pp} \qquad (5)$$

where:

s_{fp} = drawdown for pumped well for fully penetrating conditions, in feet

C_{pp} = partial penetration constant for pumped well, fraction

s_{pp} = observed drawdown for partial penetrating conditions, in feet.

The values of C_{po} and C_{pp} can be obtained from tables in Butler (1957) or Walton (1962, p. 8). To obtain these constants, one must know or assume values for 1. the distance from the pumped well to the observation well, 2. the saturated thickness of the aquifer, 3. the fractional penetration, 4. the ratio of the vertical to horizontal permeability of the aquifer, 5. the virtual radius of the cone of depression, and 6. the nominal radius of the well.

If the surficial aquifers tested had not been confined by silt and clay, drawdown data also would have been adjusted for dewatering of the aquifer.

Formulas for Determining Aquifer Characteristics

According to Hantush and Jacob (1955), drawdown data from a leaky artesian aquifer (e.g. Middleton and Tremont), where some water is derived from a confining bed, may be analyzed with the following formulas:

$$s = (114.6\ Q/T)\ W(u, r/B) \qquad (6)$$

where:

$$u = 2246\ r^2\ S/Tt \qquad (7)$$

and:

$$r/B = r/\sqrt{T/(P'/m')} \qquad (8)$$

s = drawdown in observation well, in feet
r = distance from pumped well to observation well, in feet
Q = discharge, in igpm
t = time after pumping started, in minutes
T = coefficient of transmissibility, in igpd/ft
S = coefficient of storage of aquifer, fraction
P = coefficient of vertical permeability of confining bed, in igpd/ sq. ft.
m' = thickness of confining bed through which leakage occurs, in feet,

$W(u, r/B)$ is read as the "well function for leaky artesian aquifers" (Hantush, 1956). Where there is no leakage through confining beds (r/B is zero), equation 6 reduces to:

$$s = (114.6\ Q/T)\ W(u) \qquad (9)$$

where $W(u)$ is the "well function for non-leaky artesian aquifers" (see Wenzel, 1942).

To solve these formulas, drawdowns are plotted on logarithmic paper against values of t. In addition, if data from more than one observation well are available, values of s for a particular time are plotted against r^2. These field data curves are then matched to type curves supplied in Walton (1962). A convenient point on the superposed curves (match point) is then selected and the values on the type curve plot and field data plot ($W(u, r/B)$, $1/u$, s, and t for the time-drawdown plot) are substituted into equations 6, 7, and 8 to obtain T, S, and P' (or in equations 7 and 9 to obtain just T and S).

The nonequilibrium formulas discussed above can be used to calculate the hydraulic properties of water-table aquifers if the early drawdown, data, which are affected by gravity drainage, are not used. The approximate time after pumping starts, in days, when the application of the nonequilibrium formula to the results of pumping tests under water-table conditions is justified, t_{wt}, is given by the following formula modified from Boulton (1954) by Walton (1962):

$$t_{wt} = 37.4\, S_y\, m/P \qquad (10)$$

where:

S_y = specific yield, fraction
P = coefficient of permeability, in igpd/ sq. ft.
m = saturated thickness of aquifer, in feet.

This equation is valid for observation wells which are greater than 0.2m and less than about 6 m from the pumping well.

Jacob (1946) has shown that equation 9 can be shortened to the following form where r is small and t is large:

$$T = 264\, Q/\Delta s \qquad (11)$$

where T and Q are as defined above and Δs is the drawdown difference per log cycle of time when drawdown data are plotted on an arithmetic scale versus time on a logarithmic scale. This fomula is particularly convenient for determining T from pumping well drawdown data.

As a check on the T obtained with drawdown data on a pumping well, the Theis recovery formula (Jacob, 1946) can be used:

$$T = 264\, Q/\Delta s' \qquad (12)$$

where $\Delta s'$ is the residual drawdown per log cycle of t/t' where t is the time since pumping started and t' is the time since pumping stopped, in minutes.

Boundary Conditions

The drawdown data for the Tremont pump test are complicated by the presence of a barrier boundary (a large decrease in lateral permeability). When the cone of depression reached the barrier boundary, drawdowns in the observation wells began to increase at an accelerated rate. The effect is the same as if no boundary were present and a second (image) well had been pumped at the same rate at a distance equal to twice the distance from the real pumping well to the barrier boundary. The distance from an observation well to the image can be calculated by the law of times:

$$r_i = r_p \sqrt{t_i / t_p} \qquad (13)$$

where:

r_i = distance from image well to observation well, in feet
r_p = distance from pumped well to observation well, in feet
t_p = time after pumping started, before the boundary becomes effective, for a particular drawdown to be observed, in minutes
t_i = time after pumping started, after the boundary becomes effective, when the divergence of the time-drawdown curve from the type curve, under the influence of the image well, is equal to the particular value of drawdown at t_p, in minutes.

To locate the image well, a circle is drawn about each observation well using the calculated r_i as the radius. The common point at the intersection of the arcs from three wells determines the position of the image well. The barrier boundary is located perpendicular to the line joining the image and real wells and midway between them.

Well Loss

In a pumping well, drawdown is due to aquifer loss as the water moves through the aquifer toward the well, to the effects of partial penetration, to the effects of barrier boundaries, and also to turbulent flow through screens and inside the casing (well loss). The amount of well loss can be estimated if a step-drawdown pump test is run or if drawdowns due to other factors are known.

Berwick Pump Test

A pump test was conducted at the M.W. Graves plant, Berwick (21H 2 A 38 C) in May, 1966. The aquifers are sandstones and conglomerates in the Wolfville Formation. The pumping well is screened between 204 and 214 feet and between 220 and 235 feet with a 2 inch gravel pack surrounding the screens.

During the 24 hour pump test, the pumping rate was 160 igpm. The one observation well was 264 feet away. Drawdown and recovery data for the pumping well, and drawdown data for the observation well are given in table 19. Drawdowns were measured from the top of the casing in each well because both wells flow when there is no pumping.

Time-drawdown and -recovery data for the pumping well are plotted in figure 39, and T is calculated for each case with equations 11 and 12. The scatter in the drawdown data was probably caused by slight variations in the pumping rate. These variations, however, did not affect the recovery data with the result that the slope of the recovery curve is well defined. Time-drawdown data for the observation well are given in figure 40 along with the calculations of T and S. Variations in pumping rate made the match with the type curve less reliable. There is apparently a small amount of leakage from

Table 19. Time-Drawdown Data* for Berwick Pump Test

Pumping Well		Pumping Well (Recovery)			Observation Well	
Time after Pumping started (minutes)	Drawdown (feet)	Time after Pumping started (minutes)	Time After Pumping stopped (minutes)	Residual Drawdown (feet)	Time after Pump. std. (minutes)	Drawdown (feet)
0	0	1440	00	147.51	0	0
1	118.39	1441	1		1	0.10
2	128.33	1442	2	40.00	2	0.20
3	125.44	1443	3	31.54	3	0.13
4	129.73	1444	4	25.55	4	0.34
5	125.78	1445	5	23.15	5	0.43
6	125.79	1446	6	20.67	6	0.54
7	125.14	1447	7	19.05	7	0.63
8	125.01	1448	8	19.77	8	0.83
9	125.18	1449	9	17.29	9	1.16
10	126.75	1450	10	16.32	10	1.54
15	128.34	1455	15	13.78	15	3.21
20	127.93	1460	20	12.22	20	4.10
25	127.23	1465	25	10.94	25	4.90
30	127.92	1470	30	10.00	30	5.41
40	128.80	1480	40	8.30	40	5.69
50	128.11	1490	50	7.28	50	6.36
60	130.40	1500	60	6.25	60	6.99
75	122.50	1515	75	5.10	75	7.64
90	138.40	1530	90	4.15	90	8.32
105	136.98	1545	105	3.39	105	9.20
120	137.65	1560	120	2.67	120	9.71
150	136.86	1590	150	1.44	150	10.65
180	136.38	1620	180	0.49	180	11.39
210	137.10	1640	200	0.00	210	12.02
240	136.99				240	12.53
300	137.16				270	12.05
360	140.42				300	13.36
420	141.10				330	13.75
480	141.50				360	14.16
540	145.00				420	14.85
600	144.28				480	15.36
660	144.13				540	15.82
720	145.20				600	16.36
840	145.75				660	16.69
960	146.40				720	17.00
1080	146.30				780	17.51
1205	147.20				840	17.49
1320	147.70				955	17.81
1440	147.50				1080	18.41
					1200	18.72
					1320	18.78
					1440	18.93

*Drawdowns were measured from the top of the casing of each well because both wells normally flow when there is no pumping.

confining beds because later drawdown data in figure 40 depart slightly from the nonleaky type curve; r/B is about 0.075 and P' from equation 8 is approximately 10^{-3} igpd/sq. ft. Even though P' is very small, the confining beds might yield a significant amount of water to the well over a long period of time.

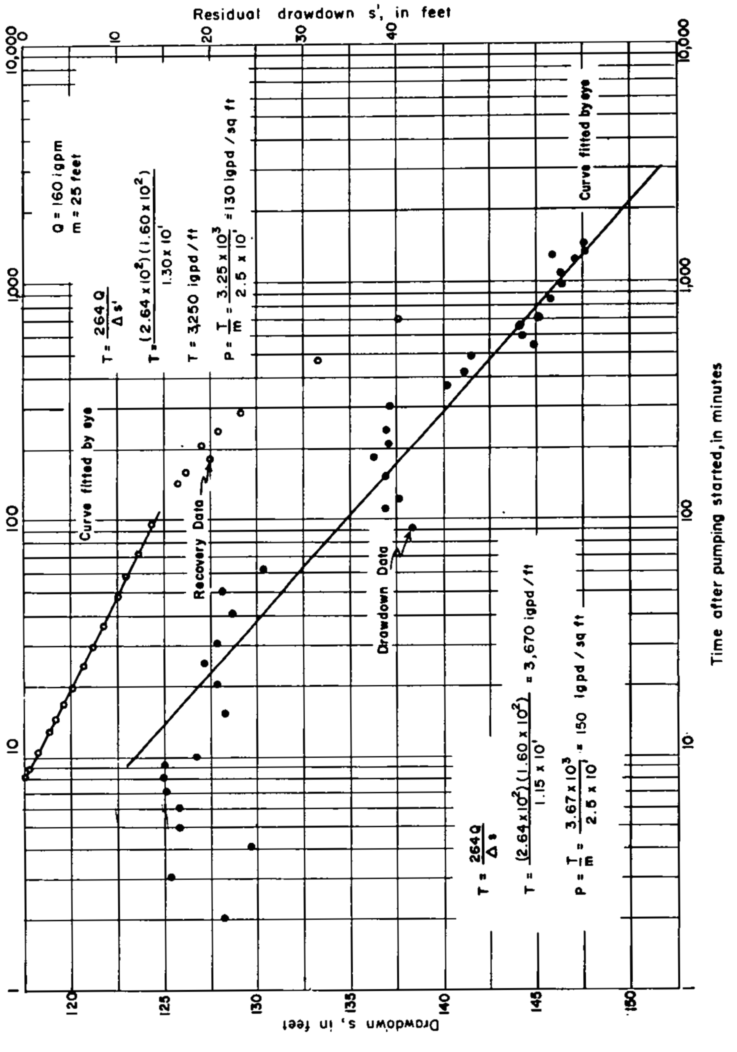


FIGURE 39. Time-drawdown and -recovery graphs for the pumping well at Berwick.

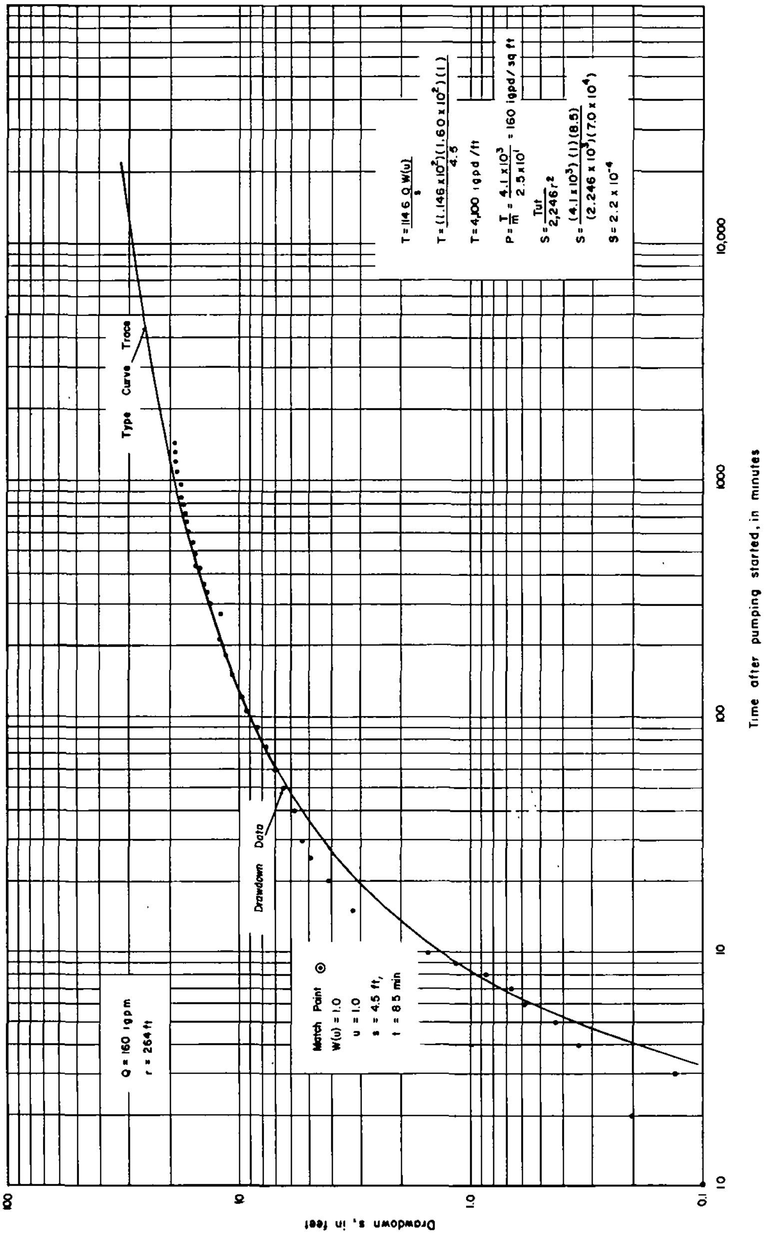


FIGURE 40. *Time-drawdown graph for the observation well at Berwick.*

The average T from the three determinations is 3,700 igpd/ft. The permeability, therefore, is about 150 igpd/ sq. ft. Using the average T in equation 7, S is 2×10^{-4}. This information can be used, for example, to determine a safe pumping rate for the well. Assuming that it is desired to pump the well continuously for 20 years, that the drawdown should not be allowed to exceed 180 feet, and that the effective radius of the well is 0.33 feet (same radius as that of the screen), the safe pumping rate is 215 igpm using equations 7 and 9, and values for $W(u)$ and u from Walton (1962). This calculation, however, has not allowed for well loss which accounts for a considerable amount of the drawdown in this well. For example, the drawdown in this well after 1 minute of pumping at 160 igpm was about 112 feet (by extrapolating the straight line in figure 39 back to 1 minute). Using T and S, the drawdown inside the casing should have been only 52 feet, leaving about 60 feet of drawdown due to well loss. With this much well loss, the safe pumping rate is reduced to about 150 igpm if the maximum drawdown is not to exceed 180 feet over a pumping period of 20 years. Note that there is a factor of safety in these calculations because leakage from the confining beds has not been considered.

If it is desired to pump both wells, the interference between wells at different pumping rates and different lengths of time can be calculated using equations 7 and 9. For example, if both of the wells in this pump test were pumped at 150 igpm for 3 months, there would be an additional drawdown in each well of 42 feet due to the pumping of the other well.

Middleton Pump Test

A pump test was conducted at Middleton in a well installed in testhole 80 (21 A 14 D 52 D) in June, 1966. The objectives of this pump test were to determine the feasibility of using Annapolis River flood plain alluvium as an aquifer and to see if water quality would be adversely affected if river water were induced into the well. The arrangement of observation wells and the logs of several of the observation wells are shown in figures 41 and 42. The aquifer is 27 feet thick and consists mostly of sand semi-confined by about 9 feet of silt and clay.

During the 26 hour pump test the pumping rate was 64 igpm. Drawdown data are given in table 20 for observation wells Nos. 2, 3, and 4. Diurnal fluctuations of the Annapolis River (due to a power station on the Nictuax River at Nictaux Falls) caused a loading effect on the aquifer near the river. Water levels in observation wells Nos. 2, 3, and 4, and the river stage were measured periodically for 2 days prior to the pump test. These observations are given in figure 43 along with the calculation of tidal efficiency which was the same for all the wells within 100 feet of the river. The tidal efficiency and the river stage hydrograph during the pump test (Fig. 43) were used to adjust drawdown data for the wells near the river. Observation well No. 5 was 600 feet from the river and was not noticeably affected by the change in river stage (Fig. 44).

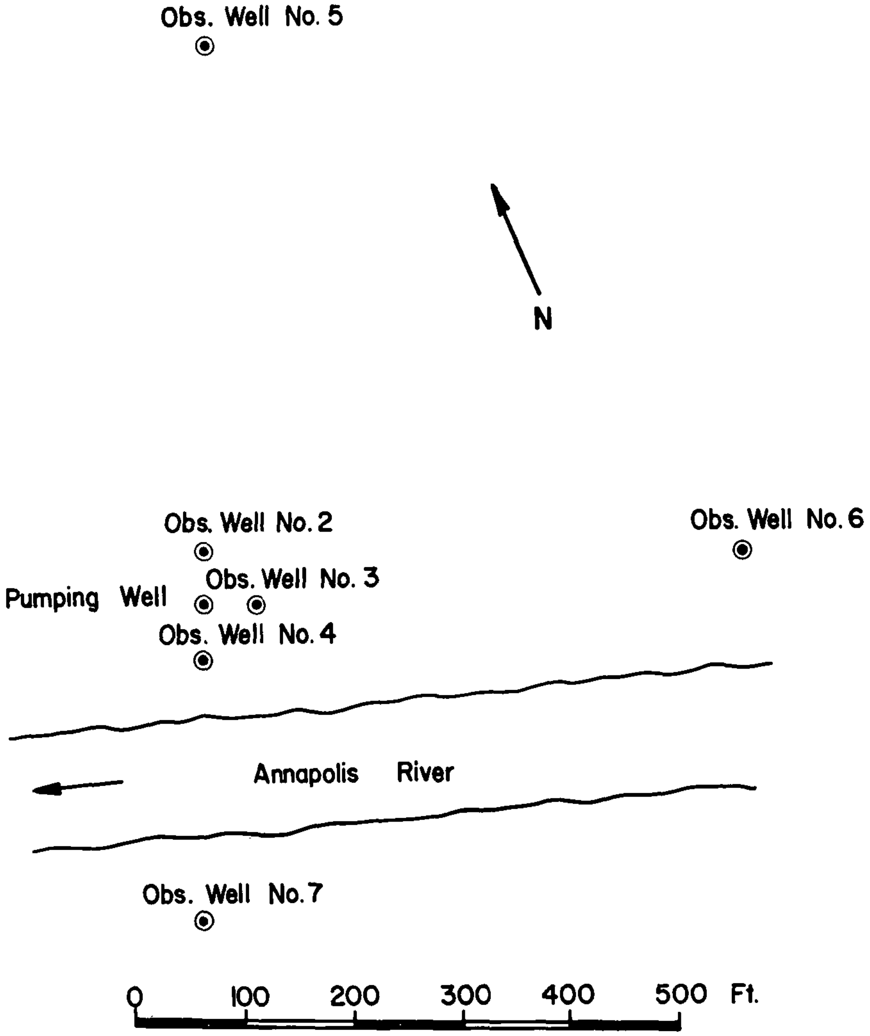


FIGURE 41. Arrangement of wells for the Middleton pump test.

The apparent groundwater recession noted during the days prior to the pump test was about 0.10 feet per day (Fig. 44). If this factor had been used to extrapolate the non-pumping water levels, the final residual drawdowns would have returned to a level above that at the start of the pump test. To avoid this, a groundwater recession of 0.04 foot per day was assumed.

The drawdown data were adjusted for partial penetration using equations 4 and 5. The major assumption made was that the ratio of the vertical to horizontal permeability is 1/10. The pumping well drawdown data were multiplied by 0.56, and the drawdown data in observation wells 2, 3, and 4 were multiplied by 0.90 to adjust for the effects of partial penetration. The more distant observation wells were not affected by partial penetration.

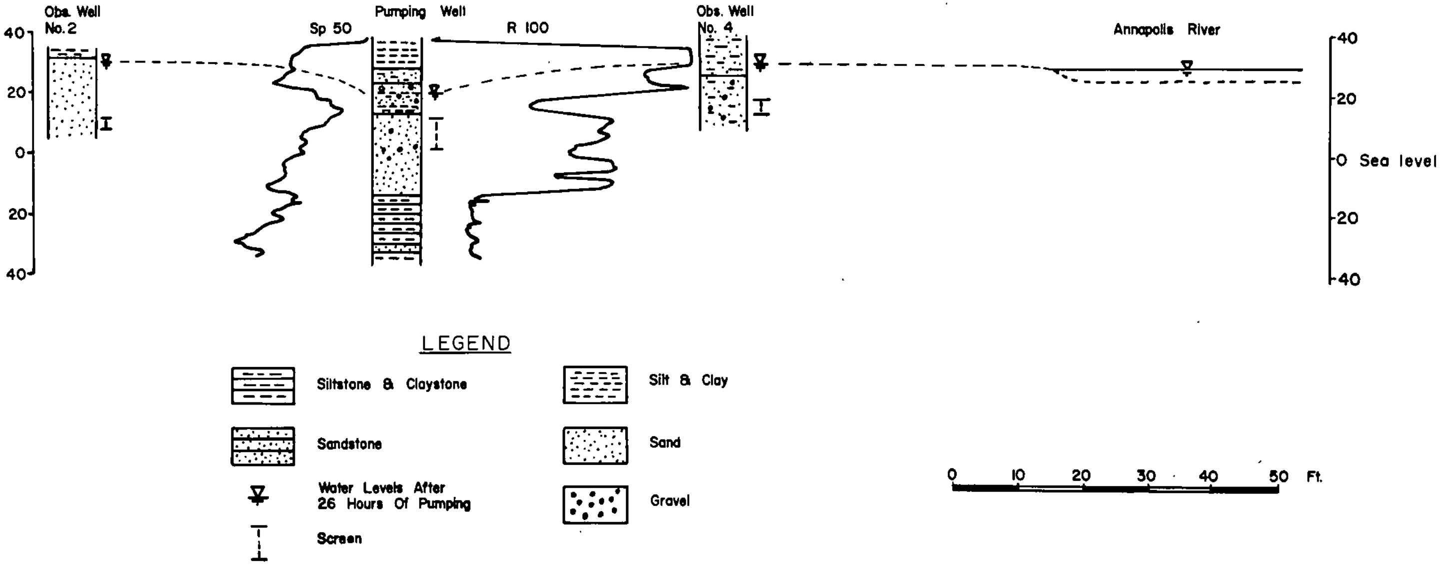


FIGURE 42. Logs for three wells, Middleton pump test.

Table 20. Time-Drawdown Data* for Middleton Pump Test

Time after Pumping started (minutes)	Drawdown in Feet		
	Obs. Well No.2	Obs. Well No.3	Obs. Well No.4
0	0.0	0.0	0.0
1	0.37	0.49	0.01
2	0.47	0.59	0.11
3	0.52	0.64	0.13
4	0.53	0.66	0.25
5	0.55	0.69	0.33
6	0.59	0.71	0.38
7	0.58	0.73	0.43
8	0.63	0.75	0.49
9	0.61	0.76	0.53
10	0.63	0.76	0.59
15	0.63	0.80	0.76
20	0.69	0.82	0.85
25	0.72	0.84	0.91
30	0.74	0.85	0.97
40	0.75	0.86	1.01
50	0.73	0.87	1.04
60	0.78	0.87	1.06
75	0.79	0.88	1.07
90	0.78	0.87	1.08
105	0.79	0.91	1.09
120	0.79	0.95	1.09
150	0.81	0.92	1.09
180	0.79	0.93	1.09
210	0.81	0.92	1.10
240	0.79	0.95	1.10
300	0.67	0.80	0.66
360	0.74	0.90	1.07
420	0.78	0.91	1.10
480	0.72	0.83	1.01
540	0.68	0.85	1.03
600	0.74	0.82	1.01
660	0.75	0.86	1.01
720	0.81	0.90	1.09
840	0.95		1.26
960	1.04	1.23(@995)	1.36
1080	1.13	1.22	1.43
1200	1.06	1.21	1.40
1320	0.91	1.06	1.26
1440	0.87	0.98	1.16
1560	0.78		

*Drawdown data have not been adjusted for groundwater recession, the effects of partial penetration, or for the river stage.

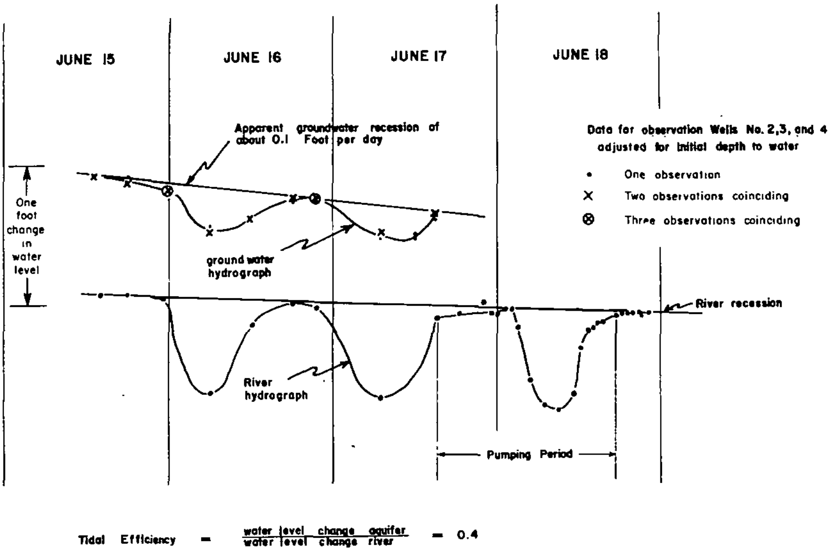
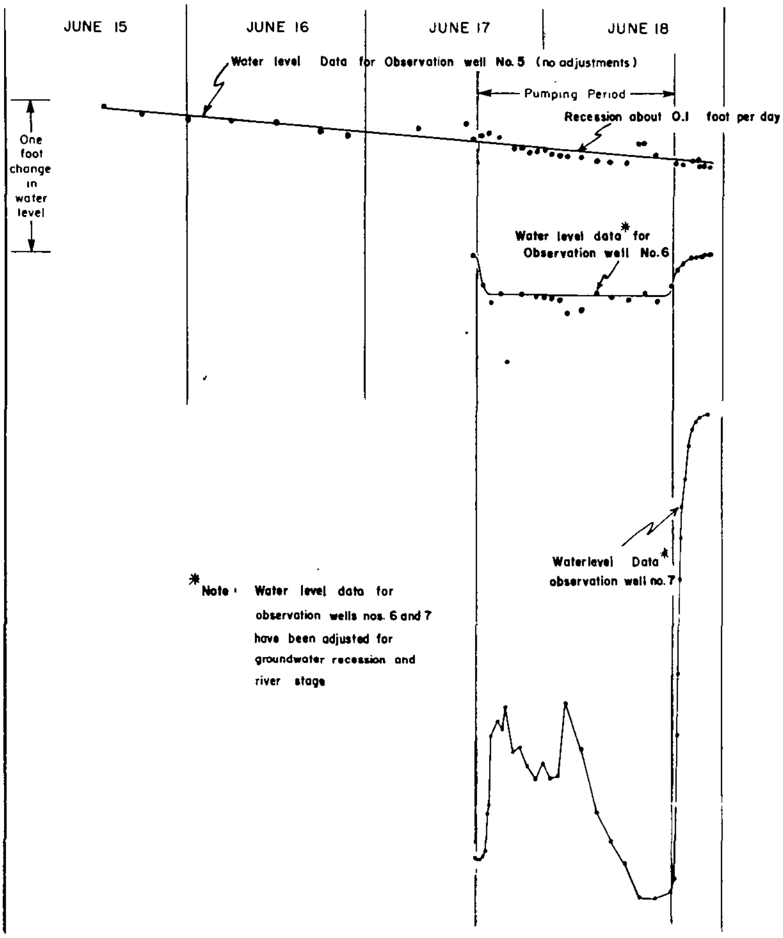


FIGURE 43. Calculation of tidal efficiency, Middleton pump test.

During the pump test, water levels in observation well No. 5 apparently were not affected by the pumping (Fig. 44). There is probably not a good hydraulic connection between this well and the pumping well because it is located across the trend of the point-bar accretions of the flood plain. Observation well No. 6, located along the trend of the point-bars from the pumping well, was affected by the pumping (Fig. 44). The hydrograph of observation well No. 7 (Fig. 44) does not seem to have been related either to the pumping or to the river stage. As a result, water level data in this well could not be used in this analysis.

The drawdown and recovery data for the pumping well are so scattered on a semi-logarithmic plot that they were not used in this analysis. Time-drawdown data for observation wells No. 2, 3, and 4 are given in figure 45. Time-drawdown data for observation well No. 4 are considerably different from data for observation wells Nos. 2 and 3. This is possibly due to the inhomogeniety of the aquifer although no boundaries were readily apparent during this 26 hour test. Distance-drawdown data for observation wells Nos. 3 and 6 are also given in figure 45.

Except for the T based on data from observation well No. 4, the T is high and averages 50,000 igpd/ft. The permeability, therefore, is about 2,000 igpd/ sq. ft. S also varies considerably, averaging 1.9 x 10^{-3}. The vertical permeability of the confining bed by equation 8 is small except for the value obtained with the data for observation well No. 4. Of the 12 feet of drawdown in the pumping well after 26 hours of pumping, about 2.5 feet are accounted for using the average T and S, about 5.5 feet are due to partial penetration of the aquifer, and the remaining 4 feet are probably due to well loss.



*Note: Water level data for observation wells nos. 6 and 7 have been adjusted for groundwater recession and river stage

FIGURE 44. Hydrographs of observation wells Nos. 5, 6, and 7 during the Middleton pump test.

As can be seen in figure 42, the cone of depression did not intercept any river water. If the screen had been set at the bottom of the aquifer and a higher pumping rate had been used, some water from the river might have been induced into the well. To be an effective recharge boundary, however, a river should penetrate the entire thickness of an aquifer. In this case, the river penetrates very little of the aquifer.

This pump test demonstrates that river alluvium and outwash sand and gravel that may underlie river alluvium are sometimes good aquifers which should be explored when considering new water supplies.

Tremont Pump Test

A pump test was conducted in a small outwash valley at Tremont (21 A 15 B 64 E). The location of wells in the valley and logs of these wells are shown in figures 46 and 47. The aquifer is about 50 feet thick and is com-

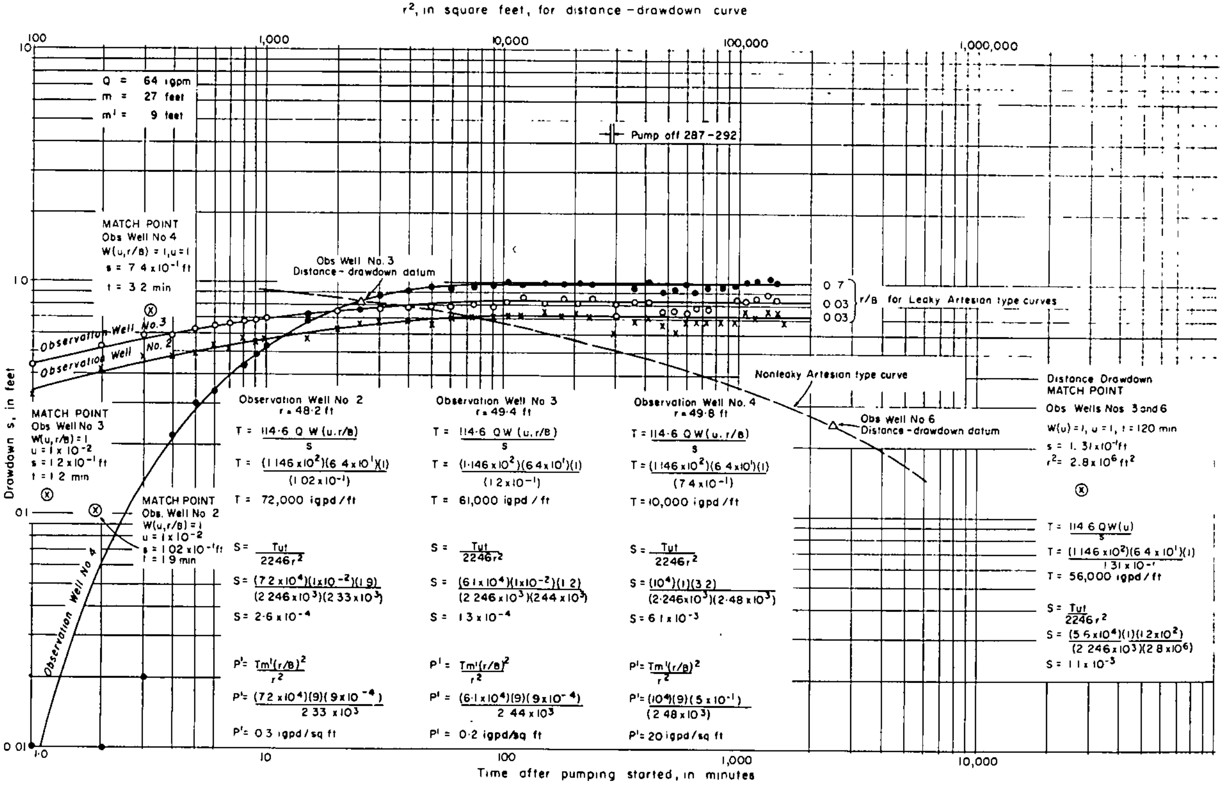


FIGURE 45. Time-drawdown graphs for observation wells Nos. 2, 3, and 4, and distance-drawdown graph for observation wells Nos. 3 and 6, Middleton.

posed predominantly of gravel with some sand, and is semi-confined by about 11 feet of silt and clay. The effect of the confining beds was demonstrated by water levels measured in observation wells Nos. 1 and 2. After sand points were installed in these holes, they were not back filled. Silt and clay, however, squeezed in around the casing because the water-table at the surface outside the casing of well No. 1 was 2 feet above the water level inside the casing; in observation well No. 2, the water-table was about 1 foot above the water level in the casing.

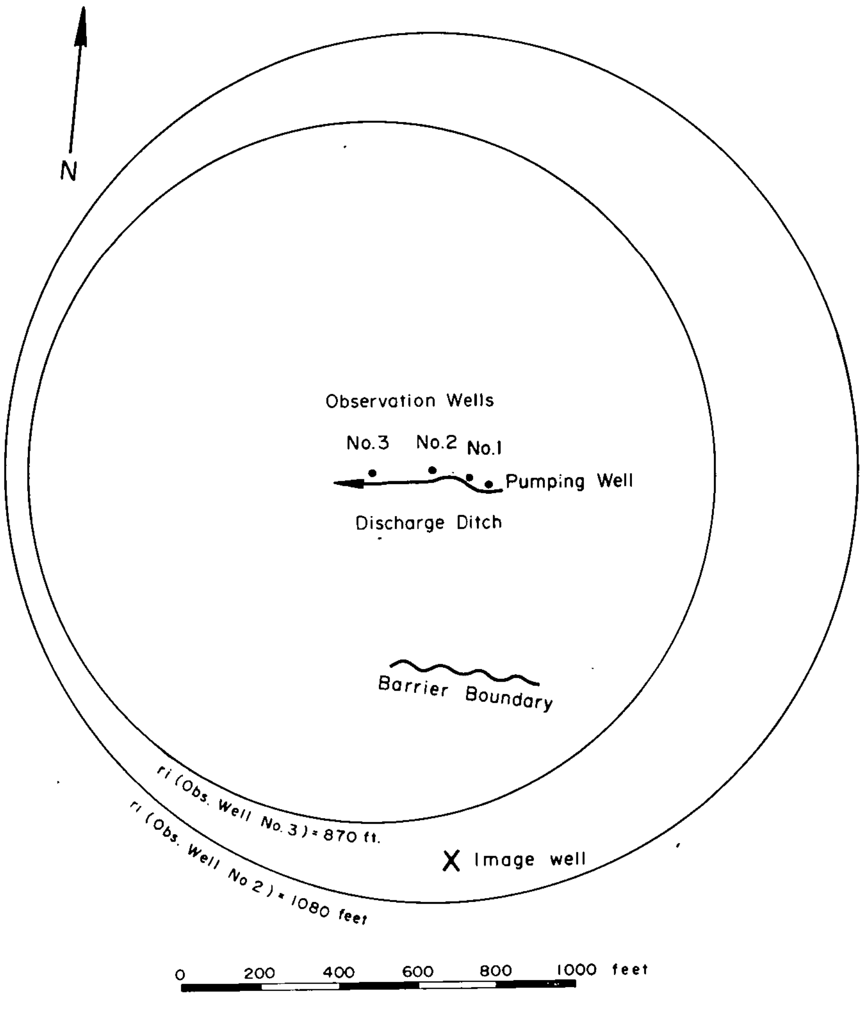


FIGURE 46. Arrangement of wells for the Tremont pump test; and location of the barrier boundary.

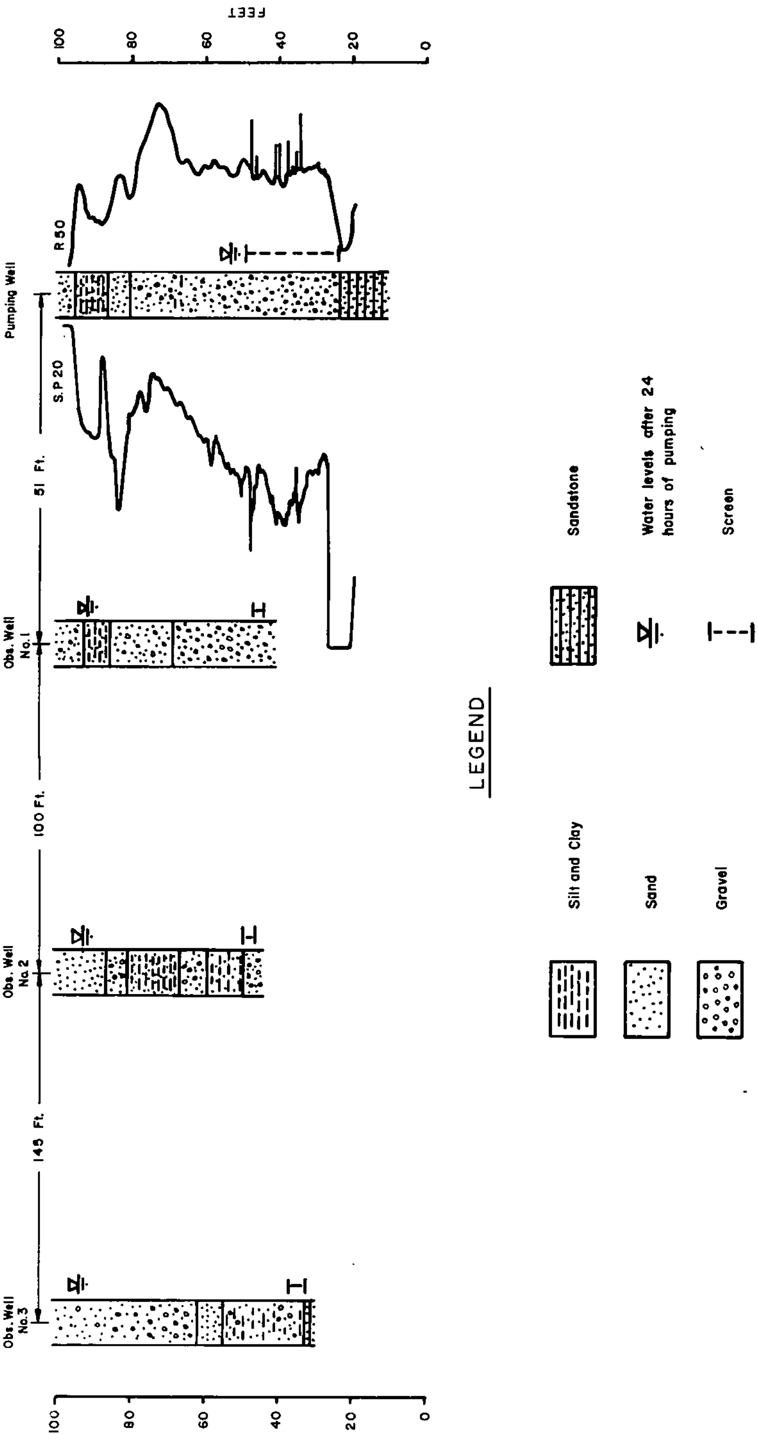


FIGURE 47. Logs of wells, Tremont pump test.

After 24 hours of pumping, the water-table in observation well No. 1 was essentially unchanged so that there was a vertical gradient of about 5 feet across the confining bed. In observation well No. 2 the water-table declined about 0.6 feet after 24 hours of pumping, but there was still a vertical gradient of about 2.8 feet. This information also demonstrates that this outwash valley is a recharge area (supported by the fact that there is no perennial stream in the valley.

The pumping rate (with a few minor adjustments) was 189 igpm for 24 hours (Fig. 48). Drawdown data for observation wells Nos. 1, 2, and 3 are given in table 21. The drawdowns were adjusted for groundwater recession which was determined to average 0.03 foot per day from continuous water level records for the 8 days prior to the pump test.

Drawdown data in the pumping well and observation well No. 1 were adjusted for partial-penetration of the aquifer using equations 4 and 5. The ratio of vertical to horizontal permeability in the aquifer was assumed to be 1/3. To adjust for the effects of partial penetration, the drawdowns in the pumping well were multiplied by 0.64, and those in observation well No. 1 were multiplied by 0.97. Observation wells Nos. 2 and 3 were too far away to have been affected by partial penetration.

Drawdown data for the pumping well were not plotted because the pumping rate was adjusted several times to avoid breaking suction. Recovery data for the pumping well were affected by the barrier boundary and leaky artesian conditions and were not used to determine T.

Time-drawdown data for observation wells Nos. 1, 2, and 3, and the calculations of T, S and P' from these data are shown in figure 49. Values of T and S based on data for observation wells Nos. 2 and 3 are nearly the same, but they do not agree with values obtained from data for observation well No. 1. As a check, T and S have been calculated from distance-drawdown data shown in figure 50. Using data for observation wells Nos. 2 and 3 only, T and S are similar to the values obtained with time-drawdown data for the same wells. Using all of the wells, however, values of T and S do not agree with the other calculations (see Fig. 50). It would appear that the best values for T and S would be obtained by averaging data for wells Nos. 2 and 3 alone. The average T is 52,000 igpd/ft and the average S is 3.1×10^{-4}. The permeability (about 1,000 igpd/sq. ft) is not as great as that calculated for the aquifer at Middleton. Sand in the interstices of the gravel probably is primarily responsible for reducing the permeability from that expected in a clean gravel.

Drawdown data for observation well No. 1 are not greater (to be expected from partial penetration effects) but less than what should have been observed using the average T and S given above (see Fig. 50). The explanation for this is not readily apparent. Possibly vertical movement of groundwater in the vicinity of the well and/or leakage from the confining bed near the well have affected the observed drawdown in well No. 1. In any case, to avoid some combination of effects (including those due to partial penetration) which may alter the observed drawdown from the theoretical, the first observation well should be at least twice the saturated thickness of the aquifer from the pumping well (see Butler, 1957).

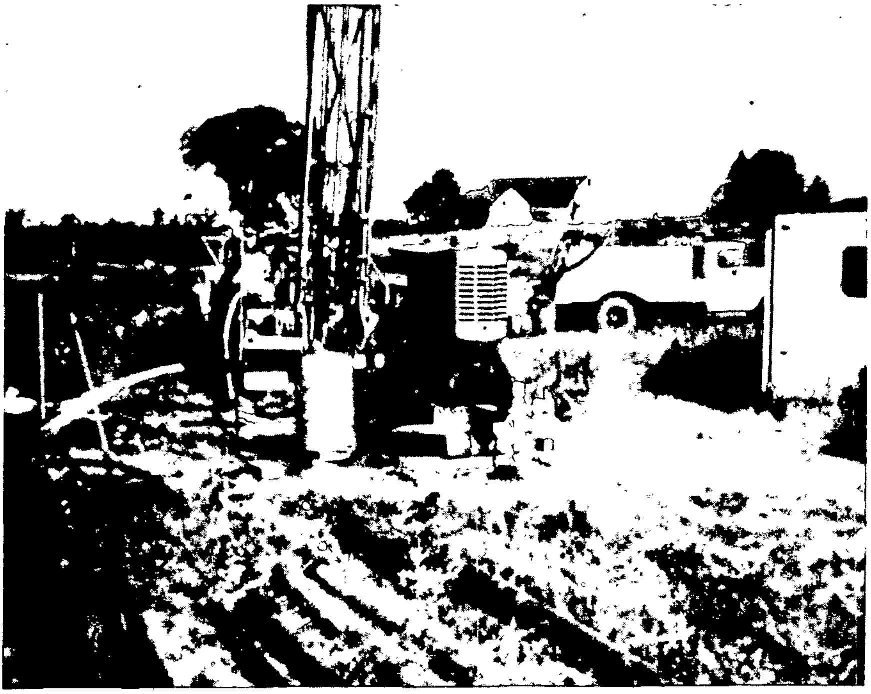


FIGURE 48. Tremont pump test.

After about 100 minutes of pumping, drawdown in all observation wells began to increase again. This may have been due either to the presence of a barrier boundary or to the existence of water-table conditions. If it were due to water-table conditions, then early time-drawdown data would have been affected by gravity drainage and the type curve should have been matched to the later time-drawdown data. By equation 10, t_{wt} is 135 minutes, assuming the specific yield is 0.10. The coefficient of storage calculated from the later time-drawdown data for wells Nos. 2 and 3 is about 2×10^{-3} which is not in the water-table range. This fact, along with evidence of confining conditions from the lithologic logs and water level observations, suggests that water-table conditions are not present and that the later increases in drawdown were due to a barrier boundary.

Assuming barrier boundary conditions, the respective type curves were matched to later time-drawdown data in figure 49. Using equation 13, the radius to the image well was calculated for observation wells Nos. 2 and 3. As can be seen in figure 46, the results are not good. This is probably due in part to the complex geology (suggested by the well logs in figure 47) and in part to the adjustments made in the pumping rate. The barrier boundary probably parallels the south side of the outwash valley because the valley

Table 21. Time-Drawdown Data for Tremont Pump Test

Time after Pumping Started (minutes)		Drawdown in Feet		Observation Well No. 3	
No. 1	No. 2	Obs. Well No.1	Obs. Well No.2	Time after Pumping Started (minutes)	Draw-down (feet)
0	0	0	0	1.5	0.12
0.35	0.33	0.29	0.15	3.0	0.24
0.73	0.67	0.53	0.26	4.5	0.44
1.08	1.00	0.77	0.38	6.0	0.52
2		1.08	0.65	7.5	0.58
3		1.22	0.75	9.0	0.62
4		1.34	0.86	10.5	0.66
5		1.43	0.94	12.0	0.69
6		1.49	1.01	13.5	0.72
7		1.55	1.07	15.0	0.74
8		1.54	1.12	21.0	0.82
9		1.62	1.16	27.0	0.85
10		1.66	1.19	30.0	0.86
15		1.75	1.29	37.0	0.92
20		1.80	1.34	45.0	0.94
25		1.77	1.35	53.0	0.98
30		1.79	1.36	60.0	0.97
40		1.84	1.42	75.0	1.05
50		1.86	1.44	90.0	1.09
60		1.88	1.51	105	1.12
75		1.94	1.55	120	1.15
90		1.98	1.60	150	1.20
105		1.97	1.62	180	1.25
120		1.98	1.63	210	1.31
150		2.01	1.68	240	1.34
180		2.05	1.72	300	1.42
210		2.12	1.76	360	1.49
240		2.20	1.83	420	1.56
300		2.22	1.89	480	1.58
360		2.29	1.92	540	1.62
420		2.35	2.01	600	1.69
480		2.43	2.06	660	1.74
540		2.40	2.10	740	1.76
600		2.45	2.14	840	1.84
660		2.55	2.17	960	1.85
720		2.54	2.19	1040	1.93
840		2.61	2.26	1200	1.98
960		2.44	2.27	1320	2.06
1080		2.68	2.33	1440	2.09
1200		2.73	2.37		
1320		2.84	2.45		
1440		2.88	2.47		

*Drawdown data have been adjusted for the groundwater recession (0.03 ft/day) but have not been adjusted for the effects of partial penetration.

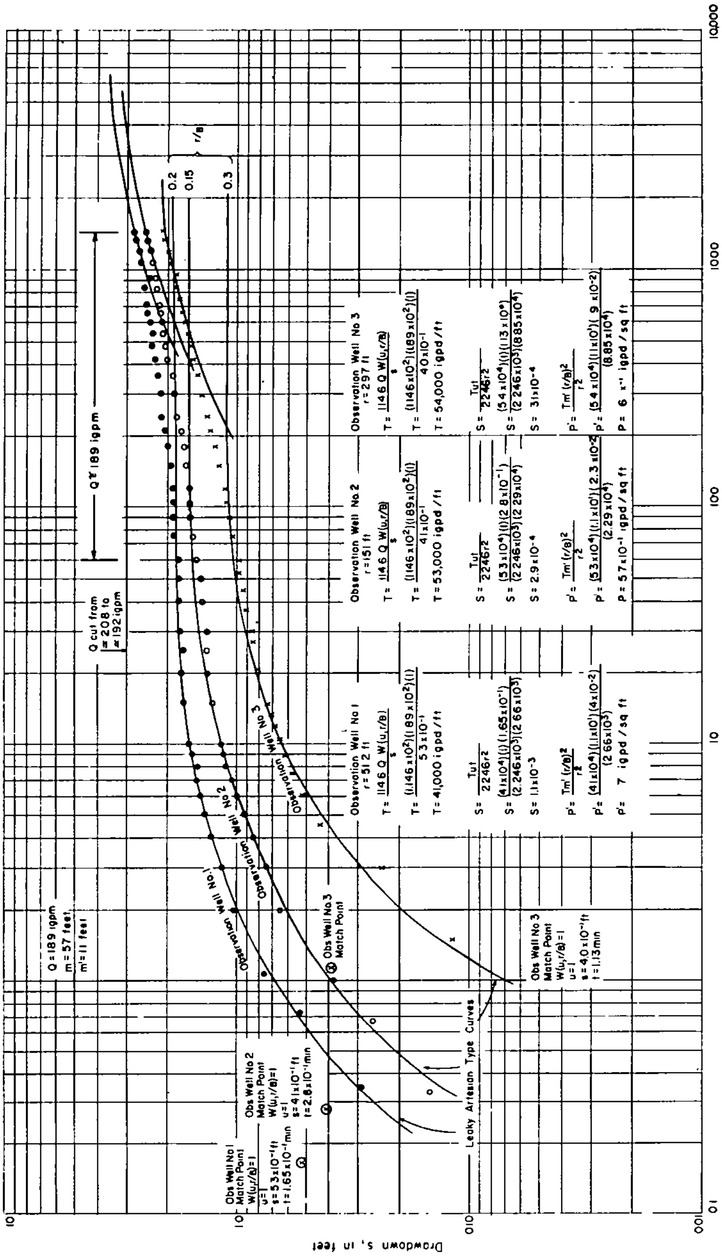


FIGURE 49. Time-drawdown graphs for observation wells 1, 2 and 3, Tremont.

follows the flank of South Mountain. Therefore, it was placed south of the pumping well and midway between the arcs drawn from wells Nos. 2 and 3.

After 24 hours of pumping, about 8 feet of drawdown in the pumping well can be considered aquifer loss; another 15 feet are due to the effects of partial penetration; about 2 feet are due to the barrier boundary; and the remaining 15 feet are probably due to well loss.

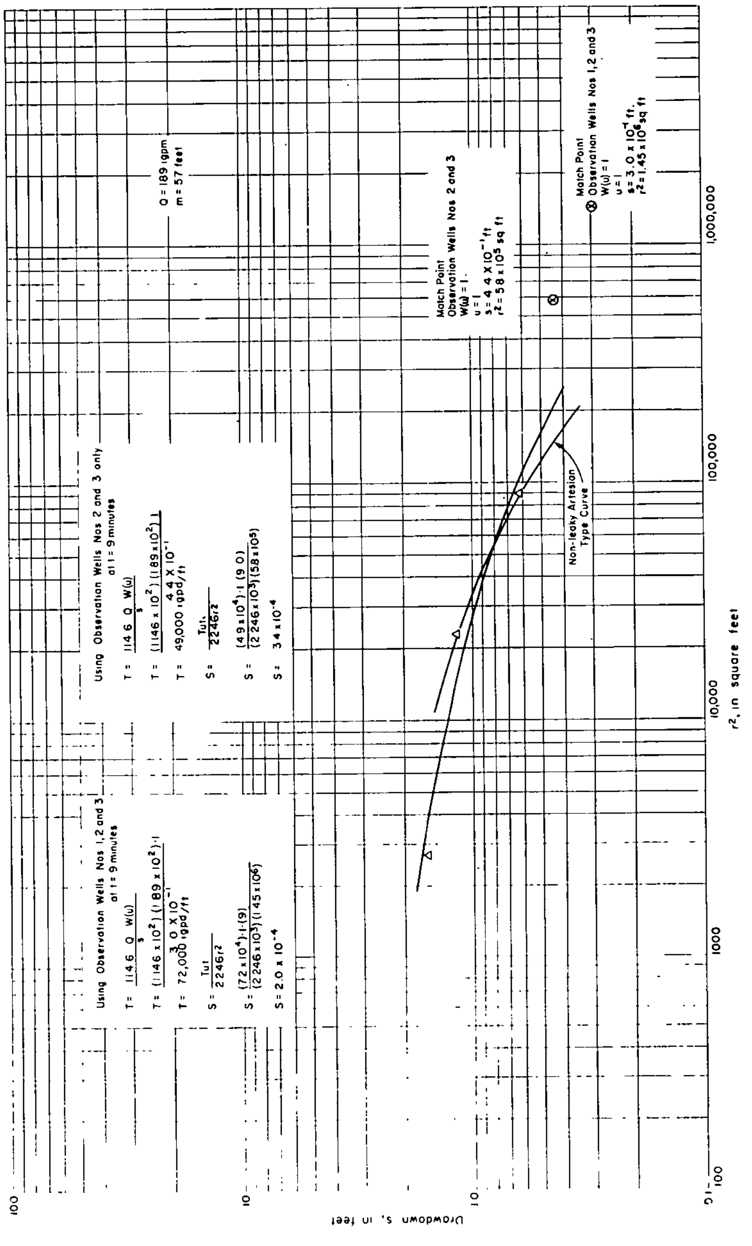


FIGURE 50. Distance-drawdown graphs for observation wells Nos. 1, 2 and 3, and for observation wells Nos. 2 and 3, Tremont.

The outwash valley aquifer at Tremont is a promising one for future development, but more test-drilling for better definition of geologic conditions and a pump test of at least three days duration should be conducted before a major development is undertaken.

APPENDIX E. CHEMICAL ANALYSES OF GROUNDWATERS IN THE ANNAPOLIS - CORNWALLIS VALLEY

						Analyses in parts per million (ppm)																		Ions in equivalents per million (epm)							
														Alkalinities										Cations			Anions				
Sample No.	Grid Location	Area	Depth of Well (feet)	Aquifer	Date Sampled	Ca	Mg	Na	Fe	Mn	SO_4	Cl	NO_3	Phenol-pthalein as $CaCO_3$	Methyl Orange	Hardness	Ignition Loss	Total Dis-solved Solids	Suspended Matter	Specific Conductance (mhos x 10^{-5})	pH	Colour	Turbidity	Ca	Mg	Na	SO_4	Cl	NO_3	SSP	SAR
1282	21A14C28E	Hampton	140	Basalt	13/9/66	19.0	1.4	8.0	0.03	T	7	12.4	T	0	72	53.2				20	8.2	<5		0.95	0.12	0.35	0.15	0.35		25	0.48
1288	21A14C61O	Young Cove	45	"	13/9/66	19.2	3.7	13.7	0.05	T	9	21.2	10	0	42	62.8			T	22	6.7	<5		0.96	0.30	0.60	0.19	0.60	0.20	32	0.76
1286	21A14C87O	Young Cove	53	"	13/9/66	16.2	3.5	17.2	1.30	0.30	4	26.6	T	0	52	54.4			T	20	6.5	<5		0.81	0.29	0.75	0.08	0.75		41	1.01
652	21H1C60L	Glenmont	40	"	28/8/64	33.2	6.9	13.6	T	T	1.9	21.3	20	0	50	111.4				28	7.4	<5		1.66	0.57	0.59	0.040	0.60	0.32	21	0.56
638	21H1C65F	Pereau	58	"	28/8/64	13.8	4.9	11.3	T	T	1.9	17.7	20	0	42	54.7				25	6.6	5		0.69	0.40	0.49	0.040	0.50	0.32	31	0.66
642	21H1C81O	Woodworth Cr.	31	"	28/8/64	39.7	8.3	15.9	T	T	2.4	24.8	20	0	82	133.7				35	6.8	10		1.98	0.68	0.69	0.50	0.70	0.33	21	0.60
649	21H1C83L	Glenmont	52	"	28/8/64	44.6	4.9	15.9	0.10	T	3.0	24.8	20	0	84	131.6				40	6.8	<5		2.22	0.40	0.69	0.06	0.70	0.32	21	0.60
648	21H1C87D	Woodworth Cr.	?	"	28/8/64	23.5	3.9	9.1	0.32	0.04	2.4	14.2	20	0	40	74.9				26	6.9	25		1.17	0.32	0.40	0.05	0.40	0.32	21	0.46
641	21H1C104H	Scott Bay Rd.	50	"	28/8/64	11.3	4.9	4.5	0.07	T	1.8	7.1	3	0	40	48.6				16	6.7	<5		0.56	0.40	0.20	0.037	0.20	0.05	17	0.29
1182	21H2B54G	Viewmont	59	"	20/8/65	28.1	4.4	11.9	0.02	0.01	10	17.7	11	0	72	88.2			T	22	6.7	<5		1.402	0.362	0.517	0.208	0.500	0.177	23	0.55
1185	21H2B78D	Victoria Harbour	47	"	20/8/65	16.8	2.9	9.5	0.02	T	10	14.2	10	0	58	54.0			T	18	6.7	<5		0.838	0.238	0.413	0.208	0.400	0.161	28	0.56
1040	21H2B87G	Morden	120	"	15/7/65	9.6	2.9	15.9	0.01	T	5	24.8	T	0	32	36.0			T	15	7.6	<5		0.479	0.238	0.692	0.104	0.699		49	1.15
1023	21H2B95J	Garland	62	"	13/7/65	48.1	10.7	37.8	0.05	0.03	17	58.7	58.7	0	44	164.7			T	46	7.8	<5		2.40	0.880	1.64	0.354	1.66	1.66	33	1.28
1024	21H2B98B	Garland	?	"	13/7/65	11.2	4.9	12.6	0.15	0.02	10	19.5	4	0	20	48.2			L	14	7.4	<5		0.559	0.403	0.548	0.208	0.550	0.065	36	0.79
1025	21H2C2B	Garland	?	"	13/7/65	11.2	0.5	12.6	0.04	T	7	19.5	T	0	16	30.0			T	11	7.7	<5		0.559	0.041	0.548	0.146	0.550		48	1.00
1026	21H2C22L	Harbourville	?	"	14/7/65	17.6	5.4	7.2	0.03	T	13	26.6	T	0	32	66.5			T	22	7.9	<5		0.878	0.444	0.313	0.271	0.750		19	0.38
1171	21H2C25C	Black Rock Lighthouse	85	"	14/8/65	15.2	3.9	9.5	T	T	10	14.2	6	0	66	54.1			T	20	7.5	<5		0.758	0.321	0.413	0.208	0.400	0.097	28	0.56
954	21H2D11L	Whites Cnrs.	50	"	20/8/65	26.9	4.4	4.8	0.07	T	10	7.1	2	0	114	85.2			T	24	7.7	<5		1.342	0.362	0.209	0.208	0.200	0.032	11	0.23
727	21H2D13L	Whites Cnrs.	60	"	22/5/65	18.4	1.5	6.3	T	T	5	9.8	10	0	26	52.0			T	14	6.9	<5		0.918	0.123	0.274	0.104	0.276	0.161	21	0.37
692	21H2D14J	Whites Cnrs.	50	"	8/9/64	30.8	2.4	5.7	0.05	T	13	8.9	12	0	86	86.9				26	7.2	25		1.54	0.20	0.23	.271	.251	.194	12	0.25
718	21H2D17F	Ross Cnrs.	25	"	22/5/65	7.2	0.5	4.5	T	T	4	7.1	2	0	16	20.0			VL	<10	6.7	<5		0.359	0.041	0.196	0.083	0.200	0.032	33	0.45
726	21H2D36D	Canada Creek	70	"	22/5/65	14.4	5.4	9.7	0.03	0.01	12	15.1	8	0	24	56.0			T	18	7.0	<5		0.719	0.444	0.422	0.250	0.426	0.129	27	0.55
691	21H2D39G	Canada Creek	50	"	9/9/64	33.2	7.2	8.5	0.05	T	18	13.3	20	0	74	112.6				28	6.8	25		1.66	0.59	0.34	.375	.375	.323	13	0.32
720	21H2D40H	Ross Cnrs.	55	"	22/5/65	6.4	4.4	5.1	0.03	0.01	7	8.0	T	0	20	32.0			T	10	6.8	<5		0.319	0.362	0.222	0.146	0.226		24	0.38
701	21H2D45G	Vernon Mines	39	"	21/5/65	28.9	5.8	6.8	0.07	T	18	10.6	15	0	44	96.3			T	24	7.0	<5		1.44	0.477	0.296	0.375	0.299	0.242	14	0.31
685	21H2D51E	West Glenmont	?	"	9/9/64	11.1	0.5	1.7	0.03	T	9	2.7	2	0	53	29.6				17	7.3	25		0.55	0.04	0.07	.187	.076	.032	11	0.13
690	21H2D56E	Chipman	96	"	9/9/64	25.3	3.4	11.9	0.06	0.03	8	18.6	15	0	57	77.0				25	6.8	25		1.26	0.28	0.48	.167	.525	.242	24	0.55
1261	21H3A3C	Prince Albert	120	"	7/9/66	16.8	1.0	3.4	0.01	T	6	5.32	T	0	82	46.0			T	19	8.0	<5		0.84	0.08	0.15	0.12	0.15		14	0.22
1260	21H3A3E	Prince Albert	72	"	7/9/66	11.4	1.0	3.4	0.08	T	9	5.3	T	0	74	32.4			T	16	7.7	<5		0.57	0.08	0.15	0.19	0.15		19	0.26
TH133	21H3A27M	Margaretsville	290	"	4/11/66	19.6	0.2	6.9	0.02	T	4	10.64	T	0	104	50.0				15	7.8	5		0.98	0.02	0.30	0.08	0.30		23	0.35
1274	21H3A48E	Margaretsville	65	"	12/9/66	16.2	1.1	6.9	0.02	T	7	10.6	8	0	48	44.8			T	18	6.9	<5		0.81	0.09	0.30	0.15	0.30	0.16	25	0.45

1273	21H3A48N	Margaretsville	95	Basalt	12/9/66	11.4	1.0	4.6	0.06	T	2	7.0	T	0	48	32.4				12	7.2	<5		0.57	0.08	0.20	0.04	0.20		24	0.35
1285	21A14C20N	Hampton	9	Basalt*	13/9/66	6.4		5.7	0.01	T	7	8.8	T	0	22	15.6			T	8	6.5	<5		0.32		0.25	0.15	0.25		44	0.62
1284	21A14C20O	Hampto	6	"	13/9/66	6.6	1.1	9.1	0.01	T	4	14.1	1	0	26	20.8			T	13	6.5	<5		0.33	0.09	0.40	0.08	0.40	0.02	49	0.87
1290	21A14C26K	Arlington W.	14	"	13/9/66	32.3	3.9	5.7	3.7	0.06	2	8.8	T	0	138	96.4			T	20	7.4	<5		1.61	0.32	0.25	0.04	0.25		11	0.25
1283	21A14C29G	Hampton	14	"	13/9/66	23.3	7.4	28.6	0.02	T	4	44.3	6	0	64	88.8			T	31	7.0	<5		1.16	0.61	1.24	0.08	1.24	0.12	41	1.32
1281	21A14C49O	Port Lorne	10	"	13/9/66	60.6	9.2	4.6	0.02	T	7	7.1	T	0	220	189.2			T	45	7.3	<5		3.02	0.76	0.20	0.15	0.20		5	0.14
653	21H1C59J	Woodside	12	"	28/8/64	5.7	2.5	1.2	T	T	1.9	1.8	T	0	24	24.3				12	6.5	20		0.28	0.21	0.05	0.040	0.05		9	0.10
639	21H1C80H	Scott Bay Rd.	10	"	28/8/64	24.3	5.4	9.1	0.09	0.08	1.5	14.2	25	0	38	83.0				25	6.5	<5		1.21	0.44	0.40	0.031	0.40	0.40	20	0.44
643	21H1C88E	Woodworth Creek	12	"	28/8/64	29.2	6.4	2.2	0.80	0.01	1.8	3.5	5	0	72	99.2				26	6.9	<5		1.48	0.53	0.09	0.037	0.098	0.08	4	0.09
647	21H1C107G	Woodworth	?	"	28/8/64	13.8	3.9	4.5	0.13	T	2.4	7.1	3	0	48	50.6				18	6.7	<5		0.69	0.32	0.20	0.05	0.20	0.16	17	0.28
955	21H2A108O	Garland	?	"	20/8/65	6.4	2.2	4.8	0.11	T	10	7.1	T	0	32	25.1			L	<10	6.6	30		0.319	0.181	0.209	0.208	0.187		30	0.42
1159	21H2B37A	Bishop Mtn.	?	"	11/8/65	20.1	1.7	7.1	1.25	0.01	5	10.6	1	0	72	57.1			L	14	8.1	15		1.003	0.140	0.309	0.104	0.300	0.016	21	0.41
1179	21H2B69K	Viewmont	12	"	20/8/65	14.4	4.1	14.3	1.20	0.03	14	21.3	2	0	64	53.1			L	21	6.3	25		0.719	0.337	0.622	0.291	0.603	0.032	37	0.85
1181	21H2B77M	Viewmont	2	"	20/8/65	3.2	1.0	4.8	0.15	0.02	5	7.1	T	0	28	12.1			L	<10	5.7	50		0.160	0.082	0.209	0.104	0.200		47	0.61
1038	21H2B89K	Victoria Harbour	31	"	15/7/65	7.2	2.4	12.5	0.10	0.02	5	19.5	T	0	18	28.0			T	<10	6.6	10		0.359	0.197	0.544	0.104	0.550		49	1.02
1028	21H2B94L	Burlington	8	"	14/7/65	25.7	5.8	23.0	0.02	0.02	20	35.5	48	0	24	88.3			T	34	7.3	<5		1.28	0.477	1.00	0.416	1.00	0.774	36	1.07
1174	21H2B101O	Victoria Harbour	13	"	20/8/65	21.6	3.9	16.6	0.02	0.02	14	24.8	10	0	64	70.0			L	26	7.1	30		1.078	0.321	0.722	0.291	0.700	0.161	34	0.86
1176	21H2B102K	Victoria Harbour	6	"	20/8/65	19.6	2.7	9.5	0.10	T	9	14.2	T	0	78	60.2			T	20	7.1	10		0.978	0.222	0.413	0.187	0.400		15	0.28
1036	21H2B103G	Victoria Harbour	12	"	15/7/65	8.0	3.9	13.6	2.9	0.05	10	21.3	T	0	24	36.0			VL	12	6.7	65		0.399	0.321	0.592	0.208	0.657		45	1.00
1033	21H2C21K	Harbourville	29	"	14/7/65	16.0	5.8	20.6	2.00	0.02	11	31.9	T	0	28	64.3			VL	22	7.7	50		0.798	0.477	0.896	0.229	0.900		41	1.12
1172	21H2C48A	Black Rock Lighthouse	6	"	14/8/65	17.2	3.9	16.6	0.22	0.02	12	24.8	10	0	102	59.0			L	30	7.8	<5		0.858	0.321	0.722	0.250	0.697	0.161	38	0.74
714	21H2D20N	Vernon Mines	10	"	22/5/65	14.4	1.5	7.9	T	T	14	12.4	12	0	24	40.0			VL	17	6.4	10		0.719	0.123	0.344	0.292	0.350	0.194	29	0.52
702	21H2D52O	Halls Harbour	20	"	21/5/65	12.8	5.8	8.5	0.08	0.01	16	13.3	12	0	16	56.0			VL	15	6.7	10		0.639	0.477	0.370	0.333	0.375	0.194	25	0.49
705	21H2D54O	Halls Harbour	?	"	21/5/65	23.2	6.8	19.8	0.43	0.02	11	31.0	T	0	50	84.3			T	31	6.7	<5		1.16	0.559	0.861	0.229	0.874		33	0.93
721	21H2D57	Huntington Pt.	15	"	22/5/65	7.2	3.9	4.5	0.15	T	5	7.1	T	0	22	32.0			VL	10	6.5	20		0.359	0.321	0.196	0.104	0.200		23	0.34
703	21H2D69M	Halls Harbour	20	"	21/5/65	8.8	2.4	7.9	0.04	0.02	16	12.4	T	0	20	30.0				14	6.7	<5		0.439	0.197	0.344	0.333	0.350		35	0.60
1255	21A14B94N	Bridgetown	?	Blomidon	1/9/66	78.2	7.8	13.7	0.01	T	23	21.2	5	0	196	226.8			T	42	7.6	<5		3.90	0.64	0.60	0.48	0.60	0.10	12	0.40
1254	21A14B99D	Bridgetown	80	"	1/9/66	43.7	1.1	8.0	0.01	T	5	12.4	4	0	110	113.6			T	24	8.1	<5		2.18	0.09	0.35	0.10	0.35	0.08	13	0.33
1302	21A14D93A	Spa Springs	spring	"	19/9/66	545.3	15.1	6.9	0.29	T	1250	10.6	T	0	88	1424.8			T	220	7.4	<5		27.2	1.24	0.30	26.02	0.30		1	0.08
1303	21A14D93A	Spa Springs	20	"	19/9/66	72.5	10.1	10.3	0.17	T	190	16.0	10	0	36	222.4			T	57	6.0	<5		3.62	0.83	0.45	3.95	0.45	0.20	9	0.30
1226	21A14D100K	Victoria Vale	113	"	25/8/66	16.8	7.6	5.7	5.00	1.0	7.0	8.8	T	0	76	73.1			T	18	6.6	50		0.84	0.63	0.25	0.15	0.25		15	0.29
1228	21A14D100P	Victoria Vale	78	"	26/8/66	19.2	1.9	8.0	0.03	T	3	12.4	2	0	62	56.1			T	22	7.3	<5		0.96	0.16	0.35	0.06	0.35	0.02	24	0.47
636	21H1C57G	Pereau	50	"	28/8/64	56.7	8.3	11.3	0.06	0.01	1.5	17.7	15	0	80	176.2				35	7.1	<5		2.83	0.68	0.49	0.031	0.50	0.24	12	0.37
595	21H2A87F	Buckley Corners	?	"	25/8/64	76.8	6.8	24.2	0.05	0.01	17	37.2	12	0	153	220.0				46	7.5	<5		3.832	0.559	1.053	0.354	1.05	0.194	19	0.71

Basalt = North Mountain Basalt   Blomidon = Blomidon Formation   *denotes till overlying this unit   T = concentration <0.01 ppm   L = low   VL = very low   SSP = soluble sodium percentage   SAR = sodium adsorption ratio

CHEMICAL ANALYSES OF GROUNDWATERS IN THE ANNAPOLIS – CORNWALLIS VALLEY CONT'D.

						Analyses in parts per million (ppm)																		Ions in equivalents per million (epm)							
														Alkalinities										Cations			Anions				
Sample No	Grid Location	Area	Depth of Well (feet)	Aquifer	Date Sampled	Ca	Mg	Na	Fe	Mn	SO_4	Cl	NO_3	Phenolphthalein as $CaCO_3$	Methyl Orange	Hardness	Ignition Loss	Total Dissolved Solids	Suspended Matter	Specific Conductance (mhos x 10^{-5})	pH	Colour	Turbidity	Ca	Mg	Na	SO_4	Cl	NO_3	SSP	SAR
694	21H2A104G	Woodville	90	Blomidon	8/9/64	87.7	3.4	11.3	0.10	T	42	17.7	20	0	143	233.1				50	7.3	25		4.38	0.28	0.46	0.874	0.499	0.323	9	0.30
693	21H2A106C	Buckley Corners	?	"	9/9/64	86.9	T	15.9	0.04	T	28	24.8	15	0	201	217.3				54	7.3	25		4.34		0.64	.583	.699	.242	13	0.43
1050	21H2B15K	N. Kingston	250?	"	16/7/65	169.9	15.6	13.6	0.10	T	400	21.3	T	0	48	489.0			T	72	7.9	< 5		8.48	1.28	0.592	8.328	0.601		6	0.27
1042	21H2B31K	Selfridge Corners	?	"	15/7/65	62.5	22.4	32.9	0.01	T	7	51.4	T	0	96	248.5			T	40	7.7	< 5		3.20	1.84	1.43	0.146	1.450		22	0.90
1049	21H2B33G	Parker Rd.	80	"	16/7/65	115.4	24.3	73.7	0.05	0.01	48	115.2	40	0	122	388.8			L	75	7.1	< 5		5.76	2.00	3.216	0.999	3.248	0.645	29	1.64
1014	21H2B52P	Weston	80?	"	13/7/65	73.1	3.9	23.0	0.04	T	23	35.5	18	6	76	200.5			T	48	8.4	< 5		3.65	0.321	1.00	0.479	1.00	0.290	20	0.71
695	21H2D22Q	Northville	70	"	21/5/65	52.9	5.8	10.2	0.02	0.01	15	16.0	15	0	76	156.3			T	38	7.7	< 5		2.64	0.477	0.444	0.312	0.451	0.292	12	0.35
629	21H1C56F	Pereau	20	Blomidon*	25/8/64	8.2	2.5	12.7	0.03	T	14	19.5	12	0	23	30.5				20	5.8	< 5		0.409	0.206	0.552	0.291	0.550	0.194	47	0.99
711	21H2A105	Buckley Cnrs.	20	"	21/5/65	43.3	5.8	6.8	0.03	0.01	42	10.6	40	0	60	132.3			T	37	6.7	< 5		2.16	0.477	0.296	0.874	0.299	0.645	10	0.26
1047	21H2B32P	Welton Cnrs.	8	"	16/7/65	10.4	2.4	11.3	T	T	3	17.7	T	0	24	36.0			T	<10	6.9	< 5		0.519	0.197	0.492	0.062	0.5000		40	0.82
677	21H2D21J	Northville	20	"	8/9/64	65.6	11.5	20.4	0.09	0.02	70	31.9	25	0	105	211.3				50	6.4	25		3.27	0.95	0.83	1.457	.900	.403	16	0.57
1251	21A14B16C	Round Hill	190	Wolfville	1/9/66	25.7	4.6	8.0	0.25	0.01	7	12.4	6	0	76	82.8			T	24	7.5	5		1.28	0.38	0.35	0.15	0.35	0.12	17	0.38
1246	21A14B16H	Round Hill	?	"	29/8/66	20.9	15.4	10.3	4.50	T	5	15.9	T	0	58	115.0			T	19	7.7	<5		1.04	1.27	0.45	0.10	0.45		16	0.42
1250	21A14B17P	Round Hill	100	"	1/9/66	13.1	0.5	3.4	1.20	T	3	5.3	1	0	50	36.4			T	14	7.2	10		0.65	0.04	0.15	0.06	0.15	0.02	18	0.26
1249	21A14B31C	Round Hill	100	"	1/9/66	21.1	1.7	3.4	0.01	T	2	5.3	T	0	70	59.6			T	19	7.7	5		1.05	0.14	0.15	0.04	0.15		11	0.19
1252	21A14B34F	Granville Centre	60	"	1/9/66	27.8	1.5	6.9	0.10	T	7	10.6	6	0	84	75.6			T	23	8.0	5		1.39	0.12	0.30	0.15	0.30	0.12	17	0.34
1253	21A14B34G	Granville Centre	173	"	1/9/66	26.5	1.0	13.7	0.15	T	6	21.2	1	4	72	70.4			T	21	8.3	<5		1.32	0.08	0.60	0.12	0.60	0.02	30	0.72
1247	21A14B42A	Bent Brook	?	"	1/9/66	8.5	0.4	6.9	0.01	T	11	10.6	4	0	26	22.8			T	14	6.0	<5		0.42	0.03	0.30	0.23	0.30	0.08	40	0.63
1248	21A14B43F	Tupperville	178	"	1/9/66	33.4	1.9	66.3	0.25	T	3	102.8	T	0	72	90.8			T	51	7.4	< 5		1.67	0.16	2.88	0.06	2.88		61	3.01
1300	21A14B43Q	Tupperville	370	"	19/9/66	139.5	4.6	304.2	0.10	T	4	471.6	T	0	40	367.2			T	280	7.5	< 5.		6.96	0.38	13.23	0.08	13.23		64	6.91
1458	21A14B44N	Tupperville	270	"	15/10/66	127.5	9.8	388.8	1.00		3	602.8	T	0	28	359.6				165	7.2	10		6.36	0.80	16.91	0.06	16.91		70	8.94
1242	21A14B69B	Bridgetown	200+	"	29/8/66	27.2	3.7	4.6	0.01	T	3	7.0	T	0	92	83.0			T	22	8.2	<5		1.36	0.30	0.20	0.06	0.20		11	0.22
1241	21A14B70F	Bridgetown	100	"	29/8/66	22.2	2.7	8.0	0.02	T	12	12.4	T	0	72	66.6			T	24	7.5	<5		1.10	0.22	0.35	0.25	0.35		21	0.43
1240	21A14B76C	Bridgetown	80	"	27/8/66	67.2	10.2	26.3	0.01	T	35	40.7	10	0	286	209.8			T	80	7.3	<5		3.35	0.84	1.14	0.73	1.15	0.20	21	0.79
1215	21A14D19P	Nictaux W.	140	"	24/8/66	126.4	6.1	152.1	0.17	T	105	235.8	T	0	196	341.7			T	120	7.4	<5		6.31	0.50	6.62	2.19	6.65		49	3.59
1204	21A14D26L	Nictaux Falls	257	"	23/8/66	8.8	0.5	6.2	0.40	T	58	9.5	T	8	86	24.0			T	34	9.2	< 5		0.44	0.04	0.27	1.21	0.27		36	0.55
1205	21A14D26N	Nictaux Falls	79	"	23/8/66	7.6	1.2	8.6	0.04	0.02	3	13.3	T	0	26	24.0			T	11	6.6	< 5		0.38	0.10	0.37	0.06	0.38		44	0.76
1207	21A14D28E	Nictaux West	125	"	23/8/66	9.2	T	25.1	0.13	0.01	65	38.1	T	0	124	23.1			T	47	8.4	<5		0.46		1.09	1.35	1.07		70	2.27
1206	21A14D28Q	Nictaux West	186	"	23/8/66	23.6	3.4	12.1	0.15	0.02	9	18.6	5	0	26	73.0			T	21	6.8	<5		1.18	0.28	0.53	0.18	0.52	0.10	27	0.62
1235	21A14D35H	Clarence	165	"	26/8/66	67.6	7.1	11.4	0.04	T	68	17.7	T	0	150	198.3			T	53	7.7	< 5		3.37	0.58	0.50	1.42	0.50		11	0.36
1203	21A14D72N	Wilmot	70	"	23/8/66	71.2	5.6	86.5	0.20	T	17	133.0	18	0	52	201.0			T	60	6.3	< 5		3.55	0.46	3.76	0.34	3.75		48	2.66

1202	21A14D72Q	Wilmot	87	Wolfville	23/8/66	22.4	0.9	4.6	0.01	0.01	6	7.1	T	0	68	60.0			T	16	7.5	5		1.12	0.07	0.20	0.12	0.20		14	0.26
1109	21A15C79O	S. Greenwood	70	"	6/8/65	20.5	0.9	7.1	0.10	0.01	15	10.6	4	0	72	55.1			T	18	7.8	<5		1.023	0.074	0.309	0.312	0.299	0.065	22	0.42
1111	21A15C80Q	Greenwood	196	"	6/8/65	15.2	1.0	7.1	0.01	T	5	10.6	4	0	88	42.1			T	21	8.2	<5		0.758	0.082	0.309	0.104	0.299	0.065	27	0.48
1062	21A15C84K	Farmington	90	"	17/7/65	16.0	1.9	103.2	T	T	4	161.3	6	0	30	48.0			T	49	8.0	<5		0.798	0.156	4.437	0.083	4.549	0.097	82	6.41
1108	21A15C101A	Millville	136	"	6/8/65	31.3	2.4	7.1	0.05	0.02	25	10.6	9	0	74	88.2			T	26	8.0	<5		1.56	0.197	0.309	0.521	0.299	0.145	15	0.33
1134	21A15C102G	Millville	195	"	11/8/65	10.0	1.0	4.8	T	T	12	7.1	T	0	50	28.1			T	11	6.7	<5		0.499	0.082	0.209	0.250	0.200		27	0.39
1059	21A15C108K	Melvern Square	80	"	17/7/65	19.2	2.4	10.2	2.50	T	9	16.0	T	0	32	58.0			VL	12	8.1	65		0.958	0.197	0.444	0.187	0.450		28	0.58
554	21H1B62C	Kentville	160	"	20/8/64	10.4	0.4	3.9	0.14	0.03	2.1	9.6	1	0	26	28.9				14	6.5	< 5		0.52	0.03	0.17	0.04	0.27	0.016	24	0.32
551	21H1B63A	New Minas	30	"	20/8/64	6.9	1.3	5.4	0.10	0.01	3.0	9.9	10	0	20	22.8				14	6.2	< 5		0.34	0.11	0.23	0.06	0.28	0.16	34	0.48
549	21H1B65K	Greenwick	40	"	20/8/64	42.0	1.6	4.0	0.03	T	1.2	13.8	5	0	67	114.1				29	7.4	< 5		2.10	0.13	0.17	0.025	0.39	0.08	7	0.16
950	21H1B81K	Port Williams	180	"	25/6/65	49.7	3.9	24.1	0.05	T	24	37.2	60	4	40	140.3			VL	24	8.6	10		2.48	0.32	1.05	0.500	1.05	0.968	27	0.89
557	21H1B82F	Port Williams	?	"	20/8/64	3.5	0.2	95.0	0.08	T	1.5	123.0	20	0	100	9.7				44	7.4	< 5		1.75	0.02	4.13	0.031	2.46	0.322	70	4.39
556	21H1B83M	Kentville	?	"	20/8/64	3.8	1.6	6.6	T	T	1.5	9.2	2	0	15	16.6				13	6.0	< 5		0.19	0.13	0.29	0.031	0.26	0.032	48	0.72
555	21H1B84L	Kentville	?	"	20/8/64	13.1	0.2	4.6	0.03	T	1.9	7.4	T	0	25	34.1				15	6.5	<5		0.65	0.02	0.20	0.040	0.21		23	0.35
581	21H1B85G	Chipman Cnr.	100	"	22/8/64	24.0	4.4	8.1	0.02	T	12	12.4	9	0	83	78.0				30	7.7	<5		1.198	0.362	0.352	0.250	0.350	0.145	18	0.40
576	21H1B88K	Port Williams	?	"	22/8/64	32.8	5.8	16.1	0.06	0.03	45	24.8	33	0	37.5	106.0				32	6.3	<5		1.64	0.477	0.700	0.937	0.699	0.532	25	0.68
610	21H1B89G	Port Williams	100?	"	25/8/64	39.1	1.5	5.8	0.04	0.02	4	8.9	5	0	102	103.5				26	7.6	<5		1.95	0.123	0.252	0.083	0.251	0.081	11	0.25
612	21H1B103H	Starr Point	?	"	25/8/64	40.8	3.9	12.7	0.07	T	35	19.5	12	0	59	117.7				32	7.5	<5		2.04	0.321	0.552	0.729	0.550	0.194	19	0.51
609	21H1B104D	Port Williams	100	"	25/8/64	4.1	0.5	3.4	0.04	T	3	5.3	1	0	154	10.2				35	9.1	<5		0.205	0.041	0.148	0.062	0.149	0.016	38	0.42
577	21H1A105D	Church Street	30+	"	22/8/64	74.2	3.9	13.8	0.45	0.03	38	21.3	36	0	122	201.0				46	7.2	<5		3.70	0.321	0.600	0.791	0.601	0.581	13	0.42
580	21H1B108L	Upper Dyke	?	"	22/8/64	73.4	2.5	8.1	0.02	T	38	12.4	9	0	131	192.9				40	7.4	<5		3.66	0.206	0.352	0.791	0.350	0.145	8	0.25
542	21H1C3L	Long Island	97	"	20/8/64	79.1	13.0	15.8	0.06	T	2.9	55.7	20	0	109	250.8				58	7.3	<5		3.95	1.07	0.69	0.060	1.57	0.32	12	0.44
613	21H1C8L	Hillaton	72	"	25/8/64	50.5	3.9	13.8	0.06	0.02	30	21.3	24	0	79	142.1				38	7.4	<5		2.52	0.321	0.600	0.625	0.601	0.388	17	50
620	21H1C9H	Hillaton	?	"	25/8/64	65.8	1.5	11.5	0.03	T	41	17.7	12	0	106.5	176.6				39	7.7	<5		3.28	0.123	0.500	0.854	0.499	0.194	13	0.38
578	21H1C10J	Canard	50+	"	22/8/64	35.1	5.9	10.4	0.04	T	36	16.0	30	0	44	109.6				29	6.3	<5		1.75	0.485	0.452	0.750	0.451	0.484	17	0.42
579	21H1C11A	Canard	100	"	22/8/64	65.2	5.9	17.3	0.05	T	22	26.6	12	0	129	186.8				42	7.3	<5		3.25	0.485	0.753	0.453	0.750	0.194	17	0.55
1H135	21H1C11M	Sheffield Mills	300	"	2/12/66	11.5	0	8.0	0.22		5	12.41	T	8.5	244	27.6				31	8.5	10		0.57	0	0.35	0.10	0.35		38	0.66
619	21H1C12L	Sheffield Mills	?	"	25/8/64	17.9	1.0	4.6	0.50	T	12	7.1	10	0	42	48.7				18	6.9	<5		0.893	0.082	0.200	0.250	0.200	0.161	17	0.29
601	21H1C13H	Sheffield Mills	40?	"	25/8/64	57.9	5.4	11.5	0.05	0.03	15	17.7	12	0	117	166.5				36	7.6	<5		2.89	0.444	0.500	0.312	0.499	0.194	13	0.39
618	21H1C14D	Sheffield Mills	125	"	25/8/64	54.6	3.4	11.5	0.17	0.02	29	17.7	14	0	99	150.2				36	7.3	<5		2.73	0.280	0.500	0.604	0.499	0.226	14	0.41
617	21H1C15E	Hillaton	?	"	25/8/64	44.8	3.9	3.4	0.12	0.01	17	5.3	5	0	100	127.9				29	7.5	<5		2.24	0.321	0.148	0.354	0.149	0.081	6	0.13
616	21H1C16K	Hillaton	50	"	25/8/64	61.9	3.4	12.7	0.06	T	30	19.5	18	0	115	168.5				42	7.4	<5		3.09	0.280	0.552	0.625	0.550	0.290	14	0.42
615	21H1C17G	Hillaton	240+	"	25/8/64	42.4	3.4	9.2	0.10	0.02	18	14.2	12	0	88	119.8				29	7.4	<5		2.12	0.280	0.400	0.375	0.400	0.194	14	0.36
614	21H1C18B	Porter Point	?	"	25/8/64	54.6	4.9	13.3	0.03	T	30	20.4	12	0	101	156.3				35	7.3	<5		2.73	0.403	0.579	0.625	0.575	0.194	16	0.46

Blomidon = Blomidon Formation   Wolfville = Wolfville Formation   *denotes till overlying this unit   T = concentration <0.01 ppm   L = low   VL = very low   SSP = soluble sodium percentage   SAR = sodium adsorption ratio

CHEMICAL ANALYSES OF GROUNDWATERS IN THE ANNAPOLIS - CORNWALLIS VALLEY CONT'D.

						Analyses in parts per million (ppm)																		Ions in equivalents per million (epm)							
														Alkalinities										Cations			Anions				
Sample No	Grid Location	Area	Depth of Well (feet)	Aquifer	Date Sampled	Ca	Mg	Na	Fe	Mn	SO_4	Cl	NO_3	Phenol-phthalein as $CaCO_3$	Methyl Orange	Hardness	Ignition Loss	Total Dissolved Solids	Suspended Matter	Specific Conductance (mhos x 10^{-5})	pH	Colour	Turbidity	Ca	Mg	Na	SO_4	Cl	NO_3	SSP	SAR
622	21H1C31K	Kingsport	?	Wolfville	25/8/64	61.1	6.9	17.9	4.50	0.07	37	27.5	22	0	121	180.7				47	6.8	<5		3.05	2.567	0.779	0.770	0.776	0.355	12	0.46
621	21H1C32A	Habitant	43	"	25/8/64	43.2	4.4	13.8	0.06	T	30	21.3	10	0	89	125.9				34	7.1	<5		2.16	0.362	0.600	0.625	0.601	0.161	19	0.54
605	21H1C33F	Canning	39	"	25/8/64	78.2	5.8	23.2	0.10	0.04	27	36.3	21	0	256	215.3				48	7.0	25		3.90	0.48	0.94	.562	1.024	.323	18	0.64
604	21H1C34P	Canning	66	"	25/8/64	41.6	2.5	11.5	0.12	T	21	17.7	12	0	73.5	117.7				30	7.1	<5		2.08	0.206	0.500	0.437	0.499	0.194	18	0.47
635	21H1C40F	Woodside	32	"	28/8/64	64.8	2.0	9.1	0.01	0.02	1.9	14.2	20	0	68	170.1				38	7.4	<5		3.23	0.16	0.39	0.040	0.40	0.32	10	0.30
628	21H1C41K	Medford	50	"	25/8/64	49.7	4.4	21.3	0.02	T	17	32.8	16	0	94.5	142.1				39	6.7	<5		2.47	0.362	0.927	0.354	0.925	0.258	25	0.78
624	21H1C43G	Kingsport	90	"	25/8/64	66.8	13.7	13.1	0.22	0.02	27	20.4	20	0	117	211.1				38	7.8	<5		3.33	1.13	0.520	0.562	0.575	0.323	10	0.35
625	21H1C54D	Medford	200	"	25/8/64	59.5	T	18.8	1.20	0.03	18	29.3	30	0	138.5	144.1				43	7.4	<5		2.97		0.818	0.375	0.826	0.484	22	0.67
573	21H2A14J	Rockland	?	"	21/8/64	36.8	3.9	6.3	0.11	T	40	9.8	15	0	45.5	108.0				29	6.5	<5		1.836	0.321	0.274	0.134	0.276	0.242	11	0.36
533	21H2A33F	Waterville	?	"	17/8/64	9.2	1.4	6.6	T	T	1.8	9.9	8	0	24	30.2				17	6.1	<5		0.46	0.12		0.037	0.28	0.129	33	0.54
574	21H2A35K	Berwick	200+	"	21/8/64	62.4	11.7	23.2	0.90	0.05	25	36.3	18	0	105	204.0				42	7.4	<5		3.114	0.962	1.009	0.133	1.02	0.290	20	0.71
585	21H2A36J	Berwick	200+	"	24/8/64	14.4	7.8	10.8	0.05	0.02	7	16.8	3	0	38.5	68.0				18	6.6	<5		0.719	0.641	0.470	0.153	0.474	0.048	26	0.57
584	21H2A37G	Berwick	600+	"	24/8/64	102.4	T	18.8	0.02	0.01	50	29.3	18	0	141	256.0				59	7.5	<5		5.110		0.818	1.01	0.826	0.290	14	0.51
583	21H2A38L	Berwick	?	"	24/8/64	40.0	3.9	6.3	0.05	0.02	21	9.8	6	0	59	116				26	7.3	<5		1.996	0.321	0.274	0.433	0.276	0.097	10	0.25
534	21H2A40K	Waterville	70	"	17/8/64	12.7	0.9	4.5	0.24	0.03	1.8	10.6	1	0	22	37.1				16	6.6	<5		0.63	0.07	0.20	0.037	0.30	0.161	22	0.34
561	21H2A53J	Coldbrook	?	"	20/8/64	6.9	0.7	4.8	0.12	0.02	2.4	8.5	2	0	18	21.5				12	6.3	<5		0.34	0.06	0.21	0.05	0.24	0.031	34	0.47
564	21H2A55C	Cambridge Sta.	100+	"	21/8/64	16.0	6.8	2.8	0.08	0.02	3	4.4	T	0	72	68.0				20	7.5	<5		0.798	0.559	0.122	0.073	0.124		8	0.15
565	21H2A56A	Cambridge Sta.	?	"	21/8/64	13.6	7.3	2.8	0.02	0.01	26	4.4	1	0	49	64.0				26	7.5	<5		0.679	0.600	0.122	0.533	0.124	0.016	9	0.15
590	21H2A58H	Waterville	?	"	25/8/64	16.8	2.4	2.8	0.50	0.18	5	4.4	T	0	51	52.0				18	7.0	15		0.838	0.197	0.122	0.113	0.124		10	0.17
591	21H2A59Q	Berwick	100	"	25/8/64	64.8	T	33.5	0.03	T	22	52.3	9	0	100	162.0				43	6.9	<5		3.233		1.457	0.453	1.48	0.145	31	1.15
586	21H2A60P	Somerset	100+	"	24/8/64	36.8	9.2	2.8	0.04	T	5	4.4	T	0	113	130.0				29	7.6	<5		1.836	7.57	0.122	0.113	0.124		4	0.10
587	21H2A61E	Somerset	?	"	24/8/64	54.4	5.3	11.5	0.02	0.01	25	17.7	18	0	117	158.0				43	7.3	<5		2.715	0.436	0.500	0.513	0.499	0.290	14	0.40
592	21H2A62F	Somerset	?	"	25/8/64	30.4	10.2	18.5	0.08	0.01	25	28.4	9	0	49	118.0				30	6.5	<5		1.517	0.839	0.805	0.513	0.801	0.145	26	0.75
59.	21H2A63K	Grafton	?	"	25/8/64	48.0	2.4	4.6	0.08	0.02	4.1	7.1	12	0	76	130.0				30	7.4	<5		2.395	0.197	0.200	0.834	0.200	0.194	7	0.18
600	21H2A64K	Kinsman Cnrs.	35	"	25/8/64	24.8	3.4	1.2	0.30	0.03	18	1.8	4	0	63	76.0				22	6.9	<5		1.238	0.280	0.052	0.375	0.051	0.065	3	0.06
665	21H2A67A	Coldbrook	140	"	9/9/64	11.1	1.9	5.7	0.13	0.02	3	8.9	T	0	56	35.6				13	7.2	25		0.55	0.16	0.23	.062	.251		24	0.39
560	21H2A69M	Brooklyn Cnrs.	?	"	30/8/64	8.5	2.4	36.0	0.02	T	1.9	47.7	T	0	61	31.2				25	7.4	<5		0.42	0.19	1.57	0.04	1.50		72	2.84
671	21H2A80G	Kinsman Cnrs.	?	"	7/9/64	34.0	1.9	6.8	0.04	T	11	10.6	T	0	93	92.8				24	7.6	25		1.70	0.16	0.28	.229	.299		13	0.29
599	21H2A81L	Grafton	40?	"	25/8/64	24.8	1.0	8.1	0.38	0.04	10	12.4	15	0	52	66.0				22	6.9	<5		1.238	0.082	0.352	0.208	0.350	0.242	21	0.43
598	21H2A82P	Grafton	?	"	25/8/64	76.8	1.0	15.0	0.04	T	4	23.0	18	0	139	196.0				44	7.3	<5		3.832	0.082	0.653	0.083	0.649	0.290	14	0.46
596	21H2A83H	Grafton	&	"	25/8/64	53.6	1.9	12.7	0.04	T	20	19.5	9	0	101	142.0				35	7.4	<5		2.675	0.156	0.552	0.416	0.550	0.145	16	0.46

709	21H2A90B	Woodville	175	Wolfville	21/5/65	77.8	2.4	18.2	0.05	0.02	37	28.4	36	0	68	204.5			T	46		<5		3.88	0.197	0.792	0.770	0.801	0.581	16	0.55
681	21H2A91L	Lakeville	?	"	8/9/64	38.7	2.4	6.8	0.04	T	21	10.6	7	0	96	106.7				26	7.9	25		1.93	0.20	0.28	.437	.299	.113	12	0.27
664	21H2A93G	Keddy Corner	112	"	7/9/64	82.2	9.6	20.4	0.08	T	28	31.9	20	0	164	244.9				50	7.6	25		4.10	0.79	0.83	.583	.900	.323	15	0.53
661	21H2A95O	Steam Mill Village	?	"	7/9/64	65.6	3.4	4.5	T	T	22	7.1	15	0	138	177.8				40	7.2	25		3.27	0.28	0.18	.458	.200	.242	5	0.14
672	21H2A97M	Steam Mill Village	129	"	7/9/64	34.8	3.8	5.7	0.08	T	17	8.9	5	0	87	102.7				24	7.2	25		1.74	0.31	0.23	.354	.251	.081	10	0.23
663	21H2A100C	Keddy Corner	100	"	8/9/64	38.7	1.0	6.8	0.05	T	10	10.6	5	0	95	100.7				24	7.3	25		1.93	0.08	0.28	.208	.299	.081	12	0.28
1002	21H2B1O	Berwick W.	180	"	13/7/65	28.9	1.0	11.5	0.02	T	2	17.7	T	2	44	76.3			T	20	8.3	<5		1.44	0.082	0.500	0.042	0.499		25	0.57
1003	21H2B2B	Factorydale	60	"	13/7/65	57.7	3.9	14.9	0.05	T	37	23.0	10	4	66	160.3			T	38	8.4	<5		2.88	0.321	0.648	0.770	0.649	0.161	17	0.51
1004	21H2B3H	Factorydale	90	"	13/7/65	37.7	2.4	13.8	T	T	3	21.3	T	2	54	104.3			T	24	8.2	<5		1.88	0.197	0.600	0.062	0.601		22	0.59
1073	21H2B4F	Millville	140	"	17/7/65	24.0	2.9	11.3	T	T	3	17.7	T	0	30	72.3			T	12	7.2	<5		1.20	0.238	0.492	0.062	0.500		25	0.58
1069	21H2B7H	Auburn	121	"	17/7/65	22.4	2.9	18.2	0.05	0.02	5	28.4	12	0	24	68.3			T	18	8.0	<5		1.12	0.238	0.792	0.104	0.801	0.194	37	0.96
1055	21H2B9O	N. Kingston	65	"	17/7/65	104.2	21.4	14.7	4.00	1.1	290	23.0	T	0	58	348.8			VL	55	7.3	100		5.20	1.76	0.640	6.037	0.849		8	0.34
1051	21H2B10E	N. Kingston	65	"	16/7/65	48.1	8.8	14.7	T	0.03	33	23.0	T	0	66	156.3			T	28	7.9	<5		2.40	0.724	0.640	0.687	0.649		17	0.51
1053	21H2B17P	Auburn	45	"	17/7/65	48.1	14.6	19.3	T	T	50	30.1	15	0	58	180.3			T	34	7.0	<5		2.40	1.20	0.840	1.041	0.849	0.242	19	0.63
1005	21H2B22E	Auburn	117	"	13/7/65	7.2	1.5	10.4	0.02	T	4	16.0	T	0	14	24.0			T	< 10	7.8	<5		0.359	0.123	0.452	0.083	0.451		48	0.92
1001	21H2B23H	Berwick W.	110	"	13/7/65	20.8	3.9	10.4	0.03	T	4	16.0	T	0	28	68.3			T	15	8.2	<5		1.04	0.321	0.452	0.083	0.451		25	0.55
1020	21H2B25B	Berwick W.	85	"	13/7/65	17.6	2.9	24.1	0.02	0.02	6	37.2	12	0	12	56.4			T	18	7.4	<5		0.878	0.239	0.001	0.125	1.05	0.194	48	1.40
1007	21H2B26O	Berwick W.	110	"	13/7/65	89.7	6.8	19.5	0.15	T	31	30.1	20	2	42	252.5			T	50	8.2	<5		4.48	0.559	0.848	0.645	0.849	0.323	14	0.54
1052	21H2B30K	Selfridge Cnrs.	?	"	17/7/65	62.5	1.9	14.7	0.01	T	14	23.0	12	0	66	164.3			T	32	7.5	<5		3.12	0.156	0.640	0.291	0.649	0.194	16	0.50
1015	21H2B45G	Dempsey	32	"	13/7/65	60.9	8.8	41.3	0.02	0.05	45	63.8	45	0	76	188.5			VL	72	7.6	30		3.04	0.724	1.80	0.937	1.80	0.726	32	1.31
1013	21H2B46O	Weston	?	"	13/7/65	48.1	2.9	16.1	0.03	0.02	17	24.8	16	2	42	132.3			T	30	8.2	<5		2.40	0.239	0.700	0.354	0.699	0.258	21	0.61
1022	21H2B48K	Somerset	100?	"	13/7/65	44.9	1.9	12.6	1.00	0.05	4	19.5	T	2	70	120.3			T	37	8.1	200		2.24	0.156	0.548	0.083	0.550		19	0.50
1021	21H2B49L	Somerset	150	"	13/7/65	49.7	3.9	18.4	T	T	14	28.4	14	2	58	140.3			T	34	8.4	<5		2.48	0.321	0.800	0.292	0.801	0.226	22	0.68
1012	21H2B51H	Weston	?	"	13/7/65	0.8	0.5	23.0	0.10	T	8	35.5	22	4	92	4.0			T	45	8.3	<5		0.040	0.041	1.00	0.167	1.00	0.355	93	5.00
676	21H2D23D	Centreville	90	"	8/9/64	28.4	0.5	6.8	0.10	0.04	5	10.6	T	0	79	73.1				22	6.9	25		1.42	0.04	0.28	.003	.104	.299	16	0.33
541	21H1C4J	Evangeline Beach	?	Wolfville*	20/8/64	13.9	6.2	158.0	0.25	0.05	3.2	24.5	T	0	207	60.3				70	7.8	<5		0.69	0.51	6.87	0.66	6.9		85	8.87
627	21H1C42A	Kingston	30	"	25/8/64	50.5	8.8	13.8	0.06	0.01	78	21.3	30	0	106	162.4				46	7.5	<5		2.52	0.724	0.600	1.62	0.601	0.484	16	0.47
626	21H1C42P	Medford	25	"	25/8/64	14.4	3.4	5.8	0.01	T	33	8.9	9	0	38	50.0				22	7.1	<5		0.719	0.280	0.252	0.687	0.251	0.145	20	0.35
680	21H2A101G	Lakeville	20	"	8/9/64	44.2	2.4	6.8	0.06	0.02	28	10.6	15	0	93	120.5				30	7.6	25		2.21	0.20	0.28	.583	.299	.242	10	0.26
1008	21H1B50G	Weston	?	"	13/7/65	19.2	6.8	28.7	0.04	T	25	44.3	20	0	10	76.3			T	30	6.7	<5		0.958	0.559	1.25	0.521	1.25	0.323	45	1.43
1292	21A14A91O	Inglisville	65	Metamorphic	13/9/66	31.4	3.1	14.9	2.7	0.20	19	23.0	T	0	86	91.2			T	29	6.9	<5		1.57	0.25	0.65	0.40	0.65		26	0.68
1236	21A14D23K	Nictaux Falls	50	"	26/8/66	27.2	5.3	9.1	0.47	0.1	17	14.1	T	0	74	90.1			T	26	6.8	<5		1.36	0.44	0.40	0.35	0.40		18	0.42
1212	21A14D26H	Nictuax Falls	275	"	24/8/66	32.8	4.9	16.1	0.07	T	4.0	24.8	T	0	138	102.2			T	26	7.9	5		1.64	0.40	0.70	0.08	0.70		26	0.69
1123	21A15C38P	Torbrook	100+	"	6/8/65	10.4	3.6	9.5	0.02	0.01	15	14.2	2	0	52	41.1			T	14	7.6	5		0.519	0.296	0.413	0.312	0.398	0.032	33	0.64

Wolfville = Wolfville Formation   Metamorphic = metamorphic rocks   *denotes till overlying this unit   T = concentration <0.01 ppm   VL = very low   SSP = soluble sodium percentage   SAR = sodium adsorption ratio

CHEMICAL ANALYSES OF GROUNDWATERS IN THE ANNAPOLIS – CORNWALLIS VALLEY CONT'D.

						Analyses in parts per million (ppm)																		Ions in equivalents per million (epm)							
														Alkalinities										Cations			Anions				
Sample No.	Grid Location	Area	Depth of Well (feet)	Aquifer	Date Sampled	Ca	Mg	Na	Fe	Mn	SO_4	Cl	NO_3	Phenol-pthalein as $CaCO_3$	Methyl Orange	Hardness	Ignition Loss	Total Dis-solved Solids	Suspended Matter	Specific Conductance (mhos x 10^{-5})	pH	Colour	Turbidity	Ca	Mg	Na	SO_4	Cl	NO_3	SSP	SAR
1137	21A15C79G	Harmony	30	Metamorphic	11/8/65	35.3	6.6	17.7	T	T	15	24.8	15	0	82	115.3			T	34	7.8	<5		1.761	0.543	0.770	0.312	0.697	0.242	25	0.72
1078	21A15C97G	Morristown	114	"	17/7/65	22.4	7.8	18.2	T	T	14	28.4	8	0	26	88.3			T	18	6.8	<5		1.12	0.641	0.818	0.291	0.801	0.129	32	0.87
271	21H1B4L	Etna	180	"	18/8/64	12.3	8.1	2.6	0.02	T	2.5	6.7	T	0	30	63.9				17	7.3	5		0.61	0.67	0.11	0.052	0.19		8	0.14
101	21H1B9J	Vesuvius	50	"	19/8/64	15.1	4.7	5.4	0.17	0.03	4.1	7.8	T	0	41	57.2				20	6.9	<5		0.75	0.39	0.23	0.085	0.22		17	0.30
2	21H1B13E	New Canaan	67	"	19/8/64	44.3	T	2.0	0.03	T	3.2	9.2	T	0	78	113.0				30	7.2	<5		2.21		0.09	0.066	0.26		4	0.09
11	21H1B36G	New Canaan	120+	"	29/7/64	5.6	6.3	6.5	0.05	0.47	4.0	10.0	15.0	0	16	40.1	18	72	5	16	5.9	<5		0.28	0.52	0.28	0.08	.28	0.241	26	0.44
49	21H1B38L	New Minas	75	"	29/7/64	9.6	2.4	7.0	0.45	0.10	T	12	8	0	34	34.1	30	76	12	18	7	10		0.48	0.20	0.30		0.35	0.129	31	0.51
59	21H1B40J	White Rock	60	"	28/5/64	5	0.3	9.8	0.03	0.12	2.9	21	15	0	8	18	36	104	3	15	5.7			0.25	0.25	0.43	0.060	0.59	0.24	46	0.86
136	21H1B56B	White Rock	83	"	3/6/64	7	0.9	6.2	0.03	0.06	1.9	26	6	0	16	32	22	96	0	15	6.6			0.35	0.074	0.27	0.40	0.73	0.10	39	0.59
71	21H1B64A	Greenwick	85	"	29/5/64	14	1.2	5.4	0.12	0.03	3.4	17	15	0	34	54	38	124	2	18	7.6			0.70	0.099	0.23	0.071	0.48	0.24	22	0.36
547	21H1B67J	Wolfville	50	"	20/8/64	8.5	5.2	5.2	2.20	0.38	1.5	17.7	T	0	23	42.9				16	5.8	<5		0.42	0.43	0.23	0.031	0.50		21	0.35
461	21H2A4K	McGee Lake	71	"	26/6/64	3	1.2	5.7	0.45	0.24	3.4	32	2	0		28	26	95	21	20	3.7			0.15	0.099	0.25	0.071	0.90	0.03	50	0.71
532	21H2A16K	Lloyds	45	"	13/8/64	6.4	2.4	3.4	0.08	T	2.4	6.0	1	0	20	26	28	50	8	12	6.7	<5		0.32	0.20	0.15	0.05	0.17	0.02	22	0.29
440	21H2A23M	S. Alton	53	"	25/6/64	3	1.3	44	0.07	0.02	3.8	20	5	0	16	30	28	78	5	11	6.0			0.15	0.107	0.19	0.079	0.56	0.08	42	0.53
497	21H2A28G	English Mtn.	76	"	6/7/64	5	0.7	6.1	0.12	0.02	3.4	20	15	0	10	24	46	120	0	15	6.1			0.25	0.058	0.27	0.071	0.56	0.24	47	0.69
1237	21A14A101A	Inglisville	13	Metamorphic	26/8/66	3.1	0.3	4.6	3.5	T	3	7.0	T	0	14	9.7			T	4	5.8	<5		0.15	0.025	0.20	0.06	0.20		53	0.67
1294	21A14A101C	Inglisville	15	"	13/9/66	4.5	0.3	3.4	3.70	T	3	5.3	T	0	14	12.4			T	1	6.4	<5		0.22	0.025	0.15	0.06	0.15		38	0.42
1276	21A14D1H	Bloomington	7	"	12/9/66	20.6	1.9	3.4	0.02	T	3	5.3	T	0	60	59.2				15	7.2	<5		1.03	0.16	0.15	0.06	0.15		11	0.19
1275	21A14D1P	Bloomington	16	"	12/9/66	66.6	4.3	4.6	0.01	T	33	7.0	2	0	160	183.6			T	38	7.2	<5		3.32	0.35	0.20	0.69	0.20	0.04	5	0.15
1151	21A15C35P	Torbrook	10	"	13/8/65	22.1	3.9	9.5	0.10	T	15	14.2	T	0	100	71.0			T	26	7.1	<5		1.103	0.321	0.413	0.316	0.398		22	0.49
1157	21A15C36F	Torbrook	7	"	11/8/65	50.5	4.6	14.3	0.05	0.01	18	21.3	T	0	158	145.4			T	38	7.7	<5		2.520	0.378	0.622	0.374	0.598	T	18	0.52
1150	21A15C39C	Torbrook	12	"	11/8/65	10.0	3.2	7.1	0.10	0.03	12	10.6	T	0	52	38.1			T	14	6.9	<5		0.499	0.263	0.309	0.250	0.299		29	0.50
1147	21A15C40M	S. Tremont	7	"	11/8/65	14.4	4.1	7.1	0.15	0.04	12	10.6	T	0	50	53.1			T	14	6.3	<5		0.719	0.337	0.309	0.250	0.299		23	0.43
1146	21A15C41L	S. Tremont	14	"	11/8/65	31.3	4.9	11.9	0.03	T	12	17.7	14	0	98	102.3			T	31	7.1	<5		1.562	0.403	0.518	0.250	0.500	0.226	21	0.52
1145	21A15C56C	S. Tremont	10	"	11/8/65	24.1	2.9	4.8	1.0	0.10	25	7.1	T	0	72	72.2			T	22	7.4	<5		1.202	0.238	0.209	0.521	0.200		13	0.25
1144	21A15C57G	S. Tremont	9	"	11/8/65	29.7	3.9	9.5	0.28	0.02	10	14.2	2	0	108	90.6			T	28	7.6	<5		1.482	0.321	0.413	0.208	0.398	0.032	19	0.43
1156	21A15C58F	Torbrook	26	"	13/8/65	42.1	5.3	23.8	0.04	T	10	35.5	10	0	116	127.1			T	38	8.3	<5		2.101	0.436	1.035	0.208	0.999	0.161	29	0.92
1142	21A15C66K	Harmony	10	"	11/8/65	16.8	3.2	7.1	0.02	0.01	15	10.6	3	0	54	55.1			T	19	7.0	<5		0.838	0.263	0.309	0.312	0.299	0.048	22	0.42
1141	21A15C67N	Harmony	11	"	11/8/65	28.9	3.9	9.5	0.10	T	15	14.2	3	0	94	88.2			T	24	7.9	<5		1.442	0.321	0.413	0.312	0.398	0.048	19	0.44
1127	21A15C75O	Nicholsville	14	"	11/8/65	3.2	T	4.8	0.02	0.02	5	7.1	T	0	30	8.0			T	<10	6.1	<5		0.160		0.209	0.104	0.200		57	0.74
1131	21A15C76N	Nicholsville	10	"	11/8/65	5.6	2.4	9.5	0.02	T	7	14.2	T	0	34	24.1			T	<10	6.0	<5		0.279	0.197	0.413	0.146	0.299		46	0.84

1133	21A15C77O	Harmony	8	Metamorphic	11/8/65	23.6	3.2	4.8	0.17	0.02	9	7.1	T	0	112	72.2			T	22	7.3	< 5		1.178	.263	0.209	0.187	0.200		13	0.25
1138	21A15C78B	Harmony	6	*	11/8/65	7.2	2.7	7.1	0.80	0.25	12	10.6	6	0	40	29.1			T	12	7.1	5		0.359	0.222	0.309	0.250	0.299	0.097	35	0.58
1130	21A15C93B	Nicholsville	11	*	11/8/65	5.2	1.2	7.1	0.22	T	12	10.6	T	0	46	19.0			T	<10	7.0	<5		0.259	0.099	0.309	0.250	0.299		45	0.71
1129	21A15C94K	Nicholsville	17	*	11/8/65	5.6	1.9	7.1	0.06	0.02	12	10.6	T	0	34	22.1			T	<10	6.3	<5		0.279	0.156	0.309	0.250	0.299		41	0.66
1128	21A15C99D	Millville	7	*	11/8/65	5.6	1.9	9.5	0.07	0.04	10	14.2	T	0	42	22.1			T	10	6.8	<5		0.279	0.156	0.413	0.208	0.398		48	0.87
275	21H1B3C	Etna	15	*	18/8/64	11 7	2.0	3.5	0.02	T	2.8	6.4	4	0	28	37.5				16	6.4	<5		0.58	0.16	0.15	0.058	0.18	0.06	17	0.25
269	21H1B5K	Etna	9	*	18/8/64	3.5	1.8	4.3	0.40	0.06	2.7	5.7	T	0	10	16.4				10	6.0	<5		0.17	0.15	0.19	0.056	0.16		37	0.48
268	21H1B6K	Davison Street	9	*	18/8/64	7.3	3.9	6.2	0.07	0.02	3.8	9.9	15	0	20	34.7				20	6.1	<5		0.36	0.32	0.27	0.079	0.28	0.24	28	0.46
216	21H1B7H	Davison Street	14	*	18/8/64	4.6	2.6	2.9	0.04	T	3.2	7.1	T	0	13	22.1				12	5.9	<5		0.23	0.21	0.13	0.066	0.20		23	0.28
140	21H1B8O	Vesuvius	9	*	19/8/64	2.3	1.4	2.0	0.20	0.08	3.2	6.4	5	0	14	11.4				9	5.7	<5		0.11	0.12	0.09	0.066	0.18	0.113	28	0.26
90	21H1B10A	Vesuvius	11	*	19/8/64	3.9	3.7	5.4	0.08	0.01	2.8	9.9	T	0	16	24.8				14	6.0	<5		0.19	0.30	0.23	0.058	0.28		32	0.46
95	21H1B15J	White Rock	17	*	19/8/64	8.5	3.3	2.6	0.13	0.04	3.1	12.1	7	0	26	34.7				15	6.4	<5		0.42	0.27	0.11	0.064	0.34	0.113	14	0.19
109	21H1B17N	White Rock	20	*	19/8/64	22.3	1.6	16.4	0.08	0.02	3.6	25	25	0	25	62.4				32	5.9	<5		1.11	0.13	0.71	0.075	0.72	0.40	36	0.90
193	21H1B18P	Newtonville	17	"	18/8/64	7.3	4.7	4.8	0.05	0.01	3.0	6.0	T	0	21	37.5				12	6.5	<5		0.36	0.39	0.21	0.062	0.17		22	0.34
225	21H1B19Q	Davison Street	19	"	18/8/64	10.0	2.7	6.4	0.14	0.03	4.2	26.6	T	0	23	36.8				18	5.5	<5		0.49	0.22	0.28	0.087	0.75		28	0.47
262	21H1B20Q	Etna	5	"	18/8/64	9.7	2.4	4.4	0.02	T	2.7	7.8	T	0	19	35.1				12	6.3	<5		0.48	0.20	0.19	0.056	0.22		22	0.33
202	21H1B30P	Forest Hill	17	"	29/7/64	2.4	4.5	3.5	0.30	0.20	2.4	6.0	T	0	20	24	10	38	6	<10	6.0	<5		0.12	0.37	0.15	0.05	0.17		23	0.30
51	21H1B34L	White Rock	14	*	29/7/64	5.6	5.8	3.7	0.12	0.28	4.1	5.9	T	0	32	38.1	4	42	5	12	6.7	5		0.28	0.48	0.16	0.09	0.17		18	0.26
35	21H1B37N	Kentville	11	*	29/7/64	12.8	4.5	3.8	0.12	0.07	2.0	6.0	T	0	42.0	50.1	0	34	3	12	6.7	<5		0.64	0.37	0.17	0.04	0.17		14	0.24
54	21H1B39J	White Rock	10	"	20/8/64	53.5	2.2	7.7	1.20	0.02	2.7	11.0	2	0	96	145.5				34	7.1	<5		2.67	0.18	0.33	0.056	0.31	0.032	10	0.28
250	21H1B43J	Forest Hill	7	"	29/7/64	1.6	1.5	4.3	0.04	0.02	4.8	7.0	T	0	14	10	10	36	4	<10	6.1	5		0.08	0.12	0.19	0.10	0.20		49	0.60
244	21H1B44L	Forest Hill	5	*	29/7/64	20.8	4.9	9.1	0.05	0.03	4.6	15.1	T	0	60	72.1	44	126	6	20	7.2	5		1.04	0.40	0.40	0.10	0.43		22	0.47
260	21H1B45N	Forest Hill	11	"	29/7/64	8.8	3.4	6.2	0.13	0.04	4.5	10.0	3	0	36	36.1	8	50	15	13	6.8	5		0.44	0.30	0.27	0.09	0.28	0.048	27	0.44
358	21H1B46O	Melanson	11	*	14/6/64	12	10	9.7	.07	.15	39.8	31	T	0	16	70.3	6	128	8	20	6.7			.60	.82	.42	.83	.87		23	0.50
167	21H1B55K	Gaspereau	9	*	5/6/64	2	0.6	4.6	0.05	T	2.4	16	T	0	14	16	16	72	5	10	6.9			0.01	0.049	0.20	0.054	0.45		77	1.16
68	21H1B57H	White Rock	13	"	29/5/64	6	1.2	5.3	0.14	0.04	2.9	14	15	0	10	34	46	120	10	14	6.3			0.30	0.099	0.23	0.060	0.39	0.24	37	0.51
462	21H2A5B	S. Alton	17	*	13/8/64	8.0	6.8	6.7	0.24	T	2.9	11.0	12	0	28	48	44	90	5	16	6.8	<5		0.39	0.56	0.29	0.06	0.31	0.19	23	0.42
570	21H2A11G	Rockland	?	*	21/8/64	28.8	6.8	7.4	0.14	0.02	3	11.5	2	0	94	100.0				25	7.2	<5		1.44	0.559	0.322	0.133	0.324	0.032	14	0.32
519	21H2A17H	Lloyds	?	*	11/8/64	3.2	6.3	9.3	T	T	3.4	15.0	12	0	28	54	56	120	2	19	6.5	<5		0.16	0.52	0.40	0.07	0.42	0.19	37	0.69
518	21H2A18P	Lloyds	17	*	11/8/64	3.2	8.8	3.0	2.2	0.20	2.9	5.0	T	0	22	44	38	64	8	13	6.4	5		0.16	0.72	0.13	0.06	0.14		13	0.20
460	21H2A22G	S. Alton	23	*	13/8/64	4.8	5.4	4.6	0.04	T	6.7	8.5	5	0	24	34	2	38	4	13	6.3	<5		0.24	0.44	0.20	0.14	0.24	0.24	23	0.34
432	21H2A24A	S. Alton	22	*	11/8/64	20.8	6.8	5.8	0.09	0.01	3.8	10.5	10	0	24	80	68	128	4	21	6.7	<5		1.04	0.56	0.25	0.08	0.30	0.16	14	0.28
431	21H2A25A	S. Alton	13	*	25/6/64	3	1.0	2.4	0.13	0.03	1.4	17	2	0	10	26	20	52	4	10	6.3			0.15	0.082	0.10	0.029	0.48	0.03	30	0.30
484	21H2A26F	S. Alton	11	*	13/8/64	8.0	3.9	2.7	0.12	0.055	2.9	5.0	2	0	14	36	40	64	6	12	6.5	<5		0.39	0.32	0.12	0.06	0.14	0.03	14	0.20

Metamorphic = metamorphic rocks * denotes till overlying this unit T = concentration <0.01 ppm SSP = soluble sodium percentage SAR = sodium adsorption ratio

CHEMICAL ANALYSES OF GROUNDWATERS IN THE ANNAPOLIS – CORNWALLIS VALLEY CONT'D.

Sample No.	Grid Location	Area	Depth of Well (feet)	Aquifer	Date Sampled	Analyses in parts per million (ppm)																		Ions in equivalents per million (epm)							
														Alkalinities										Cations			Anions				
						Ca	Mg	Na	Fe	Mn	SO_4	Cl	NO_3	Phenol-pthalein as $CaCO_3$	Methyl Orange	Hardness	Ignition Loss	Total Dis-solved Solids	Suspended Matter	Specific Conductance (mhos x 10^{-5})	pH	Colour	Turbidity	Ca	Mg	Na	SO_4	Cl	NO_3	SSP	SAR
499	21H2A29B	Tuppers Lake	10	Metamorphic	17/8/64	7.0	1.4	5.7	0.03	T	2.4	13.5	15	0	14	24.4				15	6.0	<5		0.35	0.12	0.25	0.05	0.38	0.242	35	0.52
502	21H2A30A	Prospect	9	"	18/8/64	10.8	1.1	2.3	0.02	T	1.8	15.2	T	0	22	33.2				15	6.2	<5		0.54	0.09	0.10	0.037	0.43		14	0.18
493	21H2A47J	N. Alton	9	"	26/6/64	15	2.9	16.0	0.07	0.12	5.8	66	24	0	22	86	116	230	0	29	6.0			0.75	0.238	0.70	.121	1.86	0.39	41	1.00
305	21H1B53N	Gaspereau	70+	Horton	14/6/64	25	18	5.65	.07	T	4.8	29	T	0	55.2	137	5	93	8	21	7.6			1.25	1.48	.25	.83	.82		8	0.21
322	21H1B68C	Gaspereau	?	"	14/6/64	27	18	66.4	.12	0.02	8.2	90	T	2	128	140.3	12	89	1	53	8.2			1.35	1.48	2.89	.17	2.53		51	2.43
334	21H1B69H	Melanson	60	"	14/6/64	27	10	5.6	.15	.08	4.3	23	T	0	88	107	7	110	13	24	8.0			1.35	.82	.25	.83	.65		10	0.24
544	21H1B76P	Grand Pre	120	"	20/8/64	30.8	7.1	12.4	T	T	1.9	12.8	T	0	90	107.3				30	7.5	<5		1.54	0.58	0.54	0.040	0.36		20	0.52
543	21H1B93H	Grand Pre	?	"	20/8/64	43.1	9.6	15.6	0.03	T	1.5	23.4	1	0	106	149.0				39	7.4	<5		2.15	0.79	0.68	0.031	0.69	0.016	19	0.56
540	21H1B94K	Grand Pre	98	"	19/8/64	60.8	5.3	7.7	T	0.01	1.5	31.9	2	0	80	175.9				42	7.3	<5		3.03	0.44	0.33	0.0 31	0.89	0.032	9	0.25
538	21H1B96D	Avonport	300?	"	19/8/64	64.7	14.7	28.5	0.01	T	1.0	97.9	20	0	101	224.8				60	7.2	<5		3.23	1.21	1.24	0.021	2.76	0.322	22	0.83
289	21H1B22P	Elma	13	Horton*	18/8/64	7.3	0.5	4.8	0.11	0.03	2.4	16.3	T	0	13	21.5				12	5.8	<5		0.36	0.04	0.21	0.05	0.46		34	0.47
295	21H1B24K	Hallow Brook	8	"	18/8/64	6.5	1.2	5.1	0.04	T	1.8	9.9	T	0	17	22.4				15	6.0	<5		0.32	0.10	0.22	0.037	0.28		34	0.48
374	21H1B50L	Wallbrook	14	"	29/7/64	28.1	6.3	14.9	0.15	T	4.5	24.0	3	0	80	96.2	36	174	10	24	7.0	<5		1.40	0.52	0.65	0.09	0.68	0.048	25	0.66
343	21H1B51L	Melanson	18	"	14/6/64	19	18	4.75	.05	.04	4.8	41	T	0	53.2	120.3	4	103	7	19	7.5			.95	1.48	.21	.10	1.16		8	0.19
330	21H1B53L	Gaspereau	12	"	14/6/64	13	8	5.5	.01	.05	8.2	28	15	0	18	66.8	3	97	11	18	6.7			.65	.66	.24	.17	.79	.24	15	0.30
368	21H1B70A	Melanson	12	"	22/4/64	5	0.9	4.9	0.10	0.05	1.4	14	T	0	16	26	24	101	15	12	6.5			0.25	0.074	0.21	0.029	0.39		40	0.53
392	21H1B71Q	Wallbrook	11	"	22/6/64	27	3.9	7.7	0.03	0.04	1.4	34	27	4	48	132	110	218	10	28	9.1			1.35	0.321	0.33	0.029	0.96	0.44	16	0.36
409	21H1B72Q	Avonport	10	"	22/6/64	6	1.5	9.5	0.02	T	1.9	20	12	0	20	40	50	122	2	18	6.7			0.30	0.123	0.41	0.040	0.56	0.19	49	0.90
537	21H1B74F	Wallbrook	?	"	19/8/64	24.3	5.4	6.8	0.02	T	2.4	12.1	.2	0	68	83.7				24	7.0	<5		1.21	0.44	0.29	0.05	0.34	0.032	15	0.32
546	21H1B77J	Grand Pre	?	"	20/8/64	82.4	21.9	22.5	T	T	2.9	56.4	2	0	146	300.8				64	7.0	<5		4.11	1.80	0.98	0.06	1.59	0.032	14	0.57
545	21H1B92A	Grand Pre	?	"	20/8/64	10.8	3.1	12.9	0.03	T	1.5	31.6	2	0	22	40.2				22	6.1	<5		0.54	0.25	0.56	0.031	0.89	0.032	41	0.89
539	21H1B95M	Hortonville	?	"	19/8/64	50.8	6.6	15.6	0.02	T	1.0	28.7	4	0	100	156.0				42	7.0	<5		2.53	0.54	0.68	0.021	0.80	0.064	18	0.55
1297	21A14A88P	Inglisville	6	Granite	19/9/66	7.5	0.5	2.3	3.0	T	2	3.5	T	0	30	21.6			T	8	6.5	<5		0.37	0.04	0.10	0.04	0.10		20	0.22
1298	21A14A89N	Inglisville	86	"	19/9/66	21.4	3.4	8.0	0.01	T	11	12.4	10	0	52	67.2			T	22	6.3	5		1.07	0.28	0.35	0.23	0.35	0.20	21	0.43
1295	21A14D20L	Nictaux West	Spring	"	19/9/66	76.2	6.2	3.4	0.70	T	2	5.3	T	0	110	215.6			T	49	7.0	35		3.80	0.51	0.15	0.04	0.15		3	0.16
1296	21A14D29A	Nictaux West	Spring	"	19/9/66	46.1	4.4	5.7	0.01	T	48	8.8	T	0	124	133.2			T	34	7.7	<5		2.30	0.36	0.25	1.00	0.25		9	0.22
1299	21A14B42H	Tupperville	12	SaG	19/9/66	8.3	1.4	8.0	0.01	T	13	12.4	8	0	12	28.4			T	13	5.7	<5		0.41	0.12	0.35	0.27	0.35	0.16	40	0.68
1459	21A14B43E	Tupperville	12	"	15/10/66	14.6	1.4	10.3	2.30		12	16.0	T	0	32	42.4				14	7.2	45		0.73	0.12	0.45	0.25	0.45		35	0.69
1244	21A14B52M	Tupperville	9	"	29/8/66	28.2	5.9	21.7	0.25	T	17	33.6	4	0	76	94.6			T	36	7.0	<5		1.41	0.48	0.94	0.34	0.95	0.08	33	0.97
1243	21A14B69B	Bridgetown	17	"	29/8/66	32.1	4.5	4.6	0.03	T	15	7.0	1	0	84	98.6			T	28	7.8	5		1.60	0.37	0.20	0.31	0.20	0.02	9	0.20
1238	21A14B75E	Bridgetown	12	"	27/8/66	73.8	9.8	6.9	0.03	T	24	10.6	8	0	96	224.7			T	52	7.5	<5		3.68	0.81	0.30	0.50	0.30	0.16	6	0.20

1239	21A14B76A	Bridgetown	15	SaG	27/8/66	9.6	2.3	42.3	0.55	T	8	63.6	T	0	16	34.0			T	23	5.9	<5		0.48	0.19	1.84	0.17	1.85		73	3.18
1211	21A14D17A	Lawrencetown	9	*	24/8/66	20.8	5.1	19.0	.03	T	24.0	29.3	3	0	38	73.1			T	22	6.0	<5		1.04	0.42	0.83	0.50	0.83	0.05	36	0.97
1210	21A14D18O	Lawrencetown	9	*	24/8/66	5.1	2.3	2.9	0.05	T	10	4.4	T	0	16	22.1			T	2	5.9	<5		0.25	0.19	0.13	0.21	0.12		23	0.28
1214	21A14D26B	Nictaux Falls	13	*	24/8/66	29.6	2.7	17.9	.04	T	10	27.5	T	0	102	85.2			T	22	6.6	<5		1.48	0.22	0.78	0.21	0.78		31	0.85
1213	21A14D26G	Nictaux Falls	Spring	*	24/8/66	11.6	3.9	5.8	0.03	T	6	8.9	T	0	50	45.1			T	13	6.5	<5		0.58	0.32	0.25	0.12	0.25		22	0.37
1217	21A14D70J	Wilmot	Spring	*	24/8/66	10.0	5.6	14.8	0.03	T	22	23.1	1	0	28	48.1			T	21	6.4	<5		0.50	0.46	0.64	0.46	0.65	0.01	40	0.92
1218	21A14D71O	Wilmot	?	*	24/8/66	16.4	3.2	19.4	0.12	1.0	17	30.1	25	0	8	54.1			T	38	4.9	<5		0.82	0.26	0.84	0.35	0.85	0.40	44	1.14
1220	21A14D97H	Melvern Square	21	*	25/11/66	9.6	4.2	5.7	0.40	0.1	14	8.8	7	0	22	41.1			T	14	6.3	<5		0.48	0.34	0.25	0.30	0.25	0.14	23	0.39
1120	21A15C61G	Farmington	18	*	6/8/65	13.6	3.6	19.0	0.11	0.03	25	28.4	25	0	38	49.1			T	34	7.0	<5		0.079	0.296	0.827	0.521	0.798	0.403	46	1.19
TH91	21A15C64E	Tremont	75	*	9/7/66	11.2	0.7	10.2	0.15	0.03	11	16.0	12	0	36	31.1			T	12	7.5	<5		0.56	0.06	0.44	0.23	0.44	0.19	42	0.79
1114	21A15C64K	Tremont	24	*	11/8/65	5.6	1.7	7.1	0.01	T	15	10.6	T	0	38	21.1			T	11	7.1	<5		0.279	0.140	0.309	0.312	0.299		42	0.68
1112	21A15C80B	E. Tremont	25	*	6/8/65	14.4	3.9	9.5	0.15	0.02	22	14.2	30	0	34	54.0			T	32	7.5	<5		0.718	0.321	0.413	0.458	0.299	.484	28	0.57
1154	21A15C82J	Kingston Village	46	*	13/8/65	73.8	2.0	30.9	0.03	T	18	46.1	40	0	124	192.5			T	58	8.3	<5		3.684	0.164	1.344	0.375	1.340	0.645	26	0.97
1155	21A15C83A	Kingston Village	18	*	13/8/65	2.4	0.5	7.1	0.02	0.03	8	10.6	T	0	24	8.0			T	<10	7.0	<5		0.120	0.041	0.309	0.167	0.299		66	1.10
1061	21A15C85F	Melvern Square	15	*	17/7/65	3.2	2.9	10.2	0.18	0.03	3	16.0	T	0	8	20.0			T	<10	6.2	5		0.160	0.238	0.444	0.002	0.451		52	0.98
1063	21A15C86K	Kingston	29	*	17/7/65	3.2	1.9	10.2	T	T	3	16.0	T	0	8	16.0			T	<10	6.9	<5		0.160	0.156	0.444	0.104	0.451		58	1.10
1077	21A15C98H	Factorydale	30	*	17/7/65	8.0	2.9	11.3	0.02	T	8	17.7	T	0	12	32.0			T	<10	6.5	<5		0.399	0.238	0.592	0.167	0.500		48	1.04
1075	21A15C99P	Millville	22	*	17/7/65	8.0	3.9	13.6	0.08	T	10	21.3	6	0	10	36.0			T	10	6.2	5		0.399	0.321	0.592	0.208	0.601	0.097	45	0.98
1135	21A15C103F	Greenwood	13	*	11/8/65	6.8	1.2	4.8	T	T	18	7.1	8	0	32	22.1			T	12	6.4	<5		0.339	0.099	0.209	0.375	0.200	0.129	32	0.45
1065	21A15C105L	Kingston	15	*	17/7/65	20.8	4.9	14.7	0.75	0.08	8	23.0	T	0	32	72.3			T	14	6.5	35		1.04	0.403	0.640	0.167	0.649		31	0.75
1064	21A15C106K	Kingston	20?	*	17/7/65	9.6	1.9	12.5	0.07	T	5	19.5	10	0	8	32.0			T	10	7.1	<5		0.479	0.156	0.544	0.104	0.549	0.161	46	0.96
1060	21A15C107O	Kingston	25?	*	17/7/65	14.4	1.0	10.2	0.02	T	4	16.0	T	0	24	40.0			T	10	7.1	<5		0.719	0.082	0.444	0.083	0.451		35	0.70
1222	21A15C108D	Melvern Square	30	*	25/8/66	8.0	4.6	6.9	0.03	T	12	10.6	5	0	42	39.1			T	18	6.4	<5		0.40	0.38	0.30	0.25	0.30	0.08	28	1.52
623	21H1C30L	Kingsport	20	*	25/8/64	10.6	6.9	9.1	0.04	T	18	14.2	14	0	31	54.8				22	6.0	<5		0.529	0.567	0.396	0.375	0.400	0.226	27	0.54
572	21H2A13L	Rockland	?	*	21/8/64	15.2	4.4	10.8	0.08	0.05	22	16.8	12	0	31	56.0				23	5.9	<5		0.758	0.362	0.470	0.133	0.474	0.194	30	0.63
523	21H2A31K	Prospect	30	*	11/8/64	9.6	2.4	3.2	0.04	T	2.4	5.5	T	0	28	34	14	60	1	12	6.9	<5		0.48	0.20	0.14	0.05	0.16		17	0.24
TH89	21H2A35B	Berwick	45	*	23/6/66	5.6	0.7	9.1	1.1	0.03	8	14.2	12	0	36	17.0			L	<10	7.2	<5		0.28	0.06	0.395	0.17	0.40	0.19	54	0.97
1264B	21H2A36P	Berwick	17	*	7/9/66	30.7	2.0	13.7	0.35	0.03	18	21.2	5	0	50	84.8			T	23	6.8	<5		1.53	0.16	0.60	0.37	0.60	0.10	26	0.65
521	21H2A41F	Waterville	30	*	11/8/64	10.4	3.4	16.1	0.12	0.02	2.9	25.0	12	0	16	40	70	140	3	22	6.6	<5		0.52	0.28	0.70	0.06	0.71	0.19	47	1.11
589	21H2A57D	Waterville	?	*	25/8/64	7.2	4.9	1.7	0.15	0.03	10	2.7	4	0	25	38.0				14	6.5	<5		0.359	0.403	0.074	0.208	0.076	0.065	8	0.11
669	21H2A66F	Cambridge Sta.	60	*	7/9/64	24.5	1.0	4.5	0.03	T	3	7.1	2	0	82	65.2				19	7.7	25		1.22	0.08	0.18	.062	.200	.032	12	0.22
558	21H2A73P	Aldershot	12	*	20/8/64	30.0	5.9	23.3	2.20	0.05	4.3	55.0	25	0	42	100.6				40	6.5	<5		1.50	0.48	0.97	0.089	1.55	0.40	33	0.98
667	21H2A78F	Brooklyn Cnr.	?	*	7/9/64	13.4	6.7	17.0	0.04	0.05	13	26.6	18	0	23	61.2				20	5.6	25		0.67	0.55	0.69	.271	.750	.290	36	0.88
668	21H2A79G	Cambridge Sta.	85	*	7/9/64	43.5	3.4	6.8	0.02	T	18	10.6	7	0	101	122.5				26	7.7	25		2.17	0.28	0.28	.375	.299	.113	10	0.25

Metamorphic = metamorphic rocks   Horton = Horton Group   SaG = surficial sand and gravel deposits   *denotes till overlying this unit   T = concentration <0.01 ppm   L = low   SSP = soluble sodium percentage   SAR sodium adsorption ratio

CHEMICAL ANALYSES OF GROUNDWATERS IN THE ANNAPOLIS – CORNWALLIS VALLEY CONT'D

Sample No.	Grid Location	Area	Depth of Well (feet)	Aquifer	Date Sampled	Analyses in parts per million (ppm)																		Ions in equivalents per million (epm)							
														Alkalinities										Cations			Anions				
						Ca	Mg	Na	Fe	Mn	SO_4	Cl	NO_3	Phenol-phthalein as $CaCO_3$	Methyl Orange	Hardness	Ignition Loss	Total Dis-solved Solids	Suspended Matter	Specific Conductance (mhos x 10^{-5})	pH	Colour	Turbidity	Ca	Mg	Na	SO_4	Cl	NO_3	SSP	SAR
1072	21H2B5F	Millville	15	SaG	17/7/65	3.2	3.9	11.3	T	T	7	17.7	T	0	8	24.0			T	<10	6.1	<5		0.160	0.321	0.492	0.146	0.500		51	1.00
1071	21H2B6K	Auburn	18	"	17/7/65	30.5	4.9	10.2	1.00	0.05	4	16.0	T	0	56	96.3			L	17	7.0	85		1.52	0.403	0.444	0.083	0.451		19	0.45
1269	21H2B8E	Auburn	12	"	9/9/66	10.2	0.9	3.4	0.07	0.06	4	5.3	3	0	22	29.2			T	11	6.7	5		0.51	0.07	0.15	0.08	0.15	0.06	21	0.28
1067	21H2B8L	Auburn	46	"	17/7/65	9.6	5.8	17.0	T	0.04	13	26.6	10	0	12	48.0			T	14	6.3	<5		0.479	0.477	0.740	0.271	0.750	0.161	44	1.07
1068	21H2B18F	Auburn	20?	"	17/7/65	3.2	1.9	13.6	0.02	T	3	21.3	T	0	8	16.0			T	<10	6.5	<5		0.160	0.156	0.592	0.062	0.601		65	1.48
1152	21H2B19G	Auburn	40	"	13/8/65	21.3	3.6	7.1	0.12	0.02	15	10.6	8	0	52	66.2			T	22	7.2	5		1.063	0.296	0.309	0.312	0.299	0.129	19	0.38
1017	21H2B20G	Aylesford	?	"	13/7/65	40.1	2.9	12.6	0.01	0.02	12	19.5	T	2	62	112.3			T	30	8.3	<5		2.00	0.239	0.548	0.250	0.550		20	0.52
1000	21H2B24K	Berwick W.	20?	"	13/7/65	11.2	8.8	10.4	0.85	0.02	4	16.0	T	0	16	72.3			VL	10	7.0	10		0.559	0.724	0.452	0.083	0.451		26	0.56
1266	21H2B26H	Berwick W.	19	"	8/9/66	25.4	6.0	12.6	0.30	0.04	17	19.5	20	0	24	87.6			T	25	6.5	<5		1.27	0.49	0.55	0.35	0.55	0.40	24	0.59
1019	21H2B27B	Aylesford	28	"	13/7/65	24.0	6.8	25.2	0.20	0.04	19	39.0	26	0	24	88.3			T	36	7.7	5		1.20	0.559	1.10	0.396	1.10	0.581	38	1.17
1018	21H2B28B	Aylesford	32	"	13/7/65	14.4	6.8	21.8	0.60	0.05	20	33.7	1	0	48	64.3			T	34	7.7	40		0.719	0.559	0.948	0.416	0.950	0.016	43	1.19
1271	21H2B28B	Aylesford	12	"	10/9/66	14.1	1.9	5.7	4.20	0.06	22	8.8	1	0	18	42.0			H	26	5.9	175		0.70	0.16	0.25	0.46	0.25	0.02	23	0.38
1016	21H2B29F	Aylesford	?	"	13/7/65	54.5	7.8	12.6	0.09	T	7	19.5	T	8	88	168.3			T	40	8.5	<5		2.72	0.642	0.548	0.146	0.550		14	0.42
673	21H2D2P	Centreville	?	"	8/9/64	30.8	6.2	13.6	0.04	T	13	21.3	20	0	50	102.7				26	7.6	25		1.54	0.51	0.55	.271	.601	.323	21	0.54
679	21H2D3G	Centreville	?	"	8/9/64	27.7	1.4	3.4	0.04	T	5	5.3	T	0	84	75.1				20	7.7	25		1.38	0.12	0.14	.104	.149		9	0.16

SaG = surficial sand and gravel deposits T = concentration < 0.01 ppm L = low VL = very low H = high SSP = soluble sodium percentage SAR = sodium adsorption ratio

APPENDIX F.
NOTATION

		Dimensions T = time L = length
B	$\sqrt{T/(P'/m')}$	L
C_{po}	partial penetration constant for observation well	dimensionless
C_{pp}	partial penetration constant for pumped well	dimensionless
d	one-half of a confidence interval	L
df	degrees of freedom	dimensionless
ET	evapotranspiration	L^3
Exp	exported water	L^3
F	ratio of the treatment mean square to the error mean square	dimensionless
I	hydraulic gradient	dimensionless
Imp	imported water	L^3
Kg	kurtosis	dimensionless
k	number of treatments	dimensionless
L	width of flow cross-section	L
m	saturated thickness of aquifer	L
m'	thickness of confining bed through which leakage occurs	L
N	total number of samples	dimensionless
n	number of samples in a treatment	dimensionless
P	coefficient of permeability	L/T
P'	coefficient of vertical permeability of confining bed	L/T
PE	potential evapotranspiration	L^3
P_r	precipitation	L^3
Q	discharge	L^3/T
R	stream flow	L^3
r and r_p	distance from pumped well to observation well	L
r_i	distance from image well to observation well	L
S	coefficient of storage	dimensionless

		Dimensions T = time L = length
SAR	sodium adsorption ratio	dimensionless
Skl	skewness	dimensionless
SSP	soluble sodium percentage	dimensionless
Sub I	subsurface inflow	L^3
Sur I	surface inflow	L^3
S_y	specific yield	dimensionless
s	drawdown in an observation well	L
s'	residual drawdown	L
s	standard deviation	L
s^2	variance	L^2
s_{fp}	drawdown in observation or pumped well for fully penetrating conditions	L
s_{pp}	observed drawdown for partial penetrating conditions	L
T	coefficient of transmissibility	L^2/T
T.E.	tidal efficiency	dimensionless
t	$(\bar{X}-\mu)\,/\,(s/\sqrt{N})$	dimensionless
t	time since pumping started	T
t'	time since pumping stopped	T
t_i	time after pumping started after a boundary becomes effective when the divergence of the time-drawdown curve from the type curve, under the influence of the image well, is equal to the particular value of drawdown at t_p	T
t_p	time after pumping started, before a boundary becomes effective, for a particular drawdown to be observed	T
t_{wt}	approximate time after pumping starts when the application of the nonequilibrium formula to the results of pumping tests under water-table conditions is justified	T
U	subsurface outflow	L^3
u	$2246\, r^2 S/Tt$	dimensionless
W (u)	well function for non-leaky artesian aquifers	dimensionless
W (u,r/B)	well function for leaky artesian aquifers	dimensionless

		Dimensions T = time L = length
X	value of an individual item	dimensionless
$\bar{X}$	mean value	dimensionless
α	chance of concluding that a true hypothesis is false	dimensionless
ΔR	change in river stage	L
ΔSg	change in groundwater storage	L^3
$\Delta Soil$	change in soil moisture storage	L^3
ΔSs	change in surface water storage	L^3
Δs	drawdown difference per log cycle of time when drawdown data are plotted on an arithmetic scale versus time on a logarithmic scale	L
$\Delta s'$	residual drawdown per log cycle of t/t'	L
ΔW	change in groundwater level resulting from change in river stage	L
μ	population mean	dimensionless
Ø	phi diameter	L

REFERENCES

Bailey, L.W., 1896, Report on the geology of southwest Nova Scotia: Geol. Survey of Canada, Ann. Rept., v. 9, pt. M, 154 p.

Bell, W.A., 1929, Horton-Windsor District, Nova Scotia: Geol. Survey of Canada, Mem. 155, 268 p.

________, 1960, Mississippian Horton Group of type Windsor-Horton District, Nova Scotia: Geol. Survey of Canada, Mem. 314, 112 p.

Boulton, N.S., 1954, The drawdown on the water-table under nonsteady conditions near a pumped well in an unconfined formation: Proc. (British) Inst. Civil Engrs., v. 3, pt. 3.

Bredehoeft, J.D., Blyth, C.R., White, W.A., and G.B. Maxey, 1963, Possible mechanism for concentration of brines in subsurface formations: Am. Assoc. Petroleum Geol. Bull., v. 47, no. 2, p. 257-269.

Butler, S.S., 1957, Engineering Hydrology: Prentice-Hall, Englewood Cliffs, N.J., 356 p.

California State Water Pollution Control Board, 1954, Report on the investigation of travel of pollution: Publication no. 11, 218 p.

Canada Department of Agriculture Research Station, Kentville, N.S., 1961, Summary of weather records, 1914-1958: Publication no. 1092, 34 p.

Canada Department of Transport, Climatology Division, Meteorological Branch, 1965, Temperature and precipitation normals, preliminary listing.

Chernaya, T.M., 1964, Comparative evaluation of graphical methods of separation of ground water components of streamflow hydrographs: (trans. from Russian) Soviet Hydr., 1964, no. 5, p. 454-465.

Chow, Ven Te, 1964, Runoff, p. 14-1 - 14-54, *in* Chow, V.T., (ed.), Handbook of applied hydrology: McGraw-Hill, N.Y.

Crosby, D.G., 1962, Wolfville map-area, Nova Scotia (21 H 1): Geol. Survey of Canada, Mem. 325, 67 p.

Dawson, J.W., 1848, On the New Red Sandstone of Nova Scotia: Quart. Jour. Geol. Soc. London, v. 4, p. 50-58.

__________, 1855, Acadian Geology: London, 1st ed., 833 p.

__________, 1893, The Canadian ice age, being notes on the Pleistocene geology of Canada, with especial reference to the life of the period and its climatic conditions: privately published, Montreal, 301 p.

Dement'yev, N.F., 1963, Use of underground water levels to estimate the underground feeding or rivers: (trans. from Russian) Soviet Hydr., 1963, no. 5, p. 437-449.

Department of Energy, Mines and Resources, Water Resources Branch, published monthly, Runoff conditions in Canada.

Department of National Health and Welfare, 1962 a, Aspects of pollution, Cornwallis River, Nova Scotia: a survey report, 53 p.

________________________________, 1962 b, Aspects of Pollution, Annapolis River, Nova Scotia: a survey report, 72 p.

Faribault, E.R., 1920, Kings and Annapolis Counties, Nova Scotia: Geol. Survey of Canada, Summary Rept., pt. E, p. 6-16.

Fletcher, H., 1902, Kings and Hants Counties, Nova Scotia: Geol. Survey of Canada, Summary Rept., v. 14, pt. A, p. 210-216, with map 764.

Fletcher, H., 1904, The counties of Cumberland, Hants, Kings, and Annapolis, Nova Scotia: Geol. Survey of Canada, Summary Rept., v. 16, pt. A, p. 301-318.

__________, 1911, Kingsport Sheet No. 84, Hants and Kings Counties, Nova Scotia: Geol. Survey of Canada, Map 13A.

Flint, R.F., 1957, Glacial and Pleistocene Geology: John Wiley and Sons, Inc., New York, 553 p.

Folk, R.L., and C.W. Ward, 1957, Brazos River bar: a study in the significance of grain size parameters: Jour. Sed. Petrol., v. 27, no. 1, 3-26.

Ferris, J.G., Knowles, D.B., Brown, R.H., and R.W. Stallman, 1962, Theory of aquifer tests: U.S. Geol. Survey Water-Supply Paper 1536-E, 106 p.

Freeze, R.A., and P.A. Witherspoon, 1967, Theoretical analysis of regional groundwater flow. 2. Effect of water-table configuration and subsurface permeability variation: Water Resources Research, v. 3, no. 2, p. 623-634.

Friedman, G.M., 1961, Distinction between dune, beach, and river sands from their textural characteristics: Jour. Sed. Petrol., v. 31, no. 4, p. 514-529.

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

Hantush, M.S., 1956, Analysis of data from pumping tests in leaky aquifers: Trans. Am. Geophys. Union, v. 37, no. 6, p. 702-714.

Hantush, M.S., and C.E. Jacob, 1955, Non-steady radial flow in an infinite leaky aquifer: Trans. Am. Geophys. Union, v. 36, no. 1, p. 95-100.

Harlow, L.C., and G.B. Whiteside, 1943, Soil Survey of the Annapolis Valley fruit growing area: Dom. of Canada, Dept. of Agriculture, Publication 752, Tech. Bull. 47, 92 p.

Hayes, A.O., 1916, Nictaux-Torbrook iron ores, Nova Scotia: Geol. Survey of Canada, Summary Rept., p. 273-275.

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

Hickox, C.F., 1959, Formation of ventifacts in a moist, temperate climate: Geol. Soc. Am. Bull., v. 70, p. 1489-1490.

__________, 1962, Pleistocene geology of the central Annapolis Valley, Nova Scotia: N.S. Dept. of Mines, Mem. no. 5, 36 p.

Hilchey, J.D., Cann, D.B., and J.I. MacDougall, 1962, Soil Survey of Digby County, Nova Scotia: N.S. Dept. of Agri. and Canada Dept. of Agri., Rept. 11, 58 p.

Hurtig, H., 1966, Criteria and standards for pesticide residues: Background Paper C22-3-2 *in* Pollution and our Environment, a national conference, Montreal, Oct. 31 to Nov. 4, 1966.

Hurtig, H., and C.R. Harris, 1966, Nature and sources of pollution by pesticides: Background Paper A2-4 *in* Pollution and our Environment, a national conference, Montreal, Oct. 31 to Nov. 4, 1966.

Jacob, C.E., 1946, Drawdown test to determine effective radius of artesian wells: Proc. Am. Soc. Civil Engrs., v. 72, no. 5, p. 629-646.

Jones, J.F., 1963, Aquifer-testing procedures and other information used in evaluating groundwater supplies in Alberta: Research Council of Alberta, Preliminary Rept. 63-1, 35 p.

Klein, G. DeV., 1957, The geology of the Acadian Triassic in the type area, northeastern Annapolis-Cornwallis Valley, Kings County, Nova Scotia: Univ. of Kansas M.S. thesis.

____________, 1960, Stratigraphy, sedimentary petrology and structures of Triassic sedimentary rocks, Maritime Provinces, Canada: Yale Univ. PhD thesis.

____________, 1962, Triassic sedimentation, Maritime Provinces, Canada: Geol. Soc. Am. Bull., v. 73, no. 9, p. 1127-1146.

Kudelin, B.I., 1949, Hydrogeological analysis and methods of determination of underground feeding rivers: (in Russian) Trans. Laboratory of Hydrogeological Problems Acad. of Sci., USSR, v. 5, 1949.

__________, 1960, Principles of regional evaluation of natural resources of underground waters: (in Russian) Moscow State Univ. (MGU), Press.

Kunkle, G.R., 1962, The baseflow-duration curve, a technique for the study of groundwater discharge from a drainage basin: Jour. Geophys. Research, v. 67, no. 4, p. 1543-1554.

McKee, J.E., and H.W. Wolf, (ed.), 1963, Water Quality Criteria: The Resources Agency of California, State Water Quality Control Board Publication no. 3-A, 548 p.

Meinzer, O.E., 1923, The occurrence of ground water in the United States: U.S. Geol. Survey Water-Supply Paper 489, 321 p.

Morley, H.V., 1966, New tools for detecting and measuring environmental contaminates - pesticide residues in soil: Background Paper D25-5 *in* Pollution and our Environment, a national conference, Montreal, Oct. 31 to Nov. 4, 1966.

Mukammal, E.I., and J.P. Bruce, 1960, Evaporation measurements by pan and atmometer: Canada Dept. of Transport, Met. Branch, Cir-3300, Tec-315.

Nova Scotia Department of Trade and Industry, 1964 a, Annapolis County Survey.

______________________________, 1964 b, Kings County Survey.

______________________________, 1965, Nova Scotia, an economic profile: Econ. Services Div., v. 4, 71 p.

Pauli, F.W., 1966, Some recent developments in biochemical research: Paper presented at the Halifax meeting, Geol. Assoc. of Canada (unpubl.).

Piper, A.M., 1944, A graphic procedure in the geochemical interpretation of water analyses: Am. Geophys. Union Trans., v. 25, p. 914-923.

Powers, S., 1916, The Acadian Triassic: Jour Geol., v. 24, p. 1-26, 105-122, 254-268.

Rasmussen, W.C., and G.E. Andreasen, 1959, Hydrologic budget of the Beaverdam Creek basin, Maryland: U.S. Geol. Survey Water-Supply Paper 1472, 106 p.

Richards, L.A., (ed.), 1954, Diagnosis and improvement of saline and alkali soils: U.S. Dept. of Agriculture Handbook no. 60, 160 p.

Robertson, G.W., 1953, Standardization of evaporation measurement as a climatological factor: Doc. no. 99, Com. for instruments and methods of observation, World Met. Org.

Schafer, J.P., and J.H. Hartshorn, 1965, The Quaternary of New England, p. 113-128: *in* Wright, H.E., and D.G. Frey, (ed.), The Quaternary of the United States, Princeton Univ. Press, Princeton, N.J., 922 p.

Schicht, R.J., and W.C. Walton, 1961, Hydrologic budgets for three small watersheds in Illinois: Ill. St. Water Survey, Rept. of Investigation 40, 40 p.

Smitheringale, W.G., 1960, Geology of Nictaux-Torbrook map-area, Annapolis and Kings Counties, Nova Scotia: Geol. Survey of Canada, Paper 60-13, 32p.

Steel, R.G.D., and J.H. Torrie, 1960, Principles and Procedures of Statistics : McGraw-Hill, New York, 481 p.

Stein, C., 1945, A two-sample test for a linear hypothesis whose power is independent of the variance: Ann. Math. Stat., v. 16, p. 243-258.

Stewart, D.K.R., Chisholm, D., and C.J.S. Fox, 1965, Insecticide residues in potatoes and soil after consecutive treatments of aldrin and heptachlor: Canad. Jour. Pl. Sci., v. 45, p. 72-78.

Taylor, F.C., 1962, Geology, Annapolis, Nova Scotia: Geol. Survey of Canada, Map 40-1961.

Theis, C.V., 1935, The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Trans. Am. Geophys. Union, v. 16, p. 519-524.

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

Toth, J., 1962, A theory of groundwater motion in small drainage basins in central Alberta, Canada: Jour. Geophys. Research, v. 67, p. 4375-4387.

Trescott, P.C., 1967, An investigation of the groundwater resources of the Annapolis-Cornwallis Valley, Nova Scotia: Univ. of Illinois PhD thesis, 269 p.

Turner, J.A., 1958, A simplified scheme for computing Thornthwaite's potential evapotranspiration: Canada Dept. of Transport, Met. Branch, Cir-3118, Tec-284, 12 p.

United States Public Health Service, 1962, Drinking water standards: Publication no. 956, 61 p.

Walton, W.C., 1962, Selected analytical methods for well and aquifer evaluation: St. of Ill., Dept. of Registration and Ed., Bulletin 49, 81 p.

__________, 1965, Ground-water recharge and runoff in Illinois: Ill. St. Water Survey, Rept. of Investigation 48, 55 p.

Weeks, L.J., (consult. geol.), 1965, Geological Map of the Province of Nova Scotia: N.S. Dept. of Mines.

Wenzel, L.K., 1942, Methods of determining permeability of water-bearing materials, with special reference to discharging-well methods: U.S. Geol. Survey Water-Supply Paper 887, 192 p.

Wilcox, L.V., 1948, The quality of water for irrigation use: U.S. Dept. of Agriculture Tech. Bull. 962.

Wilkenson, A.T.S., Finlayson, D.G., and H.V. Morley, 1964, Toxic residues in soil nine years after treatment with aldrin and heptachlor: Science, v. 143, p. 681-682.

Zektser, I.S., 1963, Role of artesian water in feeding large rivers as exemplified by the middle and lower reaches of the Nunan River: (trans. from Russian) Soviet Hydr., 1963, no. 1, p. 94-98.