To Marcos,
with thanks,
Heather

NATURAL AND MANMADE VARIATIONS IN GROUNDWATER FLOW AND CHEMISTRY IN THE BIRCH COVE AND SACKVILLE AREAS OF HALIFAX COUNTY, NOVA SCOTIA

By

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ABSTRACT

This study discusses the groundwater flow and quality in the Birch Cove and Sackville areas of Halifax County, Nova Scotia, as related to geology and urban influence.

The groundwater flow systems are controlled by both the bedrock topography and the northeast striking joints in both areas. In Birch Cove, local flow systems predominate. In Sackville, a regional flow system exists in the bedrock, with local flow systems in the surficial material superimposed on it; the influence of groundwater from the surficial material recharging the bedrock aquifer can be seen by the high bicarbonate concentrations in some samples from wells completed in bedrock. The groundwater flow systems as determined from water table elevations are complemented by the results of chemical variation in the groundwater.

Seasonal responses in groundwater chemistry vary widely, but the magnitude and smoothness of the variation depends on well depth and the amount of overburden. Time lags in the order of 3-4 months were found for chloride and 6-8 months for nitrate. Some marked effects on groundwater chemistry and temperature were found to be associated with biological activities and permeability differences in the rock mass.

One result of urbanization is the presence of road salt in groundwater. In Birch Cove, salting effects were most apparent in wells close to the road and were apparently independent of well depth because of the predominance of steeply dipping

joints in the bedrock and the lack of appreciable overburden material. In Sackville, salt effects were most noticeable in shallow dug wells, while drilled wells completed in bedrock were for the most part protected by the generally thick glacial till cover in the area. Many of these dug wells were put in before proper constructions regulations were available.

Another effect of urbanization is the presence of detergent in the groundwater. The magnitude of this problem is not considered in depth in this study, but is presently being studied by the Nova Scotia Department of the Environment.

DEFINITIONS, UNITS AND SYMBOLS

AQUIFER: a formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs (Lohman, 1972).

BASE EXCHANGE INDEX (BEI): (Cl - Na)/Cl (ion concentrations in epm)

BICARBONATE PERCENT (HCO_3%): $[(HCO_3)/(HCO_3 + SO_4 + Cl)] \times 100$ (ion concentrations in epm)

CHLORIDE PERCENT (Cl%): $[(Cl)/(HCO_3 + SO_4 + Cl)] \times 100$ (ion concentrations in epm)

COEFFICIENT OF PERMEABILITY, P: the rate of flow of water, in gpd, through a cross-sectional area of aquifer of one square foot under a hydraulic gradient of unity at the prevailing temperature of the water (Walton, 1962) (gpd/ft^2).

COEFFICIENT OF TRANSMISSIBILITY, T: the rate of flow of water, in gallons per day (gpd) through a vertical strip of the aquifer one foot wide and extending the full saturated thickness, under a hydraulic gradient of unity at the prevailing temperature of the water, or the coefficient of permeability (P) times the saturated thickness, m, of the aquifer (Walton, 1962) (gpd/ft).

CONFINED OR ARTESIAN AQUIFER: an aquifer in which there is an overlying or stratigraphically adjacent impermeable or confining layer. When a well is drilled into the aquifer, the water will rise to some level above the top of the aquifer because it is under pressure greater than atmospheric pressure. This level is called

a piezometric surface (Lohman, 1972).

CONFINED WATER: Groundwater derived from a well completed in a confined aquifer.

HYDRAULIC CONDUCTIVITY, K: the volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow (Lohman, 1972) (LT^{-1}).

HYDRAULIC GRADIENT (i): the change in static head per unit of distance in a given direction, usually the maximum rate of decrease of head (Lohman, 1972) (dimensionless).

PERCHED WATER TABLE: the level of an unconfined groundwater separated from an underlying body of groundwater by an unsaturated zone, or perching bed, of low permeability (Lohman, 1972).

POROSITY: the ratio of the volume of voids in a rock or soil to the total volume (Lohman, 1972) (dimensionless).

SODIUM PERCENT (Na%): [(Na + K)/(Na + K + Ca + Mg)] x 100 (ion concentrations in epm).

SPECIFIC YIELD, S_y: the ratio of the volume of water which a rock or soil, after being saturated, will yield by gravity to the total volume of the soil (Lohman, 1972) (dimensionless).

STORAGE COEFFICIENT, S: the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head (dimensionless). In an artesian aquifer, change in storage with a decline in head is a result of

expansion of the water and compression of the aquifer skeleton. In an unconfined system, these processes are negligible compared to gravity drainage of the pore spaces, in which $S=S_y$ (Walton, 1962).

UNCONFINED OR WATER TABLE AQUIFER: an aquifer in which the water surface is at a level consistent with atmospheric pressure. It is defined by the level at which water stands in a well that penetrates the water body just far enough to hold water (Lohman, 1972).

UNCONFINED WATER: groundwater derived from a well completed in an unconfined aquifer.

UNITS

Gallons per minute (gpm) or gallons per day (gpd) are generally used to express pumping rate or yield of a well or aquifer (imperial gallons are used).

Parts per million (ppm) are used for ion concentrations, and are essentially equivalent to milligrams per liter (mg/l).

Equivalents per million (epm) are equal to ppm of an ion multiplied by a factor dependent on the atomic weight of the ion; epm are used interchangeably with milliequivalents per liter (meq/l).

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Mr. W. Molanson of N.S. Technical College allowed me to use his atomic absorption facilities and also performed periodic analytical checks on water samples. Further assistance was provided by Mr. E.G. Mosher of N.S. Department of Public Health, who arranged for bacterial analyses to be carried out by the Pathology Institute, and by Mr. T. Krauch of Halifax City Field, who provided me with road salt data. Mr. M. Jackson of the Metropolitan Area Planning Commission kindly allowed me to use some seismic and soil data from the Sackville region.

I greatly appreciate the kindness and tolerance shown by the many homeowners who participated in this study. Thank you letters were sent to the individuals whose wells were monitored, along with the analyses from their own well.

I also appreciate the friendship and encouragement of Mr. E. Nielsen and Mr. C. Stehman, graduate students at Dalhousie University, during this study.

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Chapter 1

INTRODUCTION

Purpose and Scope

"Hydrogeology is the science dealing with the character, source and mode of occurrence of underground water. As such, it is an integral part of geology, the science that deals with the origin and state of the earth. Many geological phenomena can be better understood with a proper understanding of the groundwater processes that are involved, but, conversely, there is no part in the study of groundwater that can be explained without the understanding of geology. This means that hydrogeology can be used either as an auxiliary to geology, or that it may be used in a wider sense as the study of part of our natural environment." (Meyboom, 1967, p.31).

The purpose of this thesis is twofold: firstly to conduct a hydrogeological study of the relationship of groundwater flow systems chemistry to the geology in two small urban areas and secondly, to consider the effects of urbanization on water quality (mainly road salting effects) with a view to establishing rational guidelines for future development of groundwater supplies.

For the study, two areas were chosen, one in Birch Cove and one in Sackville (Fig. 1.1). The homes in Birch Cove utilize wells as a water supply source, but have reported water quality problems of iron, manganese and salt in the past few years. In this area, quartzite bedrock is at or near the surface. Selected dug and drilled wells in Maxwell subdivision, Upper Sackville were also sampled and analysed to determine what seasonal or other changes occurred. In this area, slate bedrock is

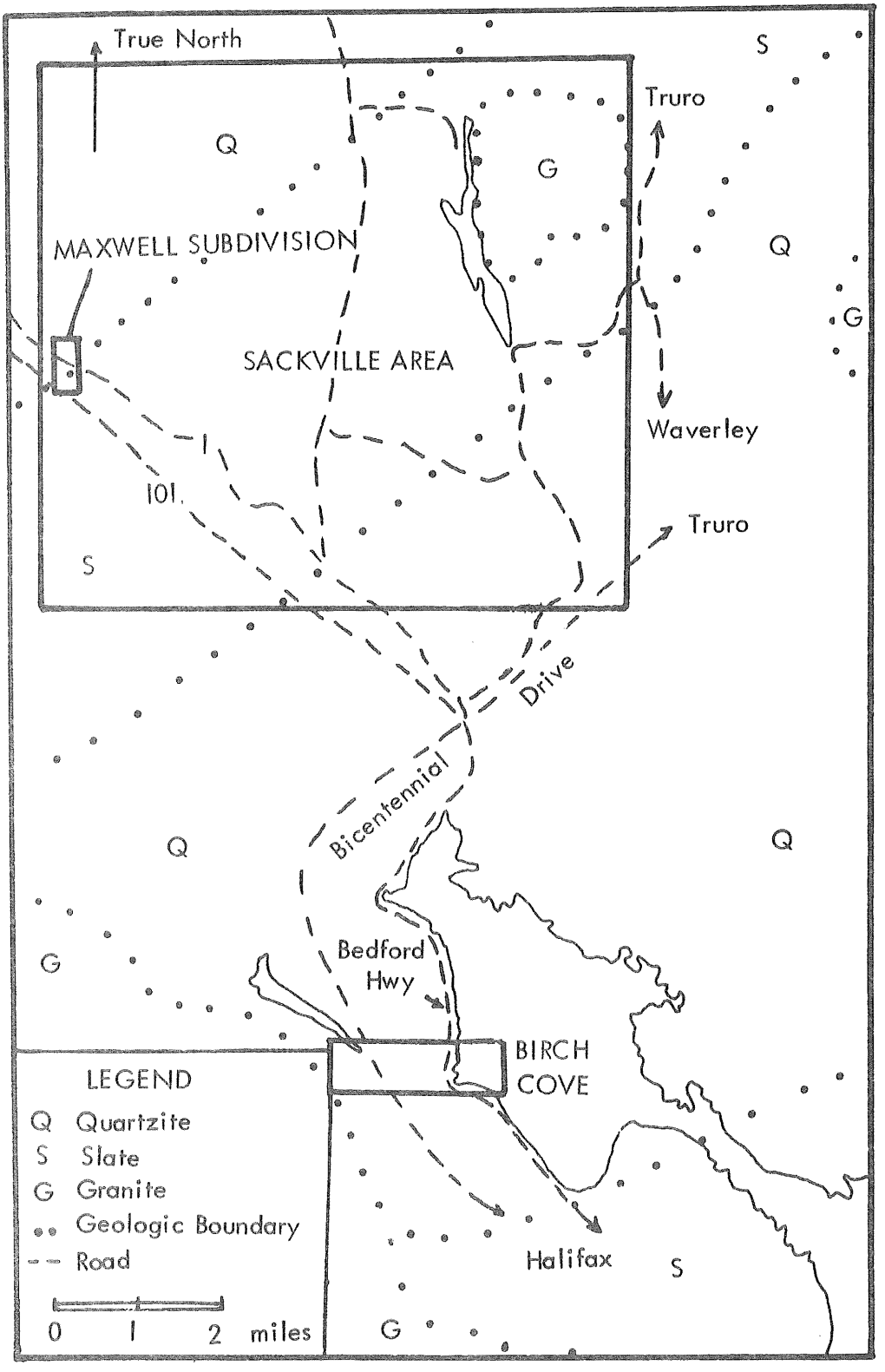


Figure 1.1. Location map of study areas.

overlain by 90 to 100 feet of glacial till. A reconnaissance study was conducted over the entire Sackville area (fig. 1.1) and surroundings, where the housing density is low (about 100 houses per square mile) and mainly in ribbon development along roads, as compared to the high density (about 800 houses per square mile or more) of the Birch Cove area.

In both areas, it was desired to relate groundwater chemistry to local geology and groundwater flow systems, as well as to assess the extent of urban influence on groundwater quality and supply.

Location and Access

The Birch Cove area encompasses about 1 square mile, and lies in the vicinity of 44°41'N and 63°40'W. Access is possible by either the Bedford Highway or Bicentennial Drive, about 3 miles from the centre of Halifax (fig. 1.1).

The Maxwell Subdivision in Upper Sackville encompasses about 0.06 square mile, and lies in the vicinity of 44°48'N and 63°45'W. It is accessible by either the Bedford Highway-Highway 1 route or the Bicentennial Drive-Highway 1 route, and is about 15 miles from Halifax.

The Sackville reconnaissance survey encompasses about 30 square miles.

Climate

Climatic records for the past 30 years from Halifax International Airport and

CFB Shearwater, show an average annual precipitation of 54.4" at Halifax, with 46.3" occurring as rain and 79.1" as snow. The minimum mean monthly precipitation of 3.4" occurs in June, the maximum of 6.0" in November (Atmospheric Environment Service, Environment Canada).

The mean annual temperature at Halifax is 44.3°F, with the minimum of 15°F below zero occurring in January, and the maximum of 92°F in July. The mean frost free period is 173 days and 142 days with frost. On the average, the first fall frost occurs on October 26th and the last spring frost on May 5th. The growing season extends from April 27th to November 5th, on the average.

Physiography and Drainage

The study areas are located in the physiographic region known as the Southern Upland of Nova Scotia, a dissected tableland with maximum altitudes ranging from 600-700 feet; two-thirds of the Upland is underlain by slates and quartzites, one-third by granite (Goldthwait, 1924).

Areas underlain by granite generally consist of gently rolling hills and bogs. Heath type vegetation is most characteristic.

Quartzite outcrops mainly on broad, smooth ridges and hollows, commonly along northeast-trending anticline axes where the overlying slate beds have been eroded off. Glacial drift is relatively thin and bouldery and acid soils have developed on it (Goldthwait, 1924). Fir trees predominate on the ridges, with hemlock, oak, birch, beech and pine on the slopes.

Slate outcrops mainly in synclinal valleys where it is protected from erosion to an extent. Glacial drift overlying slate bedrock is thick in places and may be shaped into drumlins (Goldthwait, 1924). The vegetation type depends on the drainage properties of the underlying glacial till.

On exposed bedrock, polishing of the rock and presence of glacial striations bear witness to the passage of glacial ice (Goldthwait, 1924).

Drainage in the Birch Cove area is controlled by northeast-trending fractures in the bedrock, as shown by the linearity of the streams. In the vicinity of Sackville, drainage is controlled by preglacial southeast and northeast-trending valleys (Smith, 1951). The latter trend is likely controlled by jointing and/or differential weathering. Some of the lakes, such as Second Lake (fig 6.1) have had their shorelines modified by the deposition of glacial drift. In both areas, the lakes are numerous, small and shallow and have been interpreted by Smith (1951) as either widened preglacial valleys or hollows scooped out of the bedrock by the recent glaciation. The latter origin is the most likely for lakes such as Kearney Lake in Birch Cove (fig. 5.1) and Fenerty Lake in Sackville (fig. 6.1) which are elongated in a southeast direction. Since one of the major joint sets strikes northwest-southeast, glacial erosion could have been facilitated in this direction.

The Birch Cove study area lies just outside the Kearney Lake drainage basin. The Sackville study area spans parts of two drainage basins (fig. 6.4): on the west side of the divide, water drains into the Bedford Basin via the Sackville River, while

on the east side, water drains east-northeast into Lakes Kinsac and Fletcher in the study area and from thence north into the Bay of Fundy via the Shubenacadie River system.

In summary, the main physiographic and drainage characteristics of the study areas are controlled by the resistance and structure of the bedrock, with subsequent modification by glacial action.

Field Work and Laboratory Methods

Samples were collected weekly for chemical analysis from 21 wells and 2 rain stations in Birch Cove, and from 7 wells and 1 rain station in Maxwell Subdivision, for a period of one year. A further sampling program in the Sackville region in August 1973 resulted in the collection of 65 drilled well and 57 dug well samples. In all cases, water samples were collected in clean polyethylene bottles with tight seals after the water had been allowed to run for at least 3 minutes. When possible, these samples were analyzed within 24 hours for conductance, pH, Na, K, Ca, Mg, HCO_3, SO_4, Cl, and NO_3. These ions were analyzed in order to give a fairly complete picture of the chemical content of the groundwater and to determine the time variation in the composition. Their major sources are discussed in chapter 4. Iron, manganese and temperature were checked periodically, depending on whether a well showed much change in these parameters. Occasionally problems with equipment and chemicals prevented the analysis of all ions listed above. Table 1 summarizes the methods used and their

estimated accuracy; the latter is based on analysis checks made by Mr. Wm. Molanson at N.S. Technical College and by the author. The atomic absorption methods used are described in detail in Reynolds et al (1970). The Hach methods of analysis are adapted from the American Public Health Association (1971) and were used because of the rapidity of the technique.

In addition to water sampling, measurements of joint orientation were carried out in both areas. Also, samples of surficial material were collected for determination of sand, silt and clay percentages.

Table 1

CHEMICAL PARAMETERS MEASURED, AND ESTIMATED ACCURACY

Parameter		Remarks	Estimated Accuracy
Conductance	Betz conducto-bridge, model XB14		± 10 micromhos
pH	Orion ionanalyzer, no. 401		± 0.2 pH units
Na	Atomic absorption		± 0.4 ppm
K	"		± 0.2 ppm
Ca	"		± 0.4 ppm
Mg	"		± 0.2 ppm
Fe	"		± 0.02 ppm
Mn	"		± 0.02 ppm
HCO_3	Hach DR-EL Field Kit for Water Analyses		± 5.0 ppm
SO_4	"		± 4.0 ppm
Cl	"		± 2.5 ppm
NO_3	"		± 0.4 ppm

Presentation of Water Analyses

In this study, Schoeller semilog plots are used to present water analyses. This type of plot shows simultaneously the absolute concentrations of a series of samples and their relative magnitudes. A discussion of the different uses of these diagrams can be found in Brown (1973). Raw data, in ppm, was converted to epm and percentages by program CHEM, a computer program on file with the Inland Waters Directorate, Environment Canada. This program was also used to calculate ion ratios and activities.

Conductance values are reported as micromhos at 18°C. Values of ions are presented as either ppm or epm.

Statistical Treatment of Chemical Analysis Data

A Pearson correlation analysis (Nie et al, 1970) was used to determine the degree of linear association between samples of two variables, both on a time series basis and an areal variation basis. The correlation coefficient, r, is a mathematical definition of that association, and equals the covariance in X and Y (where X and Y are the two variables being compared) divided by the product of their standard deviations (Nie et al, 1970). In this study, a value of r greater than or equal to 0.8 is considered as high or good. Significance tests for each coefficient were calculated by a Student's t test with N-2 degrees of freedom where $t = r\left[\frac{N-2}{1-r^2}\right]^{1/2}$. The term "at a significant level" as used in this study refers to

a t value significant at the 0.01 level, i.e., there is only one chance in a hundred that the observed relationship is due to chance alone. The program assumes that 1) the data are drawn randomly from a bivariate normal distribution, 2) the data is accurate, and 3) the variables are linearly related.

A discriminant function analysis was used when it was desired to find which variables were most significant in separating two or more natural groupings of data. The program, BMD07M in Dixon (1968), selected the variables with the highest Fisher's F values, the highest multiple correlation with the groups, i.e., the linear combinations of variables which gave the greatest decrease in the ratio of within groups to total generalized variances. Fisher's F values were used to test the significance of the results.

For further discussion of the programs, the reader is referred to Nie et al (1970) and Dixon et al, (1968).

Chapter 2

GEOLOGY

Description of Formations

Paleozoic

Introduction

The study areas are underlain by metamorphosed sediments of the Meguma Group, which consists of two conformable formations - the lower Goldenville and the upper Halifax, which are arbitrarily separated by a sand/silt ratio of 1/1 (Schenk, 1970). Detailed geologic maps and drillers' logs for the study areas are shown on figs. 2.1, 2.2, 2.9 and 2.10.

Goldenville Formation

The composition of this formation varies from a lithic graywacke to a feldspathic quartzite. Beds vary in thickness from a few inches to many feet, but most exposures in the study areas are fairly massive sandy beds intercalated with thin slaty beds. These interbedded slates are often rich in pyrite, but comprise only a small percent of the Goldenville exposed (estimated as less than 3% of the total thickness of 16,000 feet (4.9 kilometers) exposed in the type section (Malcolm, 1929)). The texture of the formation varies from an easily crumbled sandstone to a fine grained, dense, hard rock; the latter is most commonly found in the study areas. The quartzite ranges from grey to grey-green in colour, depending on the relative proportions of biotite and chlorite. The grain size is commonly fine to

medium sand, but conglomerate beds are found.

Sedimentary structures observed by the author include ripple marks, cross bedding, load casts, and graded bedding. Calcium carbonate concretions are numerous in the Formation, especially in the middle of massive sandstone beds (P. Schenk, personal communication). Malcolm (1929) also mentions the presence of ferruginous and manganiferous nodules (photos 1 and 2).

A very rough average composition for the Goldenville Formation in the Birch Cove area, as estimated from Schenk's (1970) trend surface analyses, is: 60% quartz, 22% matrix (sericite, muscovite, biotite, chlorite), 12% feldspar (alkali/plagioclase feldspar about 1-2%), 5% biotite and 1-1.6% rock fragments.

The age of this Formation is thought to be Upper Cambrian-Lower Ordovician (Malcolm, 1929). The only fossil form found to date is Astropolithon hindii, a trace fossil of uncertain age and origin. These were seen on a bedding plane surface on an outcrop in Birch Cove (photo 3) and had been elongated in a northeast-southwest direction by stress.

Halifax Formation

This Formation consists mainly of bluish-black, pyritic slates, often altered to brown by oxidation of sulphides or to green by chlorite (Malcolm, 1929). Thicknesses of up to 14,500 feet (4.4 kilometers) are attained in some localities in Nova Scotia (Malcolm, 1929). A soft greenish slate zone is found near the base of the

Photo 1: Weathered calcium carbonate nodules containing a small amount of iron, Birch Cove.

Photo 2: Weathered out ferruginous nodule or concretion, Sackville

Photo 3: Astropolithon hindii, Birch Cove. The mounds on the bedding plane surface represent the traces of this fossil. It was possibly a sand mound left by a burrowing organism.

Photo 4: Weathered cordierite crystals, Birch Cove. These weather out to leave a distinctive rim of weathered material.

formation, along with some sandy limestone (Malcolm, 1929). The percentage of quartzite increases greatly near the base, and in the top 3200 feet (about 1 kilometer) of slate above the Halifax-Goldenville contact, little compositional difference from the Goldenville is evident in the trend surface diagram in Schenk (1970). The slates outcropping in the Sackville area likely fall into this top kilometer, although they are richer in iron than the nearby quartzites.

Sedimentary structures observed in the slates are similar to those described in the previous section. A well developed slaty cleavage is present as a result of stress, and strikes parallel to the strata, with a dip of 80° or more in either direction (usually opposite the bedding).

On the basis of a doubtful occurrence of the fossil graptolite Dictyonema flabelliforme near Kentville, N.S., the age of this Formation is thought to be Lower Ordovician (Campbell, 1966).

Granite

In both study areas, granite outcrops nearby (fig. 1.1). Although no water samples were taken from wells completed in granite, the possibility that waters in the quartzites and slates have flowed partly through granite requires that a description be made.

In Birch Cove, the granite is a medium to coarse-grained biotite granodiorite, with the following average composition (Smith, 1974); 34.4% quartz, 34.5% plagioclase feldspar (albite/anorthite about 5/1), 14.1% perthitic alkali

feldspar, 16.0% biotite, 0.4% chlorite, and 0.4% muscovite.

Potassium argon dating has shown the granite to be of Devonian age (Reynolds et al, 1973). Field relations also show the granite to be younger than the Meguma Group: 1) the intrusive rocks cut across structures of the Meguma; 2) xenoliths of Meguma are found in the granite; and 3) intrusion of the granite resulted in thermal metamorphism near the contact - in the Birch Cove area cordierite developed, and is presently weathering out (photo4). The contact effects here extend for less than a mile.

Metamorphism of the Meguma Group

In the study area, the Meguma Group has undergone low grade regional metamorphism to a greenschist facies (Taylor and Schiller, 1966), defined by a temperature range of 400-500°C and a water vapor pressure of 1-5 kilobars (Winkler, 1967). The assemblage present is quartz-albite-biotite-muscovite-chlorite-(± epidote) (G. K. Muecke, personal communication). At the pressures mentioned, plastic deformation of the sediment would occur - the slaty cleavage possibly developed at this time.

Superimposed on the regional metamorphic facies are the contact effects produced by intrusion of the granite. In Birch Cove the cordierite indicates a hornblende-hornfels facies defined by a temperature range of 550-700°C and pressures of 1-3 kilobars (Taylor et al, 1966).

Structure of the Meguma Group in the Study Areas

Differential weathering in the study areas has produced northeast trending ridges and valleys (060-080°) parallel to the major fold axes. The amplitude between fold crests varies, but may be 10-25 miles wide in the quartzites. The Birch Cove and southern part of the Sackville areas are part of a wide quartzite belt, which has been folded into two southwest plunging anticlines (Birch Cove and Waverley anticlines) separated by the doubly plunging Bedford syncline. Severe erosion has stripped the slates from this syncline. Another band of quartzite is exposed in the northern Sackville area along the Shubenacadie Lake anticline. For the most part, bedding dips steeply (greater than about 50°). Cleavage is well developed and strikes parallel to the bedding and dips almost vertically.

In Birch Cove, 140 joint sets were measured and plotted as poles on an equal area projection, then contoured (fig. 2.3). Each measurement represents a typical joint of a joint set, since joints in the area show a persistent systematic relationship, i.e., they occur in sets parallel or subparallel in plan and section. It is evident that there are two major joint sets, one steeply dipping and striking perpendicular to the anticline axis, the other striking parallel to the axis with dips forming a "girdle effect". The latter effect is a result of joint formation parallel to both bedding and cleavage (evidence of well-developed bedding plane jointing is shown in photo 5). A minor third joint set is present, striking approximately north-south and also steeply dipping. To check on the homogeneity of the joint pattern, the area was divided into two domains separated by the anticline axis. Overall, the pattern is homogeneous (fig. 2.4) indicating a regional

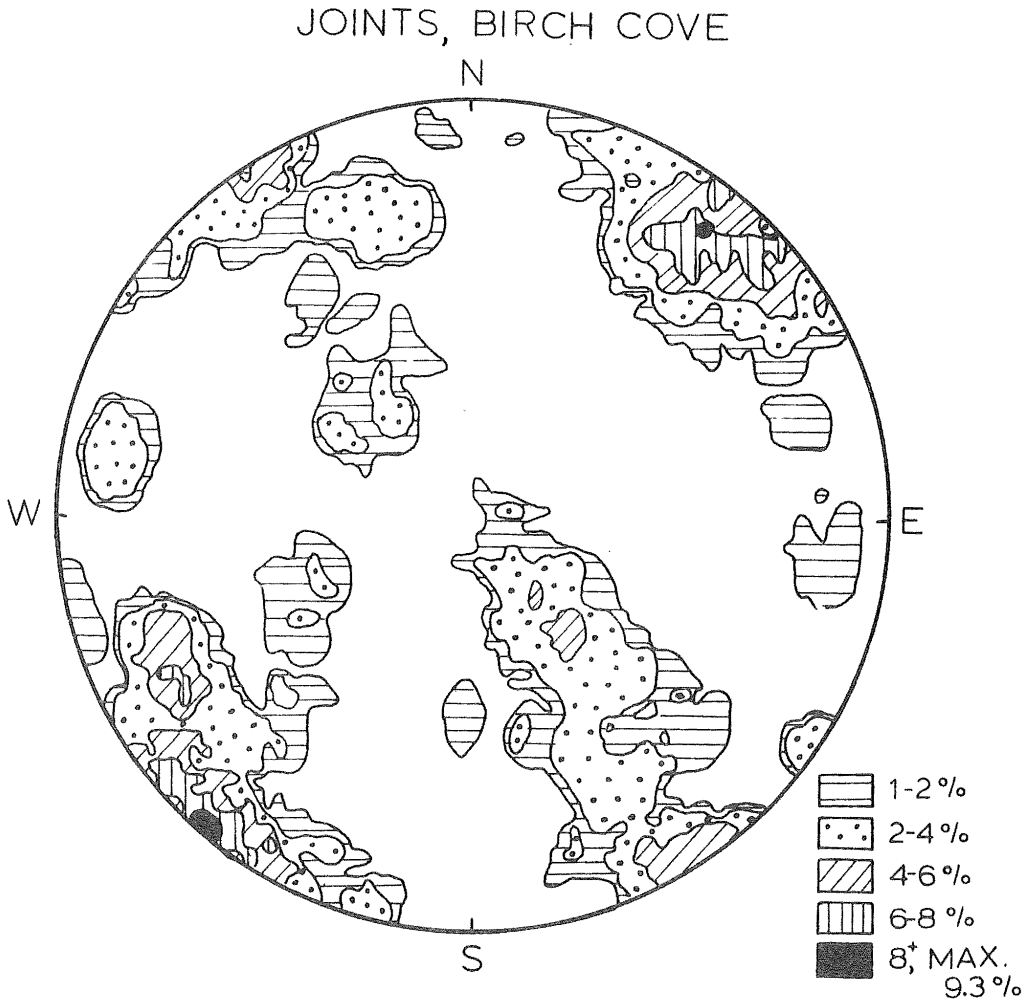


Figure 2.3. Contours of joint poles, Birch Cove.

Photo 5: Bedding plane joints, Birch Cove. Note the well-developed, continuous nature of these joints.

Photo 6: Bedding plane joints, Sackville. Note the well-developed, continuous nature of these joints.

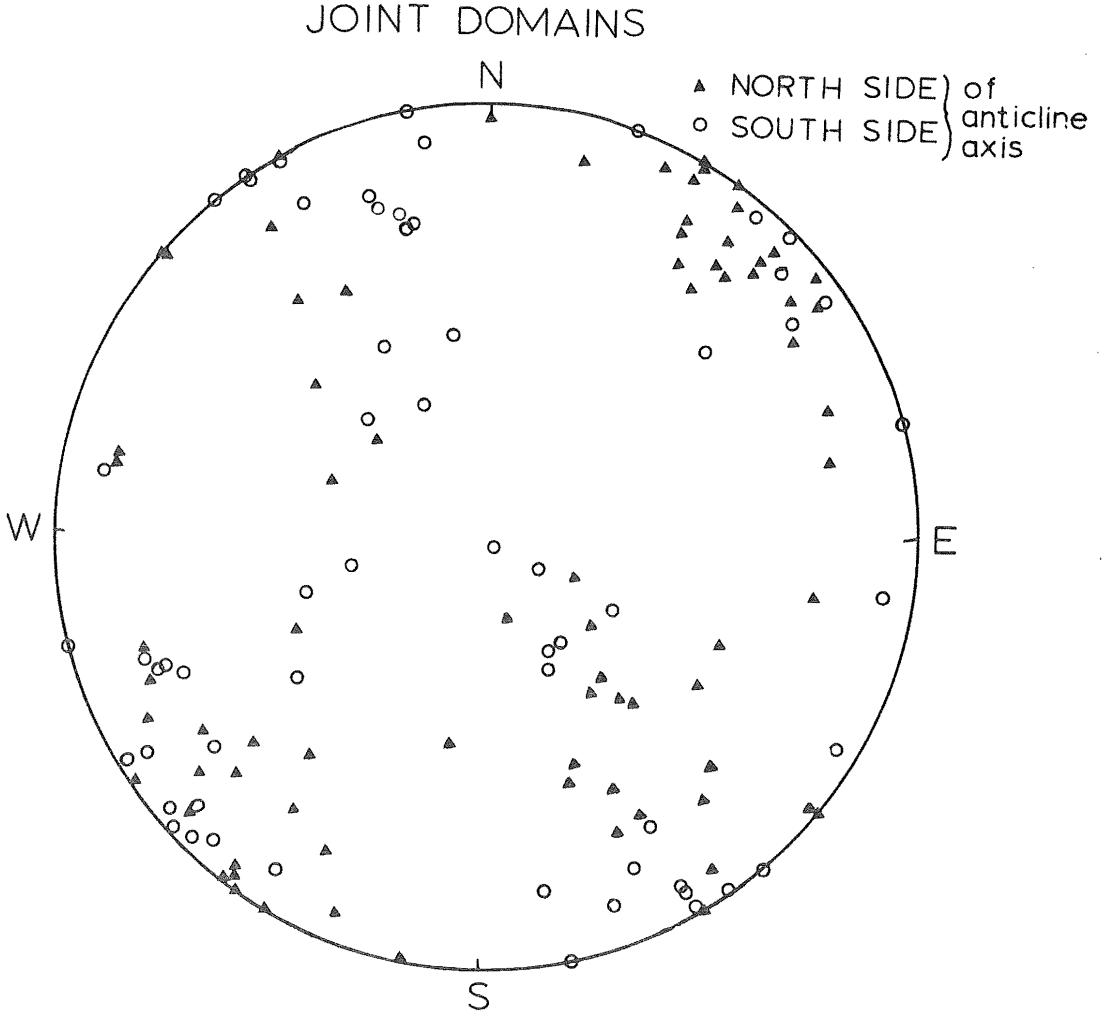


Figure 2.4. Domains of joint poles, Birch Cove.

fracture pattern with orientation consistent over large areas (Stearns, 1968). There is a slight asymmetry in that joints striking parallel to the axis tend to dip parallel to the bedding more on the north side of the axis than on the south, and joints striking perpendicular to the axis tend to dip more toward the northeast on the south side of the axis. The reason for this difference is not known - possibly asymmetry of the fold, or the effect of more than one deformation could be responsible.

The number of outcrops in the Sackville area is too small for a meaningful contour map of joints to be prepared; however, poles to the joints are shown on fig. 2.5. The clustering of the poles is remarkably similar to that of the Birch Cove area, thus supporting the hypothesis of a regional fracture pattern. Well-developed bedding plane joints in Sackville are shown on photo 6. In both areas, the major lineations visible on air photos parallel the two major joint sets (figs. 2.1 and fig. 2.2). Some of the northwest trending lineations are very prominent and could represent faults, but field verification was not possible due to the thick till cover in Sackville.

In both areas, the origin of the joints is most likely by release of residual stresses accumulated during metamorphism and folding at depth. Uplift and erosion would release these stresses. Release of tensional stresses at the axis of the Birch Cove anticline is evident by the breached nature of the fold apex (fig. 5.1). Loading and unloading by glacier ice could also contribute to the

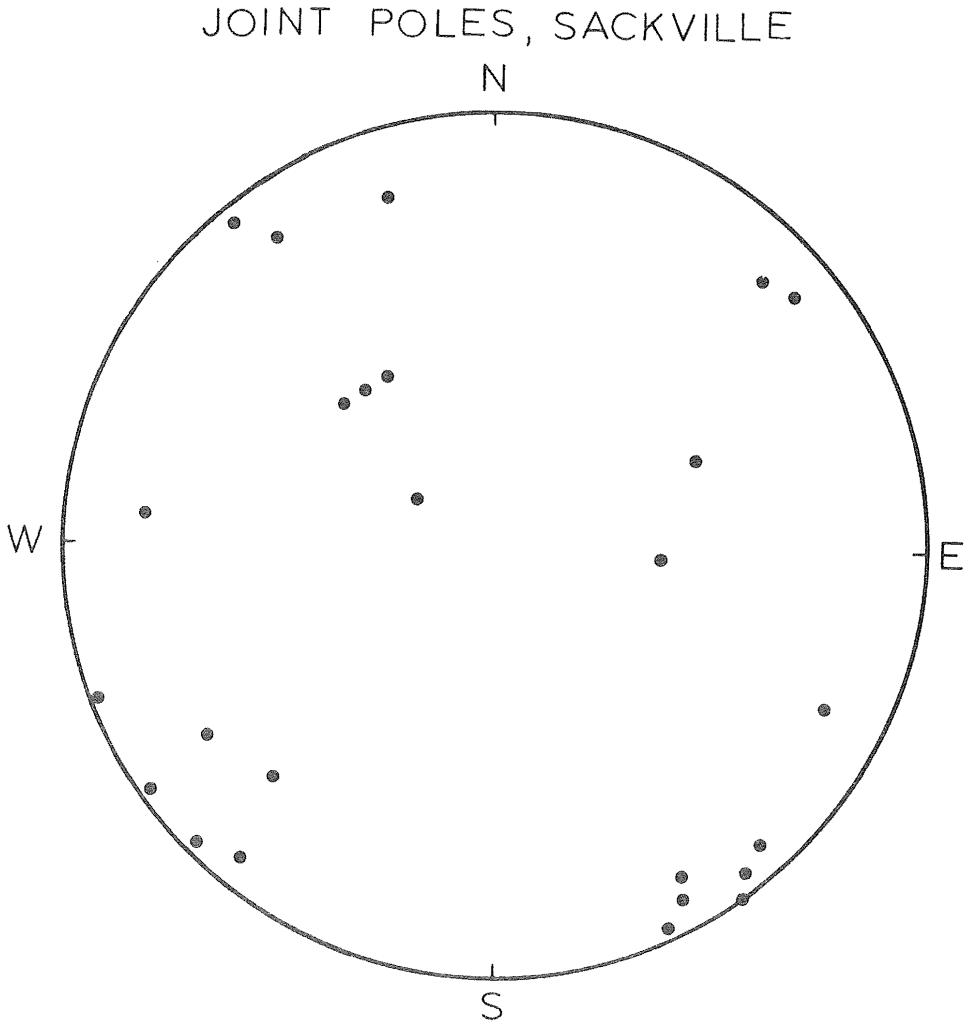


Figure 2.5. Joint poles, Sackville.

opening up of pre-existing weaknesses and trigger new failures in the uppermost part of the bedrock (Trainer, 1973). Further evidence for the stress release hypothesis is that many deep gold mines in the Meguma Group (up to several hundreds of feet in some cases) are dry at depth (Malcolm, 1929), indicating that open joints are concentrated near the ground surface.

Cenozoic

Pleistocene

The last glaciation of Nova Scotia resulted in deposition of a bouldery clay or till. In Birch Cove this till is thin, (generally less than 10 feet, as shown in fig. 2.6) and contains a high percent of boulders of local quartzite bedrock. In Sackville, the till deposits vary in thickness from zero over bedrock highs to more than 300 feet in bedrock depressions (see fig. 2.7). Elongated mounds of glacial debris in the form of drumlins are widespread in Sackville, and are found mainly overlying slate bedrock. They consist of a reddish-brown silty matrix, with pebbles of local and distant bedrock composition (slate, quartzite, granite, shale, sandstone, basalt and limestone were seen). These deposits are easily recognized by their color in roadcuts in the field, by their shape on the topographic map (fig. 6.1) and by the formation of Wolfville soil on the parent material (MacDougall et al, 1963). Bedrock cored hills mantled by glacial debris may have a similar topographic form to the above-mentioned drumlins, but differ markedly in hydrologic properties (Knutsson, 1971), such as more rapid internal drainage (MacDougall

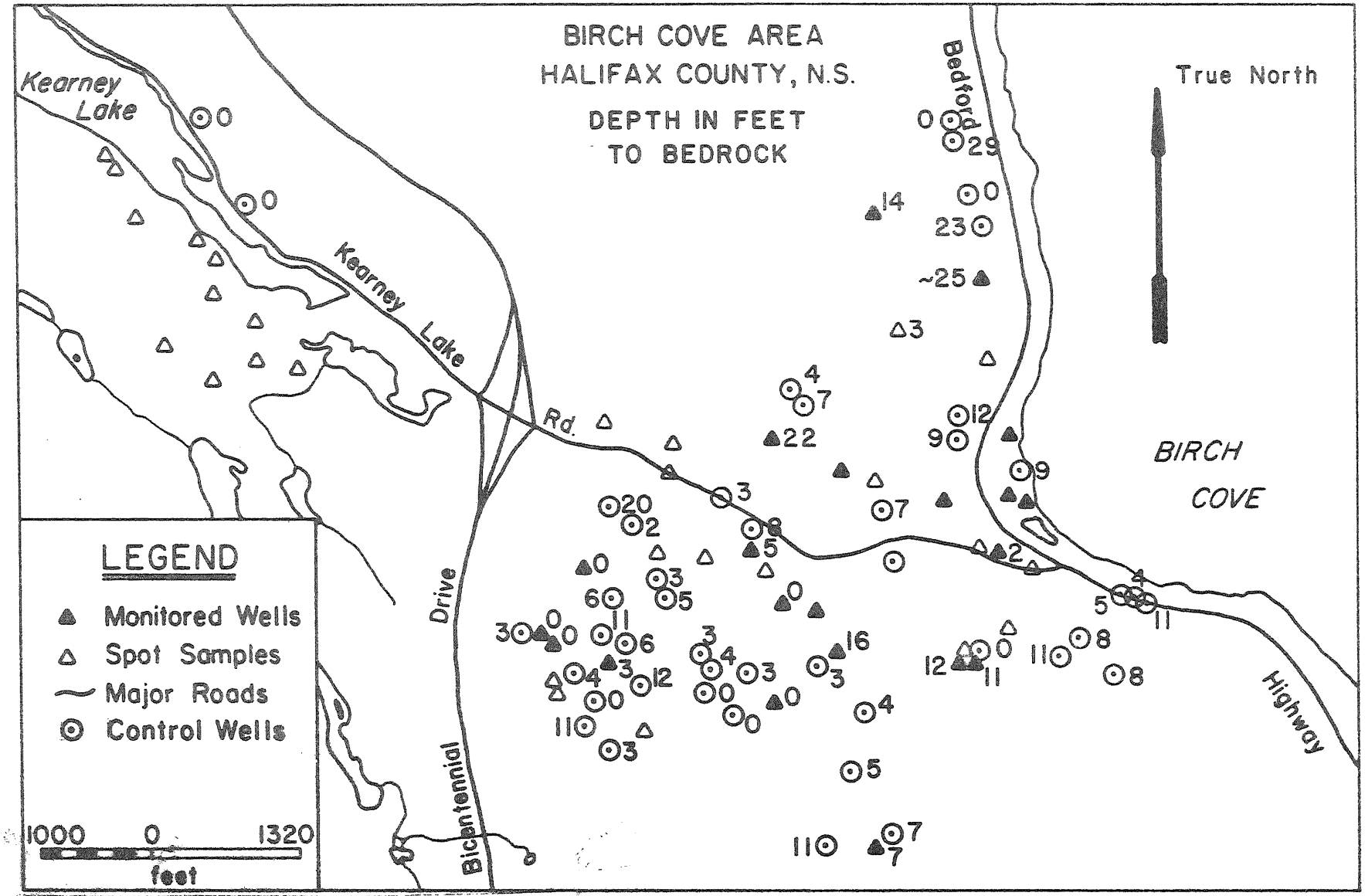


Figure 2.6. Depth in feet to bedrock, Birch Cove.

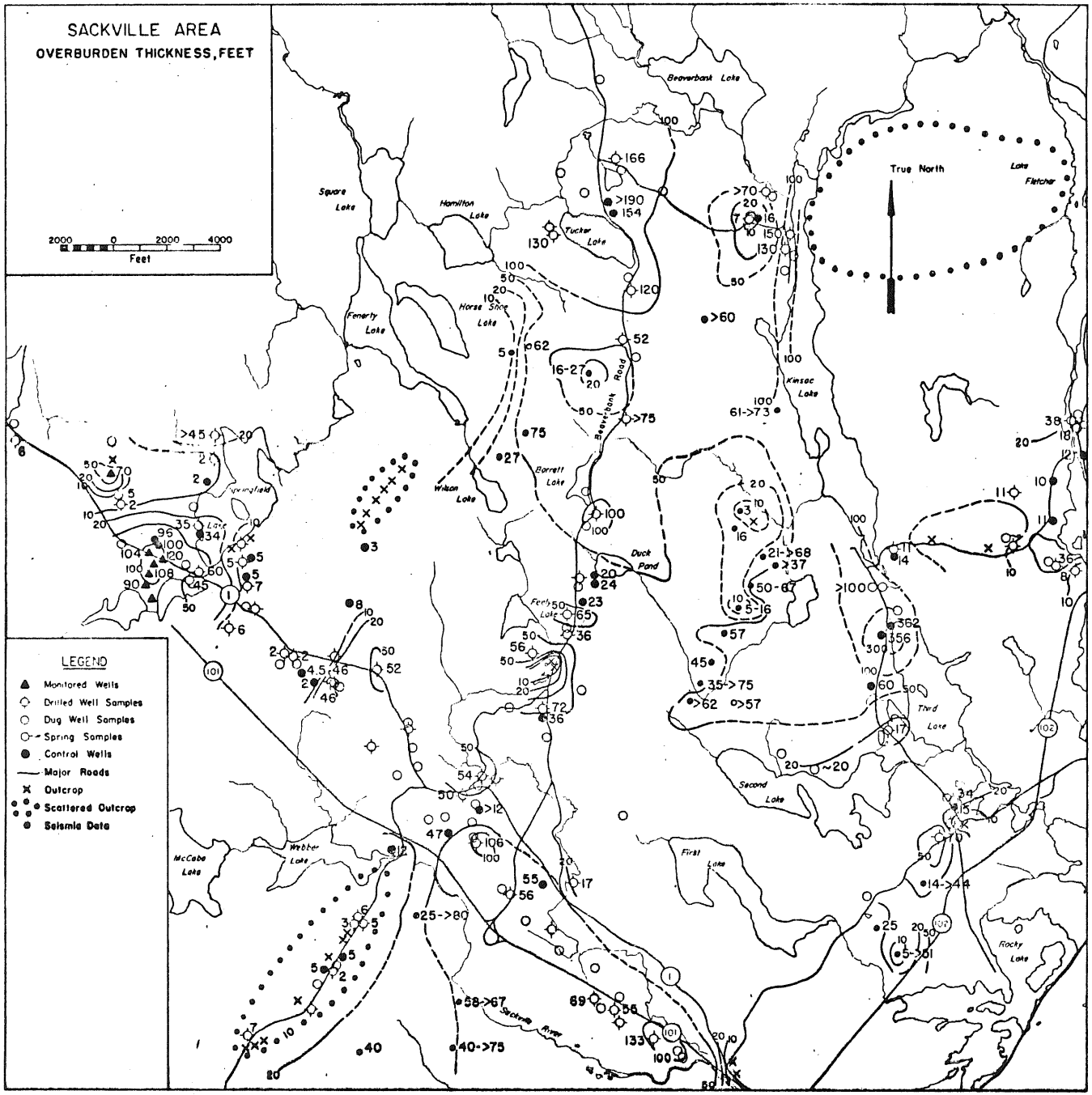


Figure 2.7.
Isopach map of glacial drift, Sackville.

et al, 1963). The mineralogy of the Wolfville soils is not known; however, the Halifax soil type developed on quartzite bedrock in Birch Cove and in parts of Sackville contains mainly quartz and albite in the silt fraction (with minor chlorite and mica), and the clay minerals illite, kaolinite, chlorite, and minor vermiculite (Brydon, 1957).

Elongation of drumlins in a northwest-southeast direction and measurements of glacial striations on bedrock indicate that ice moved southeast in a direction of about 160°. The last ice advance (Classical Wisconsin) reached its maximum in Nova Scotia about 18,000 years B.P. and the province was essentially deglaciated by 10,000 years B.P. (E. Nielsen, personal communication).

Buried Channels

An approximation of the bedrock surface (fig. 2.8) in Sackville was prepared by using well drillers' logs (fig. 2.9) on file with the Water Planning and Management Division, Nova Scotia Department of Environment. Two definite channels in the bedrock are evident - one at the northern end of Kinsac Lake, the other at the northern end of Third Lake. The Kinsac channel may be a result of fracturing in the vicinity of a tightly folded area (the fold axes are close together here on the geological map, fig. 2.2) and the Third Lake channel a result of fracturing along the slate-quartzite contact. These channels appear to have drained into a major valley draining south-southeast; the linearity of this valley suggests fault control, possibly the result of movement along the granite-

slate contact. These valleys have been infilled by glacial till (fig. 2.7), but also contain gravel on top of the bedrock as indicated by drillers' logs. Other wells showing gravel layers are plotted on fig. 2.2 - they may represent further channels, or pockets of alluvial material.

The age of these channels is not known, but they are likely preglacial.

Recent

Following deglaciation, flat or slightly depressed areas with poor drainage filled up with peat and/or muck, as found elsewhere here in Nova Scotia (Trescott, 1968 a). The bogs in the study areas are, in some cases, a result of groundwater exposed at the surface due to a topographic irregularity (see chapter 5) or of groundwater discharge.

Recent alluvium occupies the flood plains of major streams, such as the Sackville River. In the latter, the alluvium is silty sand or sandy silt and is redeposited mainly from glacial material.

Other recent activity involves the erosion and redeposition or redistribution of glacial material.

Chapter 3

HYDROLOGY

Introduction

Hubbert (1940) first developed a theoretical model for groundwater flow through a homogeneous, isotropic medium. Meyboom (1962, 1967) and Toth (1963, 1966, 1971), extending Hubbert's work, recognized that local, intermediate and regional flow systems could develop, depending on hydraulic head, topography and geologic boundary conditions (fig. 3.1). Physical and field evidence of groundwater flow is provided by springs, seepages, ice flow in winter and changing water levels and water chemistry (Toth, 1966).

Some consequences of the above theory of flow systems are (Toth, 1963): 1) if local relief is negligible and if there is a general slope only, a regional flow system will develop, and 2) if the topography has a well defined relief, local flow systems increase in importance and depth.

Hydrostratigraphic Units

Hydrostratigraphic units are defined (Trescott, 1968a) as a group of geological materials with similar hydraulic and hydrochemical characteristics. In the study areas, the major units are bedrock and surficial; the latter can be subdivided into silts and clays, and sands and gravels.

Bedrock

In the slates and quartzites, porosity and permeability are a result of

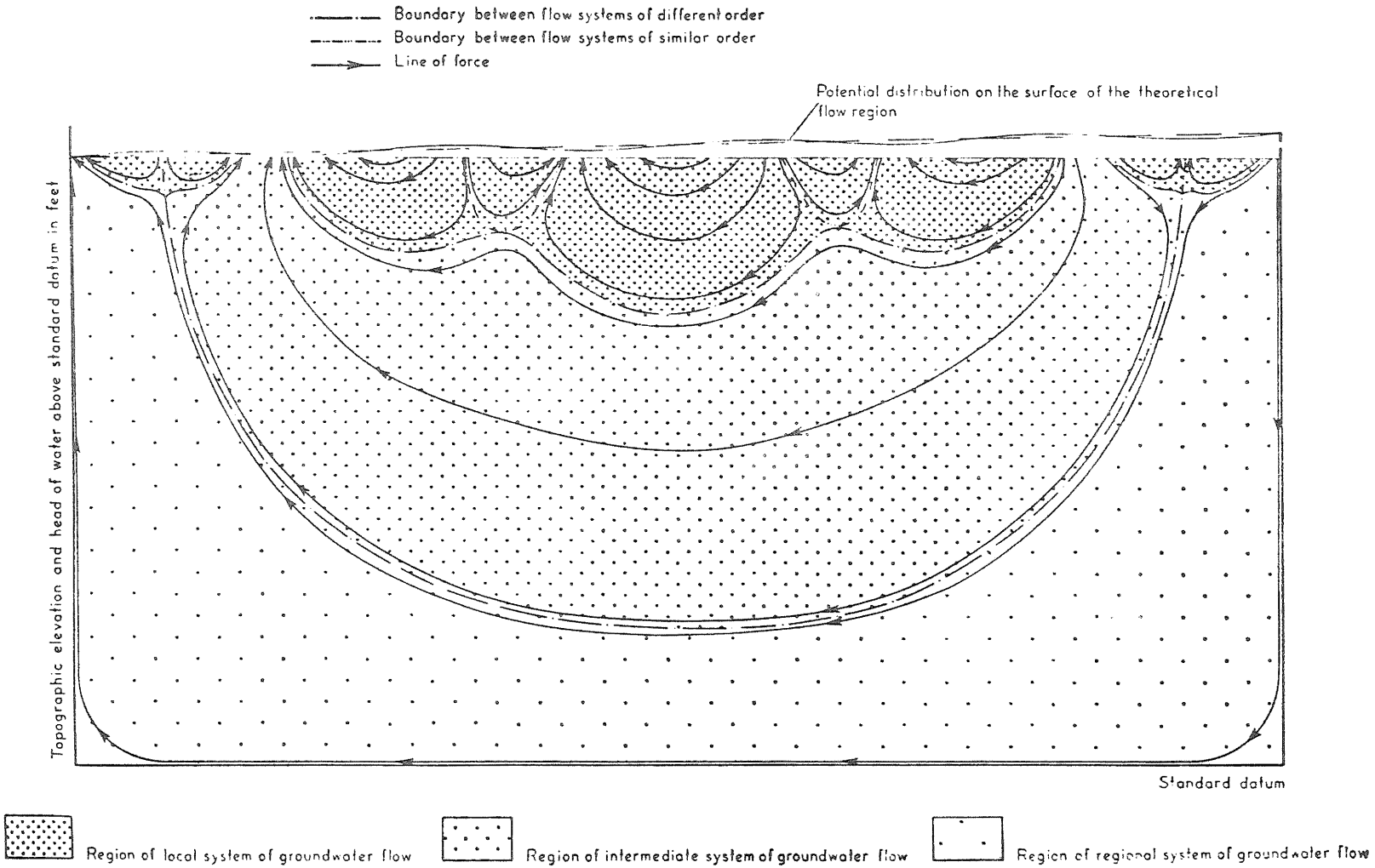


Figure 3.1. Illustration of local, intermediate, and regional flow systems (after J. Toth, 1963).

secondary fracturing in the rock mass. Any type of planar geologic feature (cleavage, joints, bedding planes and faults) can act as a fluid conductor in fractured bedrock, but the importance of any one depends on topography, bedrock strike, degree of weathering, and areal continuity of the feature. Faults usually transmit a larger volume of water than the other types of conductors. Yield of bedrock wells is greatest in competent folded rocks such as quartzites (Stearns, 1968), along geologic contacts, and along fold axes (especially anticlines). In layered rocks, groundwater flow is controlled both by topographic gradient and by strike of the strata or joints, with the flow direction being a resultant of these vectors.

For more detailed information, the reader is referred to Brown (1967), Cederstrom (1972), Davis et al (1964), Larsson (1972), and Snow (1965, 1968 a and b, 1970).

Surficial

In the study areas, these consist mainly of glacial till, with minor alluvium and buried sands and gravels.

Unconsolidated deposits transmit water through intergranular pore spaces. Permeability depends on several factors, but may be increased in glacial tills by the presence of permeable joints capable of increasing recharge to underlying units (Williams et al, 1967). On the whole, the permeability of till is relatively

low and may retard infiltration rates and act as a confining layer (Norris, 1963). Sands and gravels, on the other hand, are usually quite permeable and able to transmit and yield a larger volume of water at a faster rate.

For more detailed information, the reader is referred to Davis (1966, 1967), Knutsson (1971), Rumsey (1971) and Williams et al (1967).

Hydraulic Properties of the Bedrock Aquifers

Pump tests, drillers' logs, and flownets can be used to determine aquifer parameters such as transmissibility, storage coefficient and specific capacity, all of which are important when determining safe yield of a well and predicting the interaction of groups of wells.

Pump Tests

Discussion of the different methods used for pump test analysis and their interpretation and limitations can be found in Walton (1960, 1962), Lohman (1972), and Davis et al (1966).

Table 2 presents the results of some pump tests available in the study areas. Storage coefficient determinations were made only for tests with observation well data, since S cannot be reliably calculated from pumping well data alone. Pump test locations are shown on figs. 5.1 and 6.1.

TABLE 2

TRANSMISSIBILITY (T) AND STORAGE COEFFICIENT (S)

VALUES FROM PUMP TESTS

CODE	LOCATION	T from drawdown data	T from recovery data	T from observation well data	Average T igpd/ft	S
	BIRCH COVE AREA					
PT 1	Cresthaven, well no. 2	1553.0	960.0	1226.0	1246.3	2.5×10^{-4}
PT 2	Cresthaven, well no. 1	24.5	18.7		21.6	
PT 3	Wedgewood Park	86.8	66.6		76.7	
PT 4	Seaking Motel	8.5	6.8		7.7	
	SACKVILLE AREA					
PT 5	Uniacke mobile homes	8.4	8.0		8.2	
PT 6	Woodbine trailer park	79.2	73.5		76.4	
PT 7	Springfield estates	176.0	192.0		184.0	
PT 8	Century park	41.0	24.0	156.0	74.0	1.4×10^{-6}

The results indicate a very wide range of transmissibility values, reflecting structural inhomogeneities and permeability variation in the bedrock. The high value for pump test 1 (PT1, table 2) likely indicates the presence of a shear zone. The value of S for PT 8 is in the artesian range, as would be expected since the bedrock is confined by glacial till. For PT 1, in which the well penetrates only 3 feet of till, the value of S is in the semiconfined to artesian range; this could be a result of the fact that with drawdown, water can be released from storage only where joints occur in the rock mass, and the volume represented by these joints is only small when the total rock volume is considered.

Specific Capacity Data

Specific capacity is the yield of a well per foot of drawdown (Walton, 1962). Gabert (1961) developed a method of estimating specific capacity from drillers' logs. Results for the study areas are shown on table 3. The specific capacity values are relatively low, with a mean of 0.09 gpm/ft of drawdown for wells tested for 2 hours or more. This means that a very large increase in drawdown is required for any significant increase in the well yield; perhaps a group of wells, each with a small drawdown, would be a more effective method of increasing the yield.

Flownet Data

A flownet can be prepared from maps of the groundwater elevation (figs 5.2 and 6.3). Methods of flownet analysis are discussed in Lohman (1972) and Walton (1962).

TABLE 3

SPECIFIC CAPACITY DATA FROM WELL DRILLERS' LOGS

WELL NO	Pumping Rate gpm (Q)	Draw-down, ft (s)	Time, hours	Available Drawdown, ft (AD)	Spec. Cap. gpm/ft (Q/s)	Yield, gpm (Q/s x AD)
A. BIRCH COVE AREA						
R 18	2 1/2	23	2	143	.11	15.7
R 30	1 1/2	100	1/60	120	.02	1.8
R 31	1/2	200	1/60	200	.00	0.6
R 39	2	70	1/60	65	.03	1.9
R 51	45	460	1/30	470	.10	45.9
R 53	3/4	78	1/60	59	.01	0.6
R 66	6	15	1/60	10	.40	4.0
B. SACKVILLE AREA						
S 57	6	75	2	30	.08	2.4
S 62	3	142	2	80	.02	1.6
S 80	2 1/2	74	2	52	.03	1.6
S 106	3	15	2	29	.20	5.8
S 112	4	70	1 1/2	48	.06	2.9
S 120	2 1/2	215	1	143	.01	1.7
S 174	2 1/2	40	1/6	66	.06	4.0

Using an estimated value of transmissibility of 80 gpd/ft, the total groundwater flow through the Birch Cove study area is about 65,000 gpd and through the Sackville area 220,000 gpd. These values represent a deficit of supply versus demand; however, homeowners in general have not reported lack of water, except for some dug wells in dry summers. If we let supply equal demand, then a regional transmissibility of 180 gpd/ft in Birch Cove and 124 gpd/ft in Sackville is required. These values might be more representative on a regional basis. It is noteworthy that the calculated T values are of the same order of magnitude in both areas, although quartzite predominates in Birch Cove and slate in Sackville. It appears that quartzite may yield more water than slate, possibly because the near vertical cleavage in the latter reduces the probability of a well striking water-bearing fractures.

Hydrologic Budget

Introduction

A hydrologic budget is a quantitative statement of the balance between the total water gains and losses of a basin for a period of time (Walton, 1962). The time used is normally the water year, which extends from October 1 to September 30 in the Maritimes (Trescott, 1968a). Surface and groundwater storage are at a minimum at the start and finish of the water year.

In the budget, inflow equals outflow plus or minus changes in basin storage.

Assuming precipitation (P) to be the main input, and streamflow (R) and evapotranspiration (ET) to be the main outputs, then $P = R + ET \pm \Delta S$, where ΔS refers to changes in storage (Trescott, 1968a). Streamflow is composed of surface runoff and groundwater runoff (baseflow). Separation of these two components can be made from stream discharge hydrographs by the methods used in Kunkle (1962), Schicht and Walton (1961), and Trescott (1968 a).

Baseflow consists of bank storage and basin storage discharge. Bank storage discharge occurs only when the river stage is below the water table and is a result of bank storage recharge at times when the stream stage is above the water table. The baseflow recession (which occurs mainly during the summer) can be separated on a semilog discharge - time plot of streamflow when minimum discharge values can be connected by a straight line (Kunkle, 1962). Annual baseflow fluctuations are related mainly to changes in bank storage.

Basin storage discharge is that part of the baseflow which results from the infiltration of precipitation to the groundwater reservoir; it is normally assumed equal to the minimum discharge values of a stream, and discharge equals recharge during a typical water year (Kunkle, 1962).

For the following calculations, mean daily discharge records were used from the East River at St. Margaret's Bay and the Beaver River at Kinsac. Hydrographs for the water years 1971-72 and 1972-73 are shown on figs. 3.2 and 3.3.

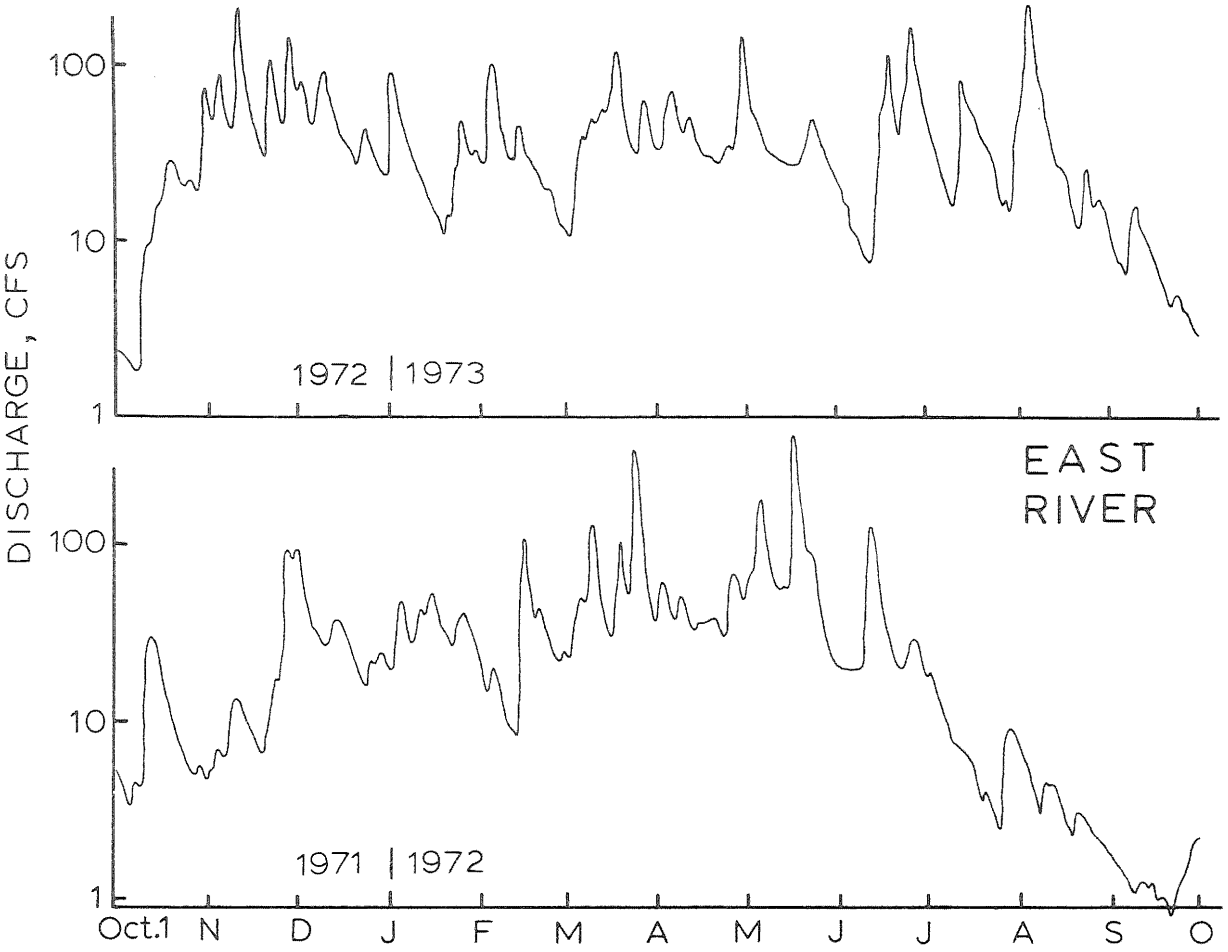


Figure 3.2. Hydrographs for the East River for water years 1971-72 and 1972-73.

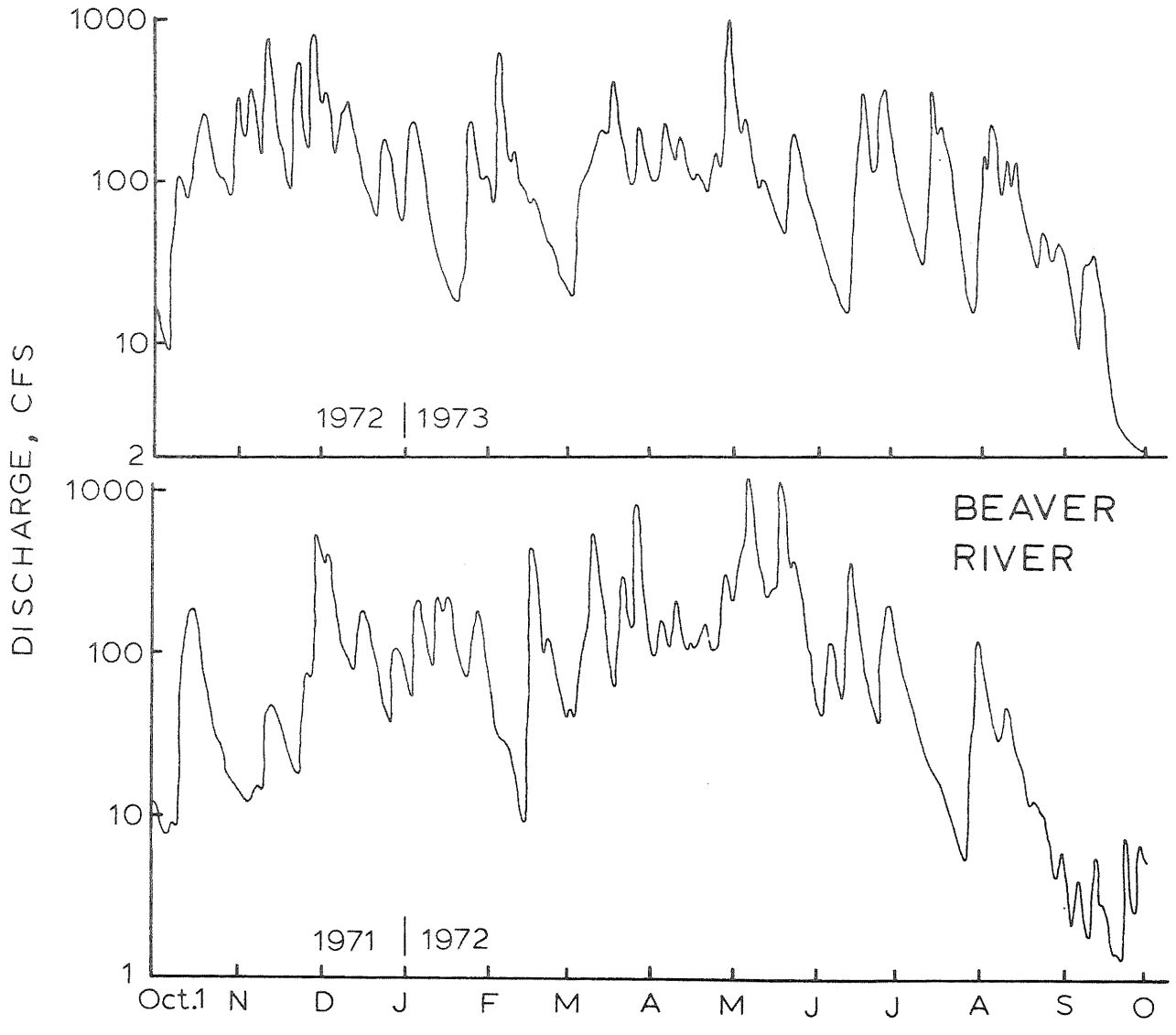


Figure 3.3. Hydrographs for the Beaver River for water years 1971-72 and 1972-73.

The East River drains a granitic area 20 miles west of Halifax. Since bedrock is at or near the surface, the relative proportion of the precipitation that appears as baseflow and surface runoff should be similar to the Birch Cove area. The Beaver River station lies within the Sackville study area. Both rivers show a much larger decrease in storage at the end of the water year 1971-72 than 1972-73 due to the lower precipitation. The more constant discharge level in 1972-73 reflects higher rainfall and possibly a more even distribution of precipitation.

The value of P in the budget equation was calculated from precipitation records from CFB Shearwater; values from this station are comparable to other stations in the Halifax area at a significant level (Dr. J.G. Ogden, personal communication). Annual evaporation in the Halifax area averages 15" (ADB Report, 1969). In table 4, changes in basin storage are considered negligible and ET is given as the difference (P-R). If an ET of 15" were used, a change in storage of 1-3" would occur in the two basins.

It is evident from table 4 that streamflow accounts for 75-80% of the total precipitation and baseflow for about 50% of the precipitation in the East River basin and 39% in the Beaver River basin , on the average. The differences in baseflow may be due to greater storage in the till or more surface runoff in the Beaver River basin.

Results

Birch Cove

The results in table 4 can be applied to supply-demand calculations of house-

TABLE 4

HYDROLOGIC BUDGET SUMMARY

A. East River, Drainage Area 6656 acres; B. Beaver River, Drainage Area 23,936 acres

River	Water Year	P inches	R * inches	R * % of P	ET inches	ET % of P	Baseflow inches	Baseflow % of P	Basin Storage inches	Basin Storage % of baseflow	Basin Storage % of P	Surface Runoff inches	Surface Runoff % of P
A	71-72	57.1	42.7	75.0	14.4	25.2	31.2	54.7	4.95	12.7	6.9	11.5	20.2
	72-73	63.6	51.9	81.5	11.7	18.5	30.9	48.6	4.95	12.8	6.2	21.0	33.0
B	71-72	57.1	43.7	76.7	13.5	23.7	22.5	39.4	2.4	10.6	4.2	21.2	37.1
	72-73	63.6	51.1	80.0	12.6	19.8	24.8	39.0	2.4	9.6	3.7	26.3	41.4

* R = total streamflow (including baseflow).

hold water use. On the basis of records kept by the Public Service Commission on monitored well R5 which supplies a 51-house subdivision (with a supplement supply of city water), the average water use is 170 gpd/house. The Birch Cove area contains about 800 houses:

Total demand = 136,000 gpd or 183 acre-feet (ac-ft)/year

Area = 1 $mile^2$

Groundwater recharge = 6.6% * of 54.4" (average annual precipitation)

= 3.6"/year = 191 ac-ft/mi^2 .

Hence 183/191 x 100 = 96% of the available supply is being used.

Sackville

The study area contains about 3500 houses, of which approximately 1000 are being served by water from First and Second Lakes. Using a requirement of 170 gpd/house, then:

Total demand = 170 x 2500 = 440,000 gpd = 590 ac-ft/year

Area = 30 mi^2

Groundwater recharge = 4% * of 54.4" = 2.2"/year = 116 ac-ft/mi^2 =

3479 ac-ft/30 mi^2 .

Hence 590/3479 x 100 = 17% of the available supply is being used at present.

* The basin storage component of baseflow is used as the percent of precipitation available for groundwater recharge since this component results directly from infiltration of precipitation. These figures are somewhat conservative.

Groundwater Level Fluctuations

When possible, water levels were measured in two dug wells in Maxwell Subdivision and one dug well in Birch Cove. The results are shown in fig. 3.4.

In general, water level fluctuations are due to: 1) actual change in volume of the water in the aquifer, due mainly to precipitation, evapotranspiration, and pumping, and 2) pressure transmission without actual volume change, due to events such as sea level changes, barometric changes, and loading by heavy vehicles (Nilsson, 1968). The sensitivity of an aquifer's response to these changes is a function of permeability, amount of water in storage, and thickness of a confining layer (if present). The time lag between a precipitation event able to recharge the groundwater reservoir and the initial response of a well depends on soil moisture content, depth to water table, pore size distribution of material above the water table, and rainfall intensity; during winter and spring, a lag of a few hours is common (Bonell, 1972).

Hydrographs of groundwater levels usually show peaks in spring and late fall when the soil moisture deficit is overcome, evapotranspiration is low, and precipitation is relatively high. A slight recession may occur in the winter due to frozen ground and moisture in the form of snow reducing the rate of recharge; the most marked recession is normally during the summer, from July to September. Little or no recession is evident in fig. 3.4 for wells R67 and S14, perhaps

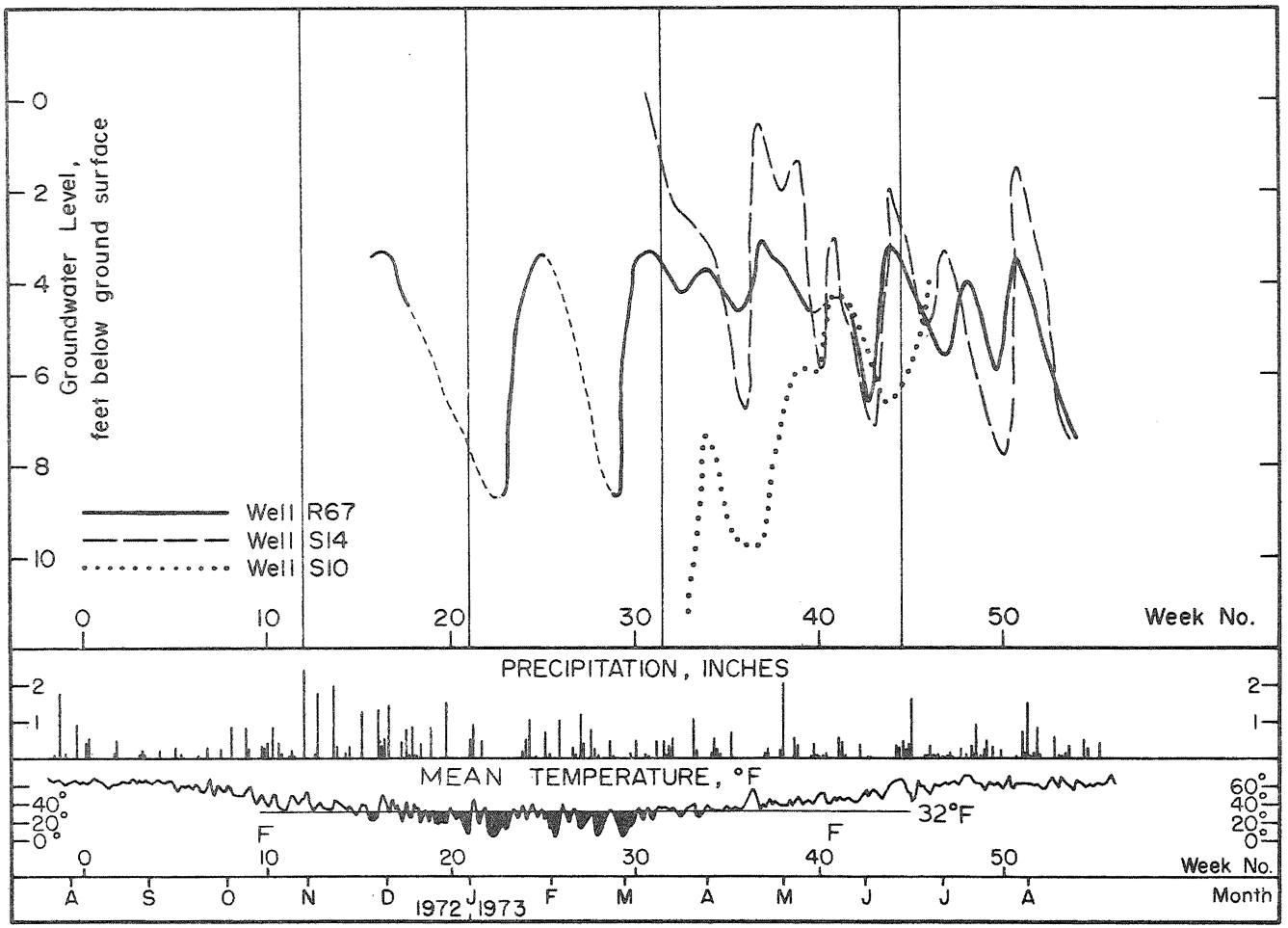


Figure 3.4. Groundwater level fluctuations.

reflecting the above average preceipitation which fell during the water year 1972-73; a longer period of measurement is needed to ensure that there is no delayed effect in the water level changes. Well S10 likely shows a delayed response since its water level rose during the summer; its situation in an impermeable zone of glacial till may account for this delay. Bonell (1972) found that water levels in boulder clay in England responded both to rapid seepage entering the wells from a widespread perched water body and to a delayed seepage from lower parts of the aquifer. This type of response could be occurring in the Maxwell area, with well S14 showing the former response and well S10 the latter. The nonuniform increase in potential throughout the till as a result of precipitation is evident from the differing responses of wells S10 and 14, which are located about 200 feet apart.

Water levels in well R67, completed in bedrock, appear to show an upper and lower limit - this may represent the effects of low storage capacity of the fractures.

Chapter 4

GROUNDWATER CHEMISTRY

General Controls on Groundwater Composition

Natural Controls

Climate, soils, and geology are the main controls on groundwater composition (Hem, 1970). Climatic effects include weathering, evaporation rates, and vegetation types. In a humid temperate climate with rainfall continuously available as a weathering agent, low evaporation rates, and profuse vegetation, groundwaters will be predominantly of calcium bicarbonate type (Hem, 1970).

The composition of rain which percolates through the soil zone is affected by factors such as soil moisture composition, availability of weatherable minerals and/or weathered products, and carbon dioxide pressure in the soil pores. The time available for reactions depends on permeability, grain size, and soil moisture deficit of the soil.

The composition of the bedrock affects water chemistry, but the rate of dissolution varies with temperature, pressure, pH, purity and crystal size of the minerals, rock texture and porosity, flow velocity, area of interface between soluble minerals and groundwater, and length of contact time between the water

and soluble minerals (Hem, 1970). The most aggressive reactions occur in the upper part of the aquifer, where the water is most undersaturated with respect to minerals of the aquifer. In fractured crystalline rocks the area of solid-liquid interface per unit volume of stored water is low, resulting in a water low in dissolved minerals (Hem, 1970). Also, a layer of water may become adsorbed on fracture walls, thus slowing down reactions. Pre-fracturing processes can also influence water chemistry; for example, change of high exchange capacity minerals (clays) to those of lower exchange capacity (micas) decreases the soluble minerals available for reaction with groundwater (Hem, 1970).

In summary, much more complex relations are possible in deep confined aquifers where a long contact time and mixing of waters is possible than in shallow unconfined aquifers recharged directly by precipitation (Hem, 1970).

Manmade Controls

Man cannot always use natural waters directly for different purposes. Various industrial processes may, for example, require hard or soft water. This concept is called water quality. Good quality drinking water should be "safe, palatable, and aesthetically appealing" and "free from pathogenic organisms, deleterious chemical and radioactive substances, and objectionable colour, odour, and taste" (Canadian Drinking Water Standards, 1969, p. 1). According to these standards, the following are recommended acceptable limits for some of the chemical parameters measured:

TABLE 5

RECOMMENDED LIMITS FOR SELECTED CHEMICAL CONSTITUENTS IN DRINKING WATER

Parameter	Acceptable Limit (in ppm or mg/l)
Ca	200
Mg	150
Fe	0.3
Mn	0.05
Cl	250
SO_4	500
NO_3-N	10
Alkalinity	30-500
Hardness	Less than 80 ppm as $CaCO_3$ is considered as good quality, but there is no definite limit

Description of Selected Chemical Parameters Measured in the Study Areas

The average composition of rainfall in the study areas is presented in the following table:

TABLE 6

MEAN VALUES OF CHEMICAL COMPOSITION OF RAINFALL (IN PPM)

Na	K	Ca	Mg	Fe	Mn	Alk.	SO_4	Cl	NO_3-N	Conductance	pH	
1.3	0.20	0.32	0.24	0.04	0.01	1.0	3.2	3.5	0.14	22	4.9	*
1.8	0.13	0.20	0.14	0.03	0.01	1.0	3.0	3.5	0.13	16	4.9	**
2.88	0.32	0.68	0.52				6.3	5.5				+
2.0	1.0	1.2	0.3			1.0	5.0	3.0	0.60		6.0	++

* Personal data, Birch Cove

** Personal data, Sackville

\+ Mean weighted values from Citadel Hill, Halifax (Wm. Hart, Dalhousie University, unpublished data)

++Data from the Annapolis Valley, Nova Scotia (Thomas, 1974)

Sodium (Na^+)

Sodium released from plagioclase feldspar during weathering is likely the major geologic source of Na in the study areas since albite is the dominant feldspar in both the Meguma rocks and the granite. Other sources include road salt, septic tank effluent, soil dust, and dry fallout from the atmosphere. Natural and artificial water softening may increase Na in groundwater since divalent ions such as calcium are preferentially adsorbed over Na.

Potassium (K^+)

Potassium is released during the weathering of alkali feldspar, but with more difficulty than Na from plagioclase feldspar, since the lower ionic potential and greater ionic radius of K make it less mobile than Na and it tends to be reincorporated into mica and clay structures. Plants tend to concentrate K as a nutrient element. Leaching of fertilizer may add K to the groundwater.

Calcium (Ca^{++})

This element is widely distributed in common rock and soil minerals such as pyroxenes, amphiboles, and plagioclase feldspar. Other sources include calcium carbonate nodules in the Meguma Group, which tend to be concentrated in the centre of thick sandstone beds (P. Schenk, personal communication), soil dust (Tamm, 1955), and $CaCO_3$ and/or $CaSO_4$ in glacial till. The reddish brown till in the Sackville area contains calcareous material derived from the Windsor Group

(limestone, gypsum, sandstone and shale). Calcium carbonate weathers as follows:

$$CaCO_3 + CO_2 + H_2O \text{ (or } + H^+) \rightleftharpoons Ca^{++} + 2HCO_3^-$$

Calcium is less mobile than Na and tends to be adsorbed on negatively charged mineral surfaces, a process called ion exchange. The solubility of Ca in water in contact with air is 16-20 ppm (Hem, 1970), controlled mainly by pCO_2 (see equations in appendix 3). Oxidation of pyrite may cause Ca to be brought into solution in amounts greater than indicated by the above equation for $CaCO_3$ weathering.

Magnesium (Mg++)

Magnesium is widely distributed in rock and soil minerals. The most likely sources in the study areas are biotite, chlorite, and cordierite.

Iron (Fe++ and Fe +++)

Pyrite, biotite, magnetite, iron oxides and hydroxides in soil, and carbonate nodules in the bedrock are some possible sources of Fe in the study areas. Organic wastes and plant debris may contribute Fe, since this element is essential in plant and animal metabolism. In the pH range 5-7 found in the study areas, stable forms of Fe include FeS_2, Fe^{++}, and $Fe(OH)_3$. In many cases the common range of concentrations of iron in groundwaters is 1 to 10 mg/l (Hem, 1970).

Manganese (Mn^{++})

Commonly found in rocks and soils, this element is highest in dark silicate minerals with hydroxyl groups such as biotite (1% Mn) and hornblende (0.3% Mn) (Hem, 1970). Manganese in the soil is also found as hydroxides and bicarbonates. Manganiferous layers and nodules are found in slaty beds of the Meguma Group. Organic circulation of Mn is important - it has been found in high concentrations in tree leaves (Hem, 1970). Bacterial reduction of organic material may release large amounts of Mn from oxides into solution. In the pH range 5-7, Mn^{++} is stable, and a concentration of 1 ppm is stable in oxygenated water unless the pH is very high (Hem, 1970).

Alkalinity (HCO_3^-)

This is defined as the capacity of a solution to neutralize an acid. The source of alkalinity is mainly anions of weak acids which are not fully dissociated above pH 4.5, such as dissolved OH, CO_3, and HCO_3 (Hem, 1970). Alumina and silicic acid anions are minor contributors. In the study areas essentially all the alkalinity is due to HCO_3, hence it was assumed that total alkalinity equals HCO_3 alkalinity, and this was used to calculate the HCO_3 concentration. Carbonate does not become an important contributor until pH 8.3 or more.

A water in equilibrium with the atmosphere will dissolve about 63 ppm HCO_3 alkalinity, while one in equilibrium with soil air can contain more than

100 ppm (Parsons, 1967) due to the higher pCO_2 of the soil air (induced by both decomposition of organic materials in the soil and lowering of pH at the surfaces of roots (Garrels et al, 1971).

Sulphate ($SO_4^{=}$)

Oxidation of pyrite and of hydrogen sulphide gas are two possible sources of SO_4 in the study areas. The latter source is found mainly in wells receiving recharge from swampy areas, especially those associated with Sphagnum moss. At the pH ranges encountered in the study areas SO_4 is the stable sulphur form under oxidizing and slightly reducing conditions and H_2S under highly reducing conditions.

Sulphate is the major anion in precipitation over Nova Scotia, possibly due in part to sulphur dioxide from combustion processes. Higher sulphate is found in winter precipitation recharging the groundwater as a result of burning of home fuels (Herman, 1957). Higher values of SO_4 may be found also in waters associated with faults or shear zones (Feth, 1964).

Chloride (Cl^{-})

Geologic sources of chloride are scarce in the study areas. If the Meguma Group (deposited in a marine environment) has not been completely leached, then some residual or fossil water contained in pores of the rock or within crystals may

contain Cl. Hydroxyl groups in biotite, muscovite, and hornblende can be replaced by Cl. This source is unlikely to contribute significant amounts of Cl to the groundwater system.

Dry fallout, sea spray, and evaporation can double or triple the background value of Cl (table 6) in groundwater (Eriksson, 1960 and Jacks, 1973). Chloride circulation is mainly physical, hence it is a useful tracer. However, chloride does participate in a minor way in ion exchange reations, e.g. 100 grams of clay can adsorb 0.3 meq of Cl at pH 6.7, 1.1 meq at pH 6.1, and 2.4 meq at pH 5.8 (Feth, 1964). Hence in a clayey medium, with long contact time, some Cl may be removed from groundwater.

Urban sources of Cl in the study areas include road salt, septic tank effluent, industrial air pollution, and input by water softeners. In this study, human contributions to Cl concentrations are considered to be operating when values are greater than 50 ppm.

Nitrate (NO_3^-)

The main sources of NO_3 in groundwater in the study areas are the atmosphere (air pollution) and soil and biologic material. Fertilizers and organic wastes from humans and animals may also increase NO_3 when present in excessive amounts.

pH

Most of the groundwaters in the study areas lie within the pH range 5 to 7. In Sackville, a few samples are greater than 7.

Silica (SiO_2)

This ion was not monitored, but was measured once on each monitored well and on some spot samples. The main source of the ion is dissolution of quartz and/or equilibrium with weathered products containing SiO_2 (such as kaolinite). The latter source controls the water composition by its presence (Feth, 1964 and Garrels et al, 1967, 1971). The common range of concentrations encountered in the study area is 5-15 ppm.

Temperature

The degree of fluctuation of groundwater temperature decreases with depth while the time lag between air and water temperature changes increases (Brown, 1973). Anomalous temperatures may occur in the vicinity of fault zones.

Temperatures were measured every few weeks on the monitored wells.

Groundwater Chemistry and Flow Systems

In sequences of sedimentary rocks, Back (1966), Vandenberg et al (1969), and others have found that parameters such as Cl%, Na%, HCO_3%, and total dissolved solids can be used to indicate increasing age or metamorphism of

groundwaters; Chebotarev (1955) predicted the following progression:

$$HCO_3 \rightarrow \begin{matrix} HCO_3 \\ + \\ SO_4 \end{matrix} \rightarrow \begin{matrix} SO_4 \\ + \\ HCO_3 \end{matrix} \rightarrow SO_4 \rightarrow \begin{matrix} SO_4 \\ + \\ Cl \end{matrix} \rightarrow \begin{matrix} Cl \\ + \\ SO_4 \end{matrix} \rightarrow Cl$$

Bicarbonate is high in recharge areas since solution of Ca and Mg carbonates in the soil is rapid compared to other processes. Sulphate is added more slowly by processes such as dissolution of gypsum and oxidation of sulphide minerals. A SO_4 zone may be lacking if SO_4 is being reduced and hydrogen ion is being used up. Chloride is added gradually by attack on silicates containing Cl (e.g. biotite, muscovite, and hornblende). Thus Cl% and total dissolved solids are high in the discharge areas. Sodium percent also increases toward the discharge area as a result of base exchange processes which preferentially retain Ca and Mg. The general order in which the cations tend to become fixed is (Vandenberg et al, 1969): $H^+ > Ca^{++} > Mg^{++} > K^+ > Na^+$. Thus the trend in groundwater metamorphism is towards enrichment in those ions with the greatest affinity for the dissolved state, i.e. Na and Cl (Chebotarev, 1955).

Seasonal Fluctuations in Groundwater Chemistry

Several types of processes can account for seasonal or short-term water chemistry variations. Seasonal biological activity can affect K, NO_3, Ca and HCO_3. Plant nutrient elements such as K and NO_3 should be higher during periods of plant dormancy. Gorham (1961) found that Ca and Mg were released from forest vegetation in the fall and caused a rise in conductance and pH in lake

waters. Jacks (1973) found HCO_3 to be lower in winter due to decreased biological activity and lower pCO_2.

Short-term chemical variations may also be a result of active infiltration into the groundwater system and accentuation of slight volume changes by the small storage volume of fractured bedrock. Precipitation-evapotranspiration relations are common causes of dilution-concentration effects in water chemistry. "Slug" type inputs to the groundwater system can cause short-term changes. These may be as a result of man's activities or of natural effects such as retardation of infiltration in the winter by frozen ground and input of ions concentrated in a slug in the spring. Snow-covered forest soils may, however, remain unfrozen throughout the winter and allow perennial infiltration (Likens et al, 1967). The effect of slug input on water chemistry (as to whether changes are sharp or subdued) depends on factors such as aquifer permeability, composition and concentration of the source, and effects of dilution between the source and point of measurement. Chemical changes due to urbanization may also result from faulty well construction, high pumping rates, and input from contaminated surface water runoff.

Seasonal variations in chemistry were monitored in Birch Cove and Maxwell Subdivision. Emphasis will be placed on variations in salt content in the well waters, since road salt contamination has been a documented problem for some time in the Halifax area.

Chapter 5

DISCUSSION OF RESULTS IN THE BIRCH COVE AREA

The general topography, geology, and water table elevation of the study area are shown in figs. 5.1, 2.1, and 5.2 respectively.

Movement of Groundwater in Birch Cove

A topographic profile extended inland from the study area, parallel to the strike of the Birch Cove anticline, shows that the topographic high in Birch Cove is the main relief on a general regional slope from the Blue Mountain Hills (water divide) to the sea (fig. 5.2). This indicates that a regional flow could develop, with the Birch Cove high serving as a local or intermediate recharge area for most of the wells in the study area. Evidence of groundwater flow is shown in photos 7 and 8 by perennial seepage from joints in a road cut.

Well drillers logs (fig.2.10) were located in the area to provide some control for depth to water and depth to bedrock. The water table elevation was calculated from topographic elevation minus depth to water in the well, using sea level as datum. The resulting water surface (fig. 5.2) will be called a water table since it is essentially unconfined; however, fluid pressures in the joints are greater

Photo 7: Seepage of groundwater from joints during the summer, Birch Cove. Note the abundant moss growth indicative of a good moisture supply. This flow during the dryest part of the summer implies a perennial supply of groundwater.

Photo 8: Seepage of joints during the winter, Birch Cove. Note the ice sheet covering the joint face, fanning out from its discharge point along a joint plane (a bedding plane joint in this case).

than would be expected if equilibrium with the atmosphere was attained. This water table is not actually continuous in the bedrock - there are blocks of unfractured rock - but fig. 5.2 represents the probable levels to which water would rise if the aquifer were penetrated by a well. These levels are lines of equal fluid potential, and groundwater flows at right angles to these lines, from higher to lower potential. Although the water levels obtained from the well logs pertained to different seasons and different years, the author considers the result to be a reasonable approximation in the lack of other data because 1) the water table is essentially a subdued replica of the topography, and 2) theoretical spring locations (intersection of the water table and topography) shown on fig. 5.2 appeared as dark red on infrared photos of the area, indicating groundwater discharge; also, several homeowners reported the presence of springs in the vicinity. A similar procedure has been used by Novakovic et al, 1974.

Lakes and swamps in this area are surface expressions of the water table exposed by topographic irregularities in the bedrock. Water levels in wells are similar to the levels of nearby surface water bodies, thus it appears that the lakes are not perched above the water table but form part of the groundwater flow system. Streams in the area are controlled by the northeast striking fracture system (fig. 5.1). Groundwater flow is also in this direction in the vicinity of the anticline axis, but follows the topography in the rest of the area. The main recharge area corresponds to the Birch Cove topographic high; the discharge area is Bedford Basin. The average hydraulic gradient is 0.065 ft/ft.

From the geological map of Birch Cove (fig. 2.1) several prominent lineations parallel to the major joint sets are evident, representing possible shear zones. If groundwater is flowing through both these joint sets, the resultant direction of movement should be from west to east, which does occur in part of the area. Near the anticline axis, tension fractures should provide a permeable conduit - this is evident by the channelling of the flowlines toward the axis in fig. 5.2. The well-developed bedding plane fractures in this area may also contribute to the northeasterly component of flow, and will likely carry the largest volume of water since the northeast striking joints parallel the topography near the axis.

By comparison of the water table and topographic maps (figs. 5.2 and 5.1, respectively) it is evident that some irregularities in the water table are associated with topographic depressions and/or lineations on the geologic map (fig. 2.1), indicating that shear zones may be present. For example, area 1 in fig. 5.2 is associated with the intersection of a northwest-southeast draining stream and a prominent northeast striking lineation in fig. 5.1 (area 1A). A pump test nearby (table 2, test 1) shows an unusually high transmissibility. The water table configuration in areas 2 and 3 (fig. 5.2) likely results from channelling along to shear zone depression (fig. 5.1, area 2A) and building up of the water table in the less permeable area 3 (fig. 5.2) away from the shear zone. Fracturing associated with the stream in area 4A (fig. 5.1) appears to control the water table shape in area 4 (fig. 5.2). From this evidence it appears that unusual water table configurations result from inhomogeneities in bedrock structure and may be used to indicate possible shear zones in conjunction with other geologic evidence.

Common well yields in the area range from 1-5 gpm. The distribution of wells with yields greater than 3 gpm (considered as good) on fig. 2.1 appears to correspond to possible shear zones (e.g. wells R41 and 51) or the anticline axis (e.g. wells R7 and 26). The presence of lakes along the granite-quartzite contact (e.g. Washmill and Charlie Lakes in fig. 2.1) could indicate high permeability along the contact; however, there were no wells along this contact with data on yield.

Groundwater Chemistry and Flow Systems

The predominant water types here, based on anions, are Cl-HCO_3, Cl-SO_4, HCO_3-SO_4, and HCO_3-Cl (appendix 5, figs. 1 and 2). Type 3 and 4 waters likely represent either uncontaminated and/or recharge waters, and are found in two types of locations (fig. 5.3): near the anticline axis or shear zones (e.g. wells R3 and 21), and in areas where recharge could come from a local topographic high unaffected by roads (e.g. well R46 and wells near the granite contact southwest of Kearney Lake). Groundwater types 1 and 2 could represent groundwater discharge in some wells along Bedford Basin but for the most part represent salt-contaminated waters since many are either close to roads or downslope from them with respect to groundwater movement. Evidence of some control of water types and flow by the northeast striking joints can be seen from type 2 wells R53, 92, 91 and type 4 wells R21, 3, 46 (fig. 5.3).

Indication that chloride is most likely not a regional discharge indicator

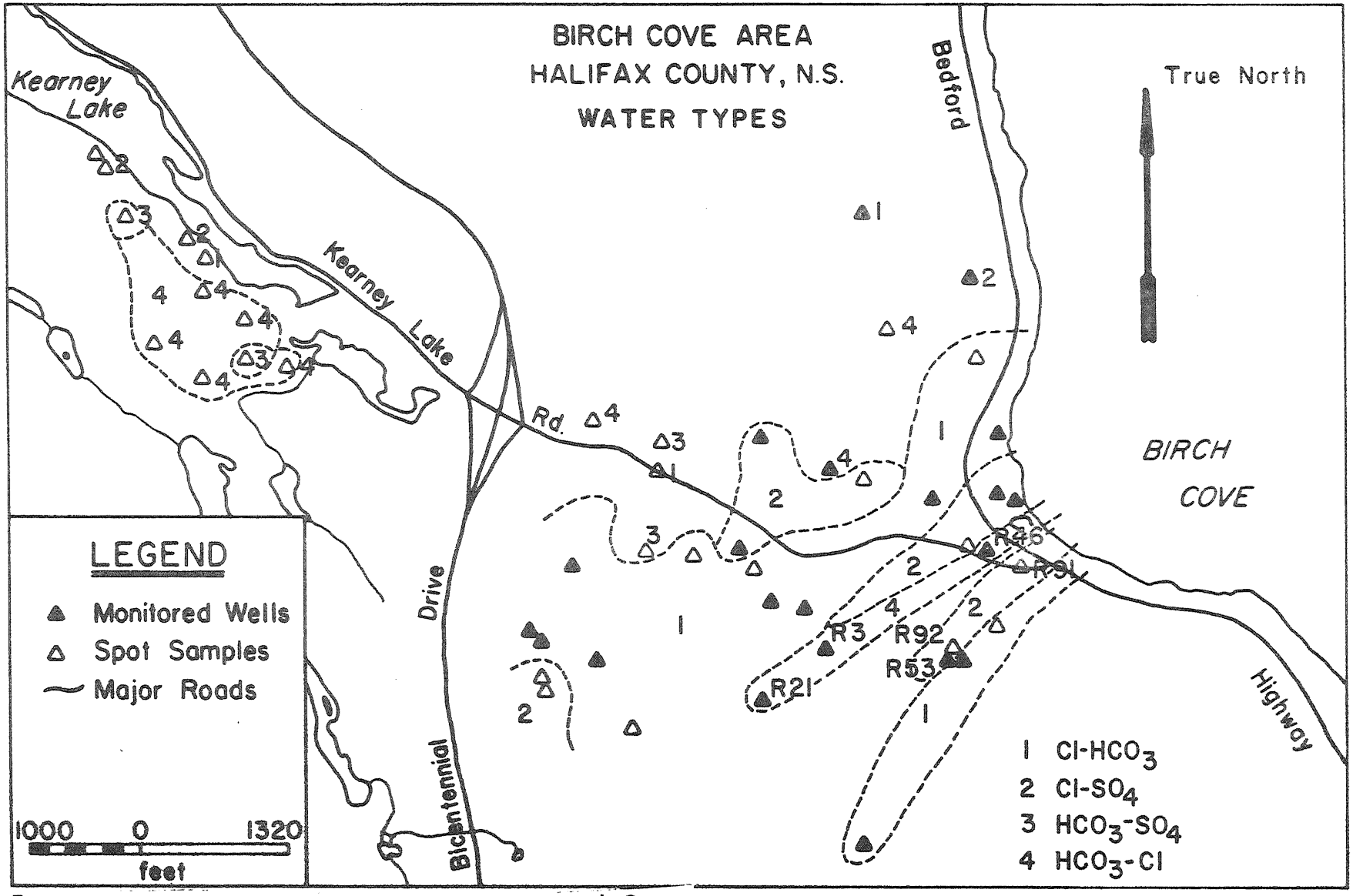


Figure 5.3. Areal variation in groundwater types, Birch Cove.

in this area is illustrated by figs. 5.4 and 5.5. Chloride increases almost exponentially as distance to a road decreases, but shows only a wide scatter relationship with well depth, reflecting variation in the degrees of hydraulic connection between various wells and the roads near them. Thus Cl must be considered with caution as a chemical facies indicator when areal variations alone are considered.

Areal variations in various parameters are shown in figs. 5.6 to 5.13. Both spot samples and monitored wells were used to prepare these maps. The time based means of the monitored wells' parameters were used since they represent a stable composition (Hem, 1970). The mean values and standard deviations of these parameters are presented in appendix 4.

Iron and Manganese (figs. 5.6 and 5.7)

Contours of these ions, especially Mn, show definite northeast trending contours, indicating control by bedrock structure. A zone of low concentration of these ions is found along and near the anticline axis, reflecting rapid recharge. If the values on the maps are compared with the recommended limits in table 5 for these ions, it is evident that Mn poses a much greater problem than Fe. Usually, Fe concentrations are greater than Mn in natural waters (Hem, 1970), but the reverse case is often found in Birch Cove, indicating a disequilibrium condition in the groundwaters since Mn is more soluble but generally less abundant than Fe. Possibly Mn is high in the bedrock, or is derived from organic material,

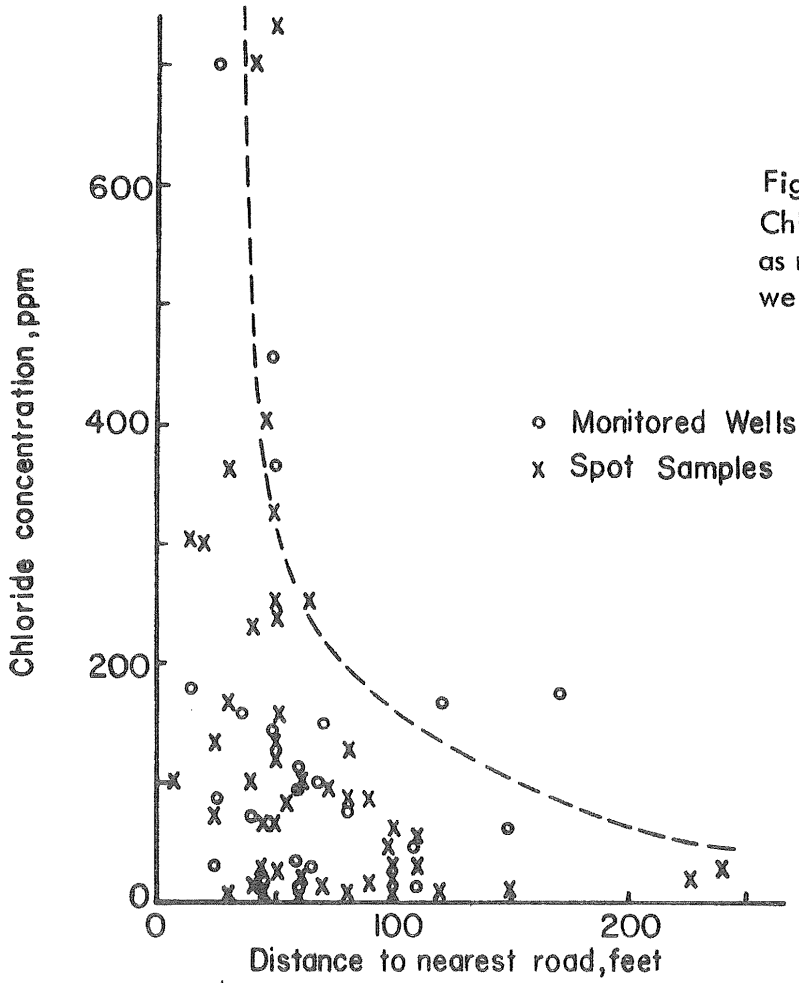


Figure 5.4.
Chloride concentration as related to distance of wells from roads.

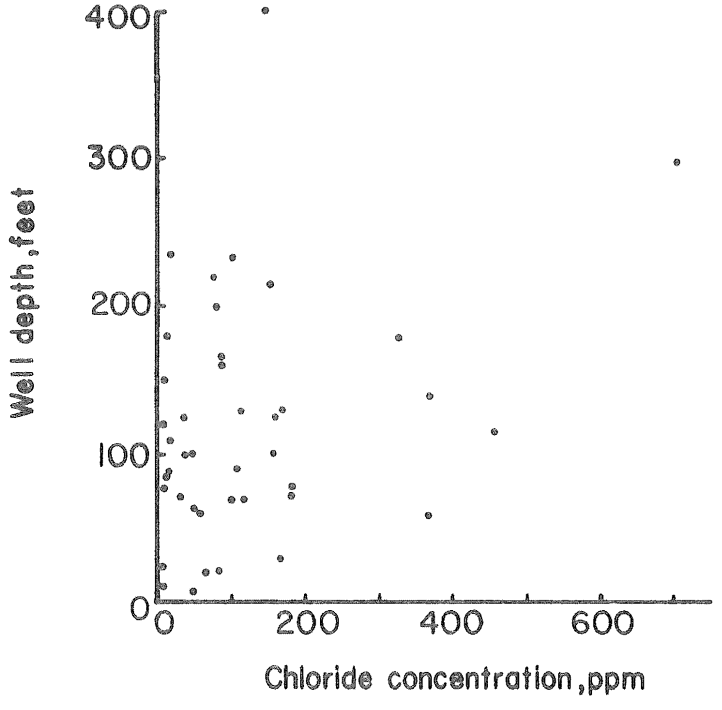


Figure 5.5.
Chloride concentration as related to well depth.

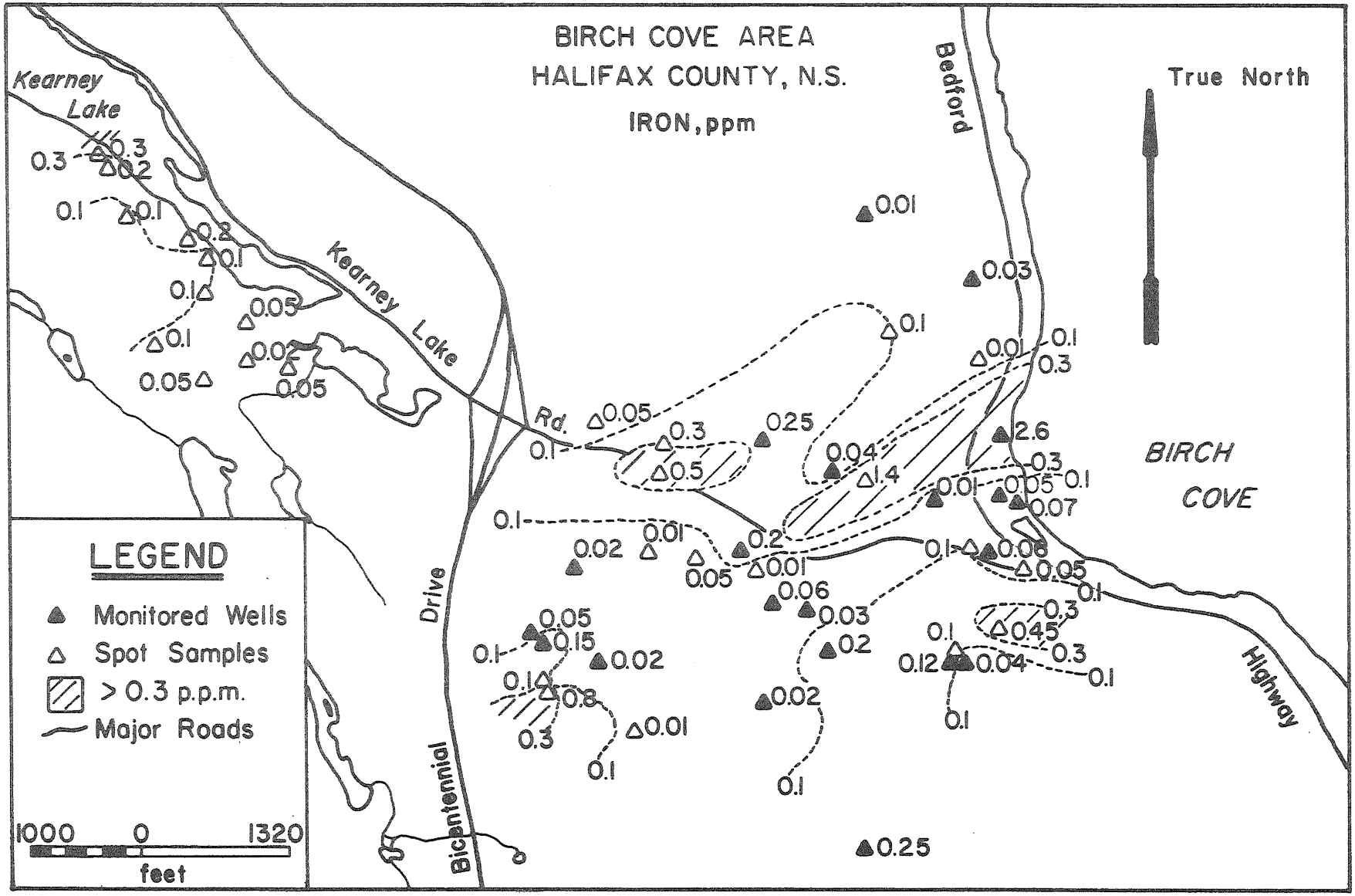


Figure 5.6. Areal variation in iron, Birch Cove.

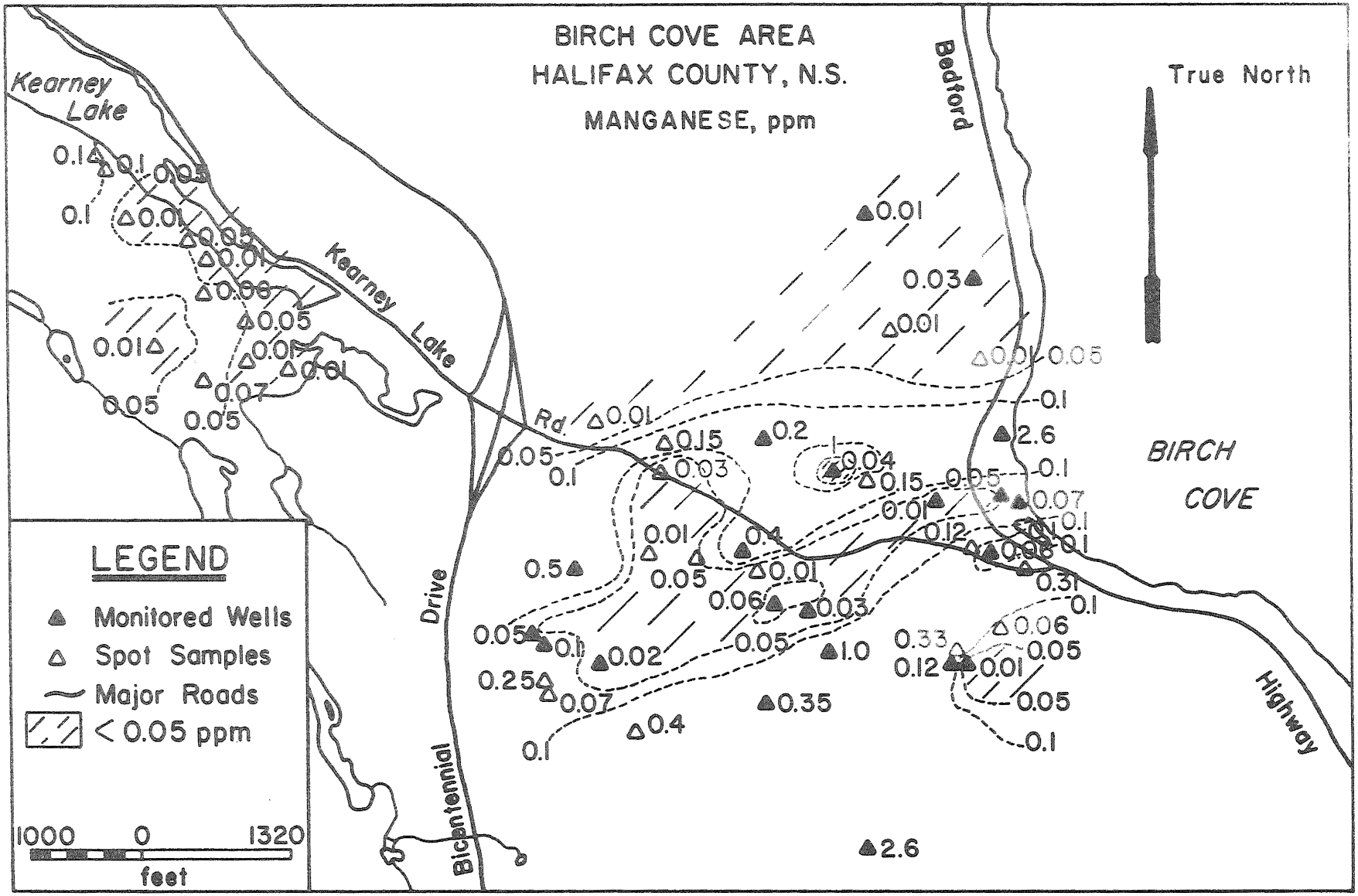


Figure 5.7. Areal variation in manganese, Birch Cove.

for example from bogs where they form part of the groundwater system. Manganese concentrations are low in the northern, forested nonurbanized part of the map area, indicating that Mn release from plants and/or bedrock may be slow under these conditions. However, Fe and Mn appear to be higher in the urbanized part of the area, which supports findings by the N.S. Department of Environment that Fe and Mn concentrations are greater in salt contaminated groundwaters from urbanized areas (John F. Jones, personal communication).

Silica (fig. 5.8)

The variation of silica shows a tendency to reflect the increasing age of groundwater as it moves toward Bedford Basin, although structural control is also evident in the northern part of the map where silica contours parallel flowlines. Wells R67, 90 and 91 near the discharge area do not show high silica values; two of these wells are dug wells and likely reflect rapidly moving shallow groundwater of local origin. The lobe of high silica concentration on the southwest part of fig. 5.8 could represent the discharge of older water; however, these wells also show high concentrations of salt, which implies that groundwater recharge from the major topographic high (Birch Cove High) is moving radially outwards and picking up road salt from the road topographically upslope from these wells. The salt could cause accelerated rock weathering (salt increases the ionic strength of an aqueous solution, which in turn increases the solubility of other ions (Langmuir, 1972)).

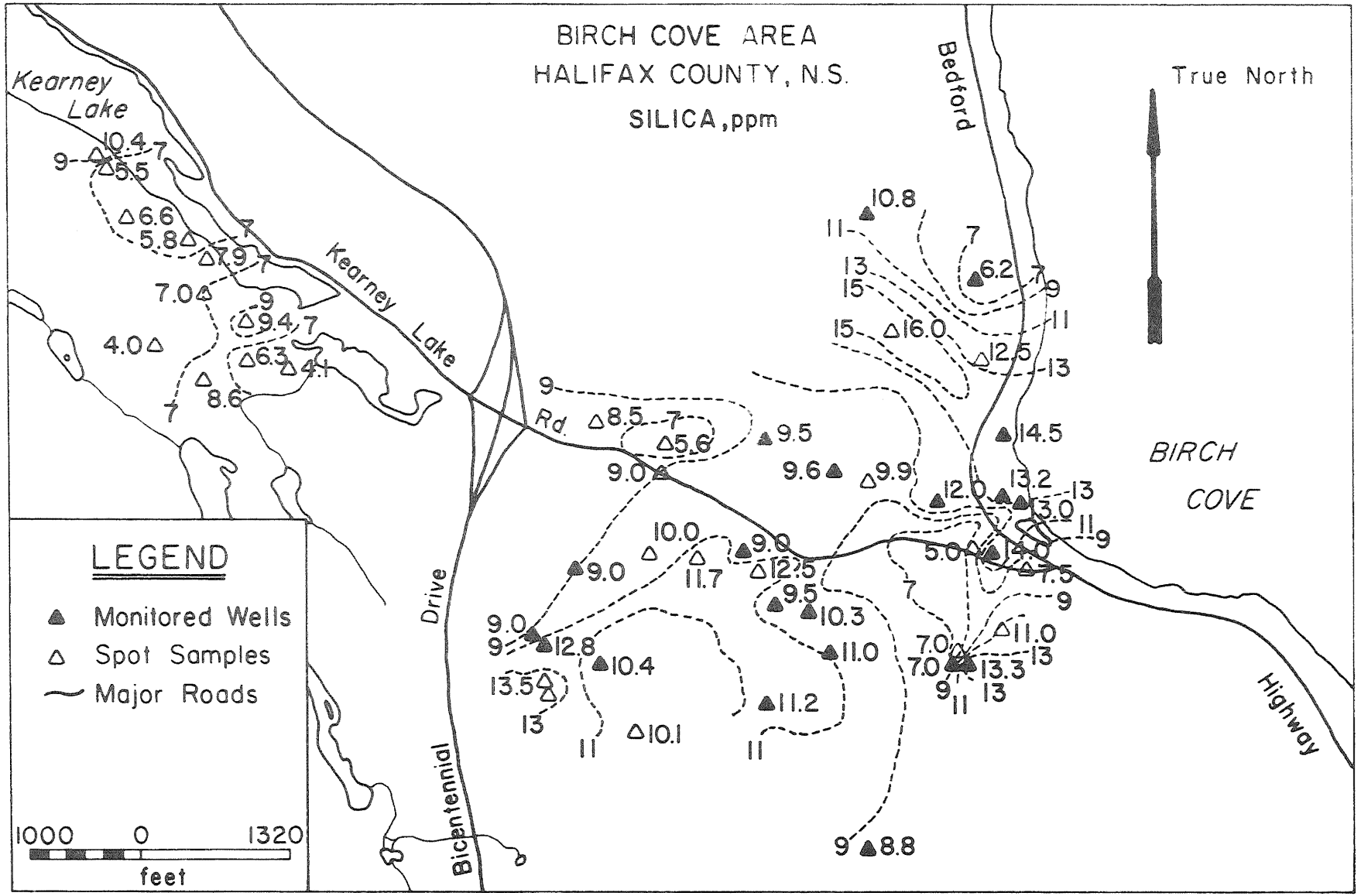


Figure 5.8. Areal variation in silica, Birch Cove.

Sodium and Bicarbonate Percents (figs. 5.9 and 5.10)

These parameters show some evidence of structural control by northeast striking joints. Rapid groundwater movement along the anticline axis is reflected by low values of Na% (< 40%) and high values of HCO_3%(> 20%). Other zones of high HCO_3% (> 40%) coincide with small topographic highs which could be local recharge areas. Bicarbonate percent decreases towards Bedford Basin; however, this could be a result of increase in Cl%.

Chloride (figs. 5.11 and 5.12)

Chloride percent shows a similar areal distribution to Na%. On the whole Cl% is generally above 60% with small local zones less than this, indicating fairly widespread salt contamination. Raw values of Cl (fig. 5.12) show that uncontaminated waters are found on or near the anticline axis and on topographic highs. Highly contaminated wells are found in areas of dense housing and where wells are downslope from a road with respect to groundwater movement. Only a small part of the Cl has a septic tank source (see chapter 7). Road effects are well illustrated by the group of samples southwest of Kearney Lake - all wells on the downslope side of the road contain greater than 50 ppm Cl.

Calcium to Magnesium Ratio (fig. 5.13)

This ratio shows a general decrease in the flow direction, as expected.

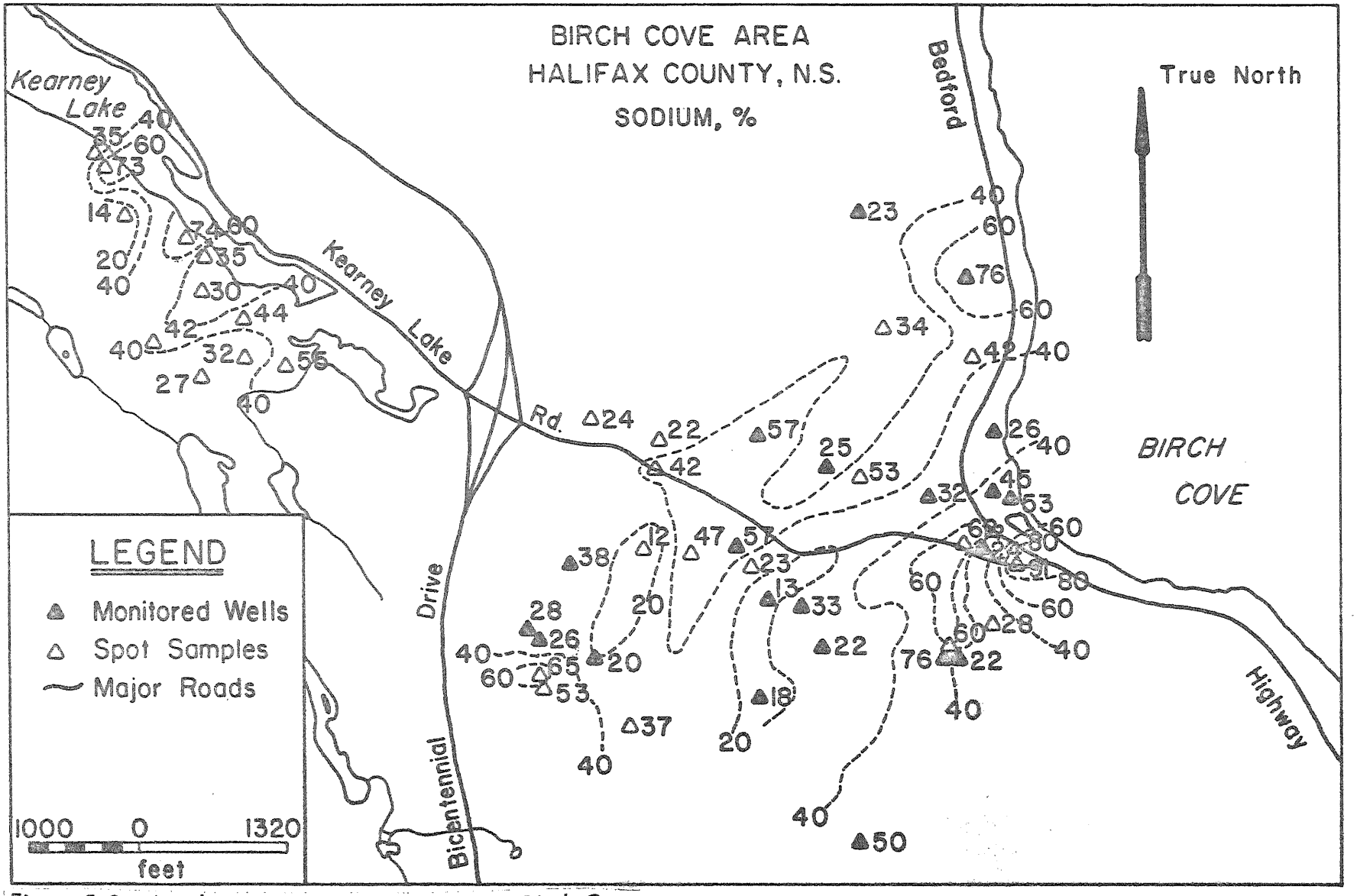


Figure 5.9. Areal variation in sodium percent, Birch Cove.

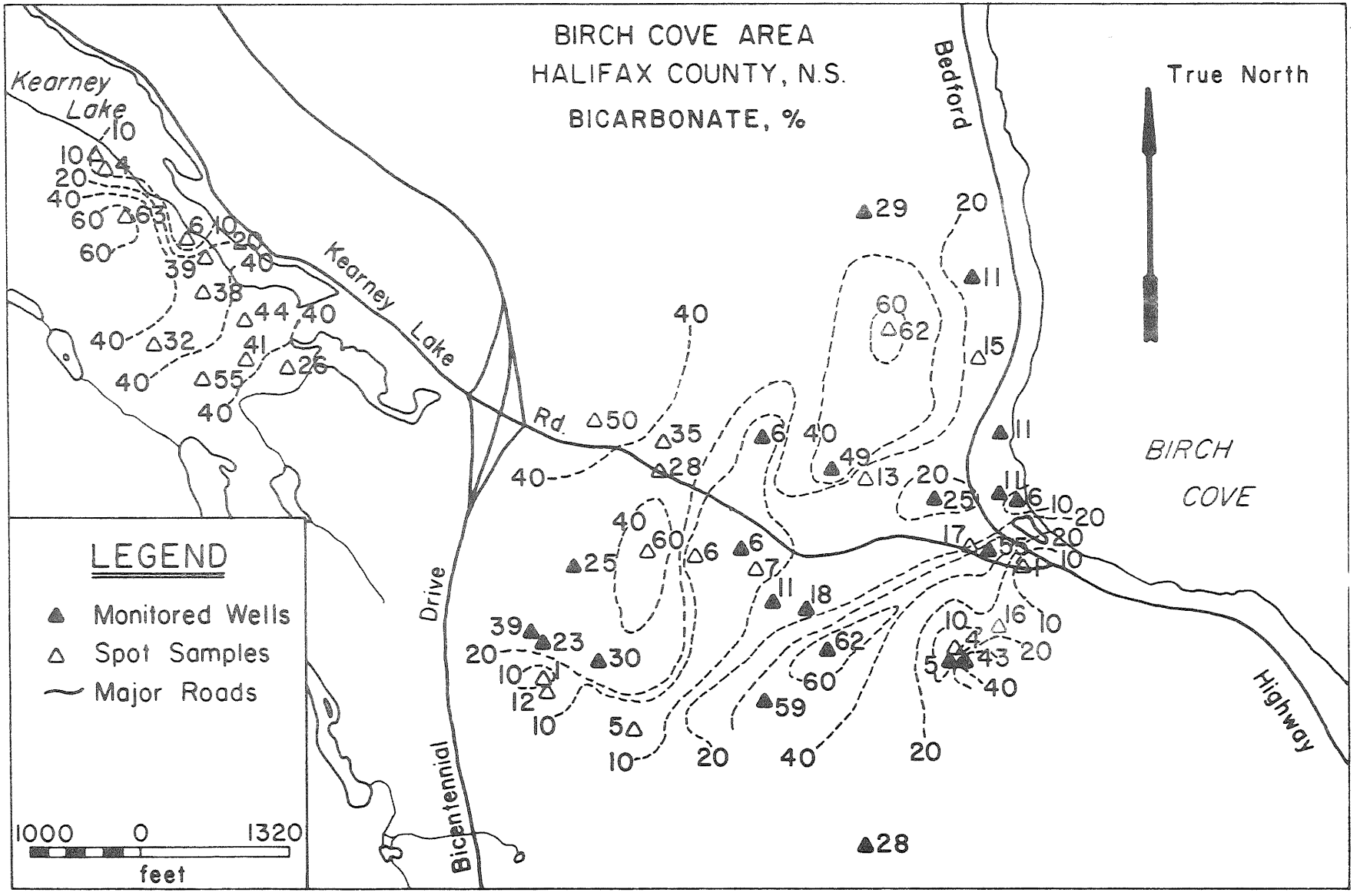


Figure 5.10. Areal variation in bicarbonate percent, Birch Cove.

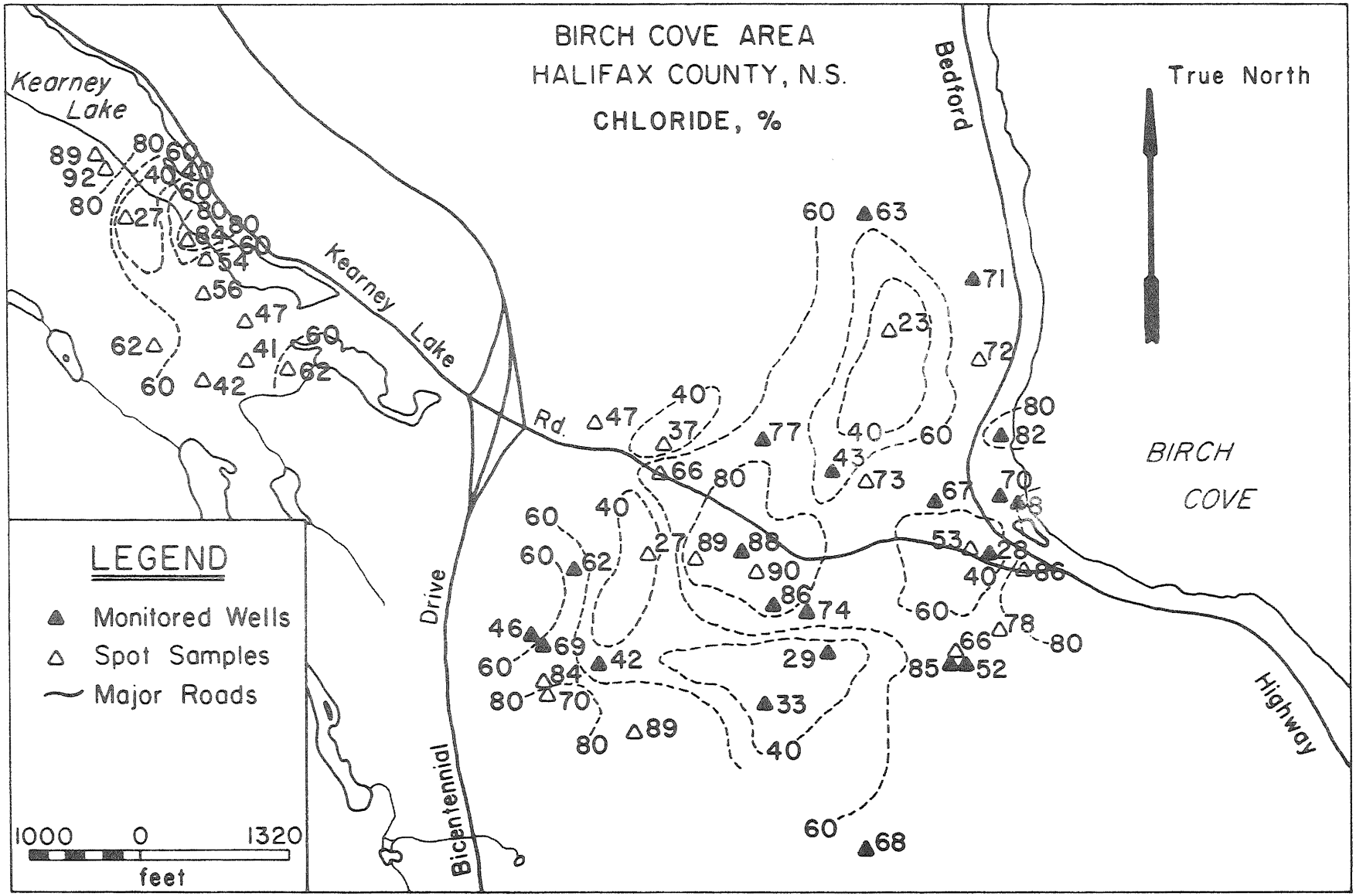


Figure 5.11. Areal variation in chloride percent, Birch Cove.

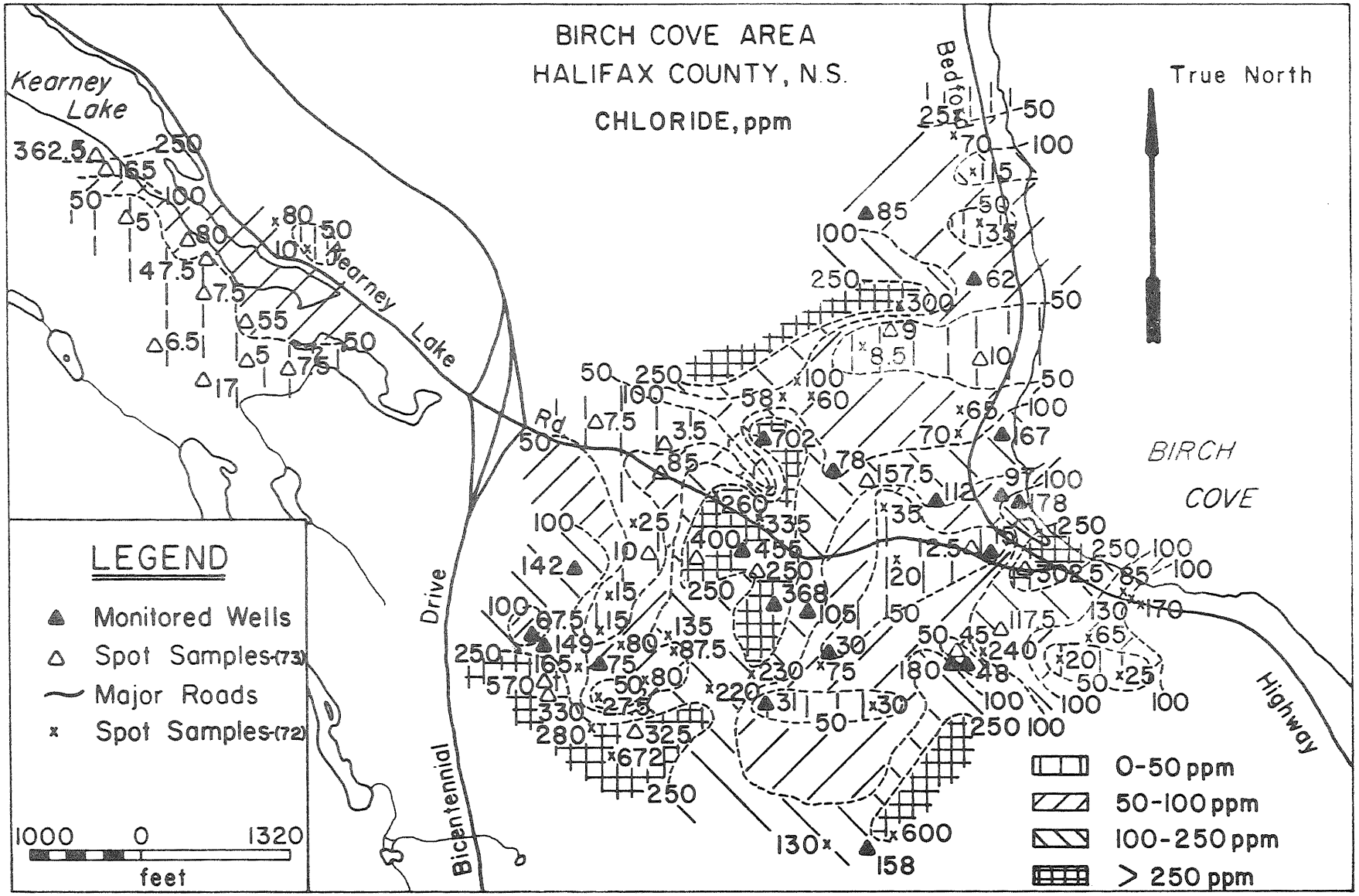


Figure 5.12. Areal variation in chloride, Birch Cove.

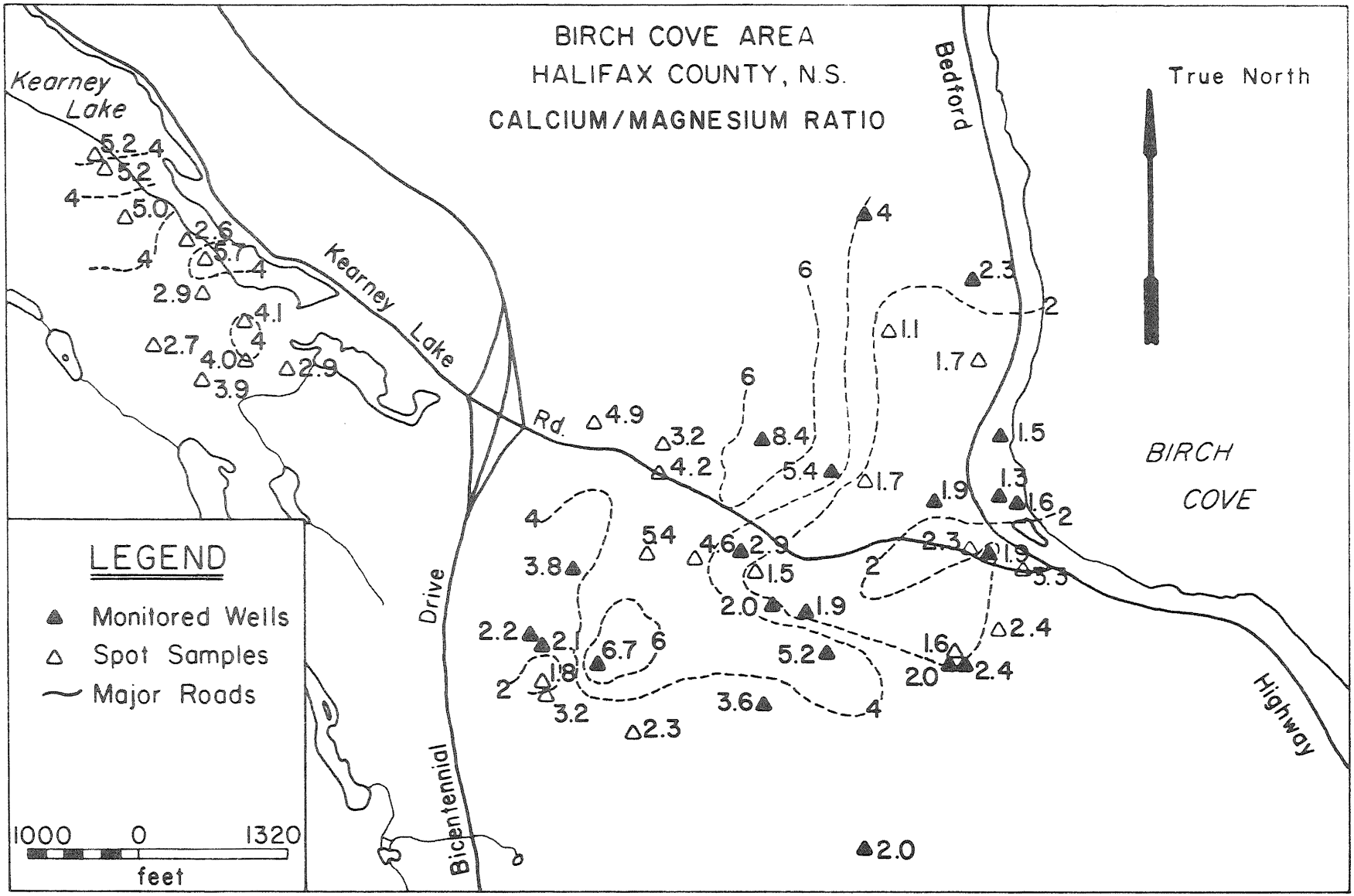


Figure 5.13. Areal variation in calcium to magnesium ratio, Birch Cove.

Ratio values of 4-6 characterize recharge areas, 2 or less discharge areas. A granitic area exists upslope from the wells near Kearney Lake, hence these waters could show a higher Mg content or lower Ca/Mg ratio (Gorham , 1957) than the rest of the waters. They do not show a lower ratio, which illustrates the difficulty in distinguishing groundwaters from granite and quartzite by major chemical constituents alone.

Mineral Equilibria and Weathering

The equilibrium status of the groundwaters was investigated using mineral stability fields from Bricker et al (1967), Garrels et al (1971), and Jacks (1972, 1973). They are constructed from thermodynamic data for the minerals, as detailed by Garrels et al (1965). All water samples from Birch Cove fall within the kaolinite field (figs. 5.14 to 5.17 a and b), indicating a relatively intensely leached aquifer since the water is in equilibrium with the weathered product of the feldspars and chlorite rather than with the minerals themselves (Jacks, 1972). Although K from alkali feldspar is only present in small amounts (due to differential weathering of the feldspars), it does play a role in the equilibrium, because many of the samples have a pK-pNa value close to 1, the value that is found when both alkali and plagioclase feldspar systems are present (Eriksson, 1968).

Turnover rates in the upper part of the aquifer can be investigated by the plots shown on fig. 5.18 (Jacks, 1972, 1973). The points show no clustering at

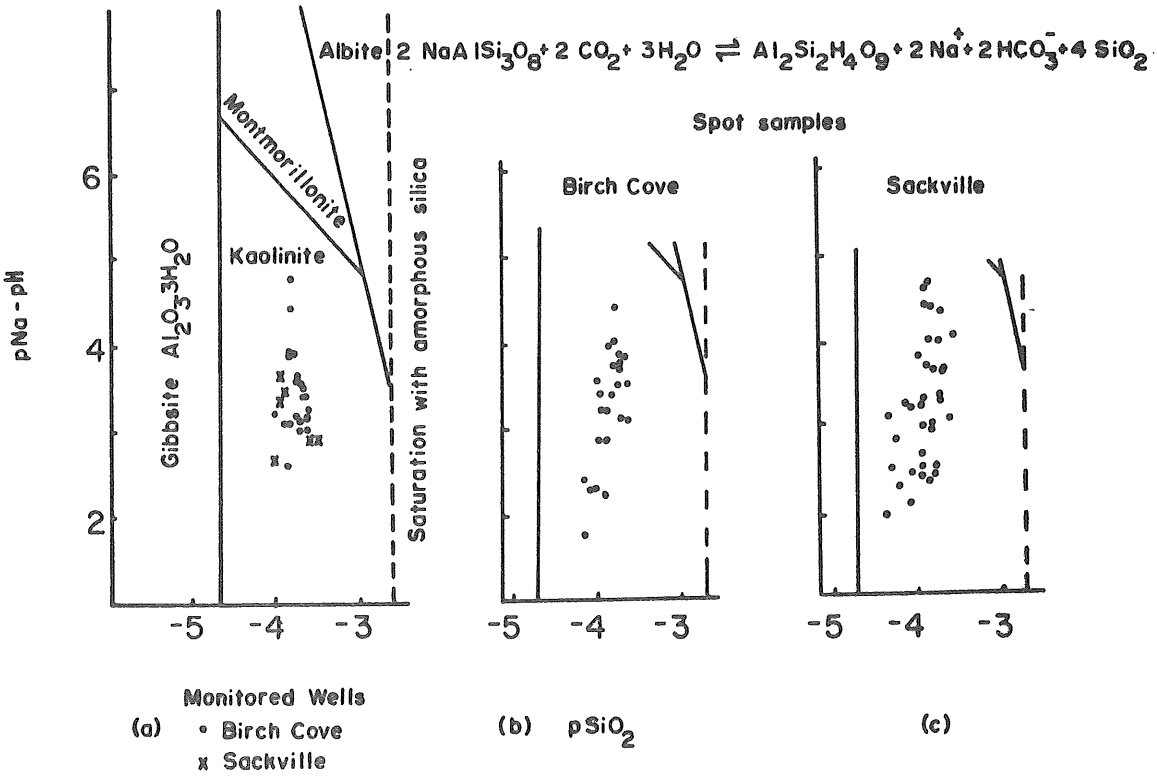


Figure 5.14. Stability field plots for sodium feldspar, Birch Cove and Sackville.

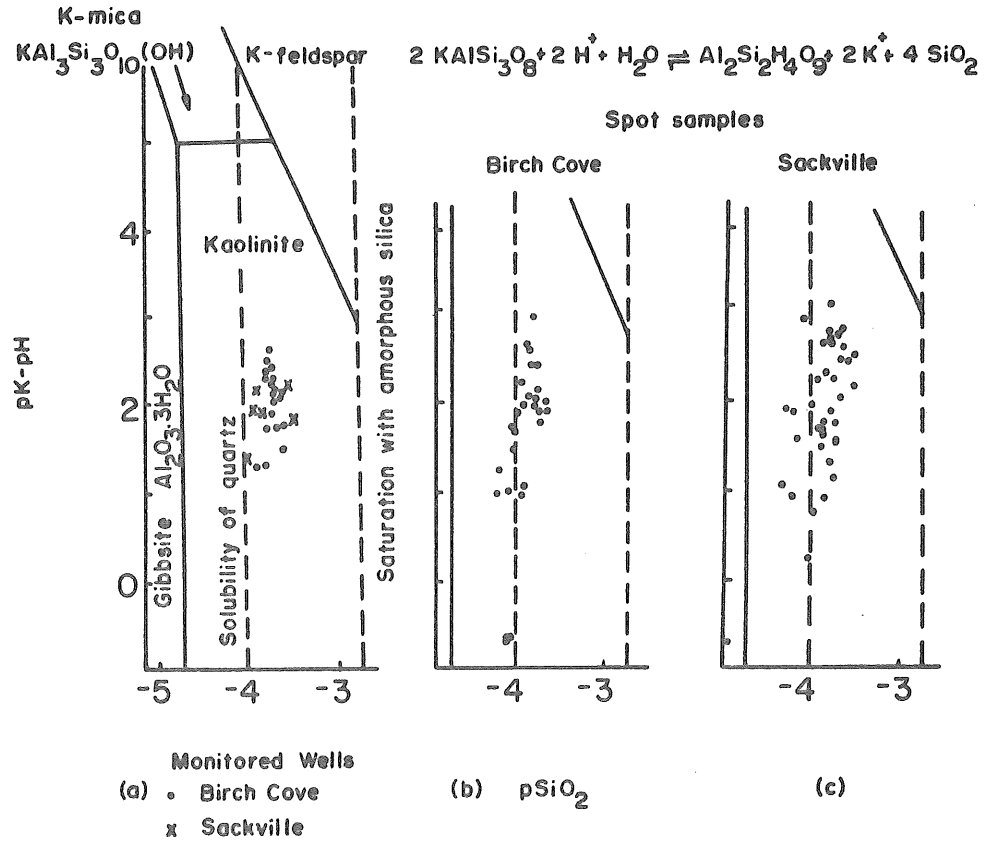


Figure 5.15. Stability field plots for potassium feldspar, Birch Cove and Sackville.

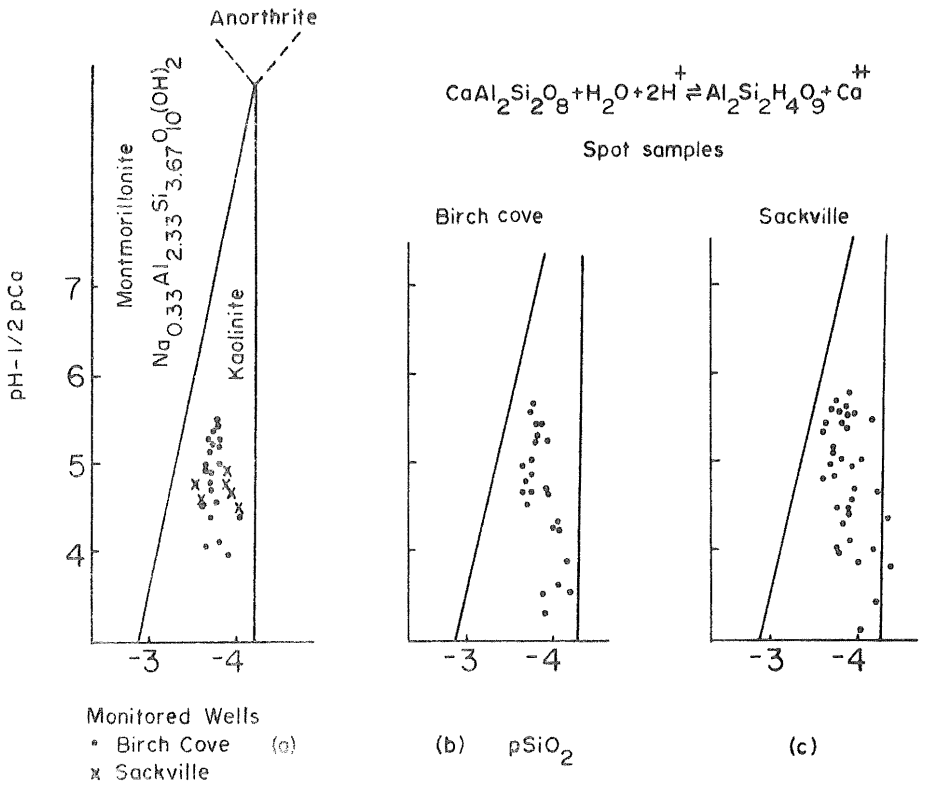


Figure 5.16. Stability field plots for calcium feldspar, Birch Cove and Sackville.

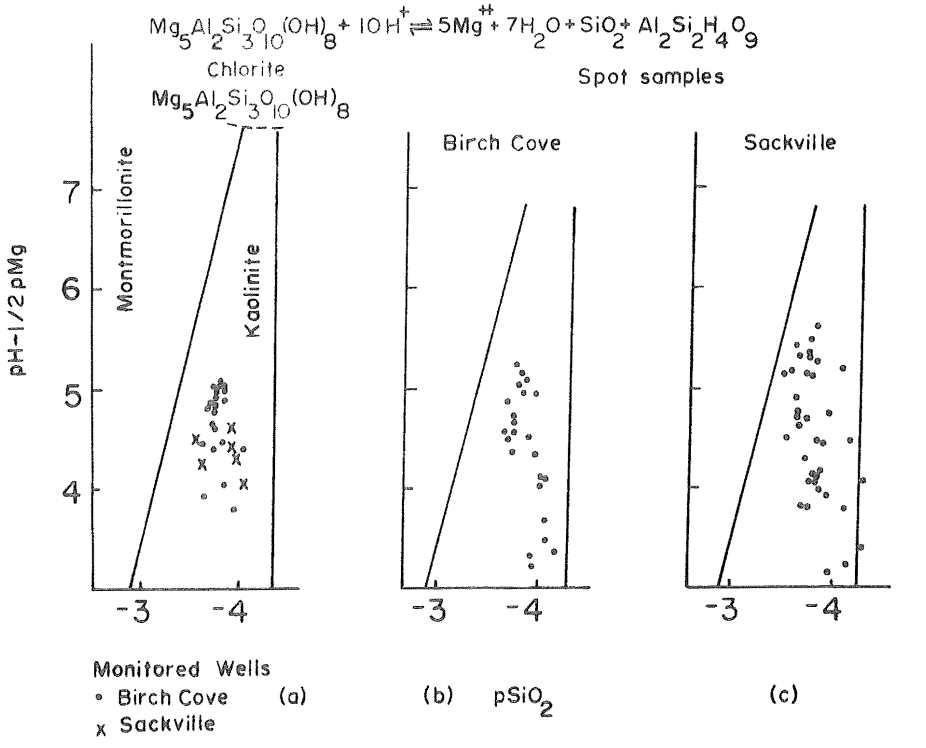


Figure 5.17. Stability field plots for chlorite, Birch Cove and Sackville.

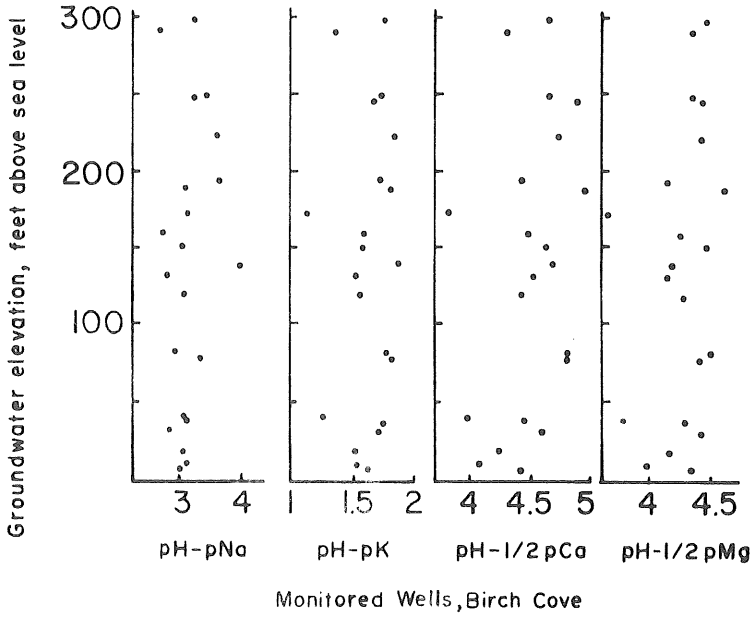


Figure 5.18. pH-pNa, pH-pK, pH-1/2 pCa, and pH-1/2 pMg against groundwater elevation, Birch Cove.

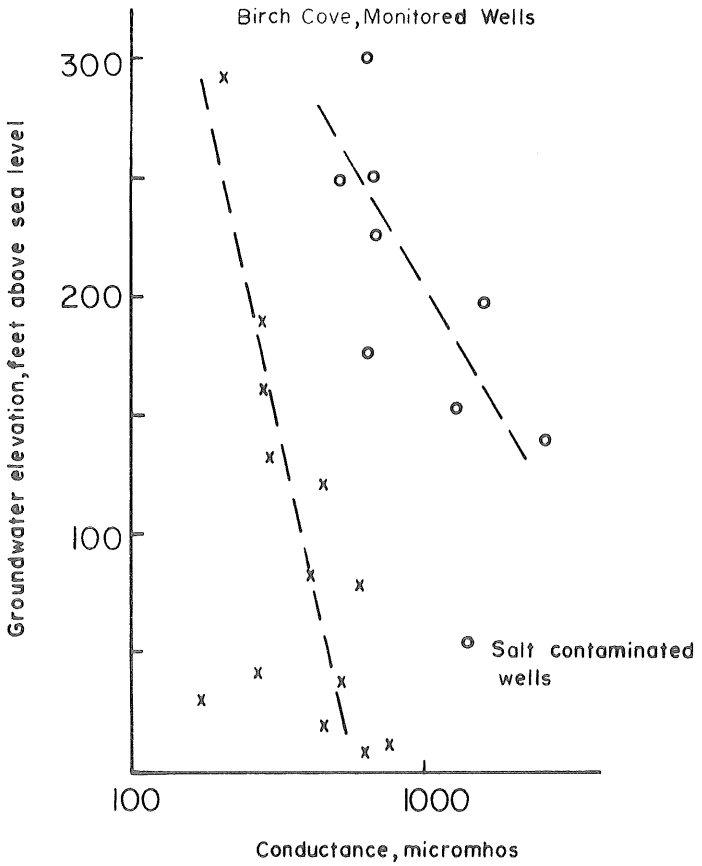


Figure 5.19. Conductance versus groundwater elevation, Birch Cove.

any particular groundwater level, indicating relatively rapid turnover rates. The actual rate is not known here, but Eriksson (1968) suggests a period of 10 years is required for groundwater from igneous rocks in Stockholm to reach equilibrium by weathering. If this figure is applied to Birch Cove , then the turnover rate must be less than 10 years, since none of the groundwaters reach equilibrium with the source minerals. The activity ratios in the above figures are relatively constant throughout the groundwater elevations investigated, indicating that about the same degree of weathering has been achieved throughout these levels. This supports the stability field conclusion of relatively intense leaching. The variation present in the activity ratios is likely because other factors (such as permeability and hydraulic gradient) beside groundwater elevation influence groundwater flow velocity.

The effects of weathering are also illustrated in fig. 5.19. Conductance should, theoretically, increase towards sea level since groundwater velocity decreases with depth. The plot does indicate this, especially if probable salt contaminated wells are treated separately. Since fig. 5.18 has revealed a relatively stable weathering profile at the groundwater levels investigated, the increase in conductance in fig. 5.19 may indicate salt accumulation in deeper parts of the aquifer toward the discharge area. Calcium could also produce part of this increase in conductance. Carbonate nodules or concretions in the bedrock may contain up to 50% $CaCO_3$ in the centre as compared

to less than 3% in the rest of the rock (M. Purves, personal communication). If unsaturated waters penetrate to depths of 200-300 feet, then these nodules could be weathered. Figures 5.20 a and b show that Ca is being continuously added to the groundwaters by dissolution of $CaCO_3$, and that the vertical permeability is likely greater than the horizontal. The deep penetration of aggressive waters is allowing intense leaching to take place: although not shown, pCO_2 increases with depth, causing pH decrease and hence accelerated weathering. The well waters are enriched in CO_2 as compared to the atmosphere, as shown in appendix 3. Pyrite oxidation, which results in the production of H^+ ions, could also influence Ca concentrations since the latter are higher in some cases than would be expected from the pCO_2 equilibria. The Ca values in wells R10, 14, and 62 are thought to be anomalous and will be discussed further in chapter 7. It is not possible to determine from the data if high ionic strength is also increasing the solubility of $CaCO_3$ in the bedrock.

Statistics

Table 7 summarizes the results of a Pearson correlation on areal variations in water chemistry. Most of the ions show a positive correlation with one another, with correlation coefficients of 0.8 or more for Cl with Na, K, Ca, and Na with SO_4. These results support the previous hypothesis that salt may be increasing the solubility of other ions. It is also possible that some of these ions, such as Ca and K, are present as impurities in the road salt. Iron and Mn are correlated at a significant level, as would be expected from the geology of the area and geochemistry.

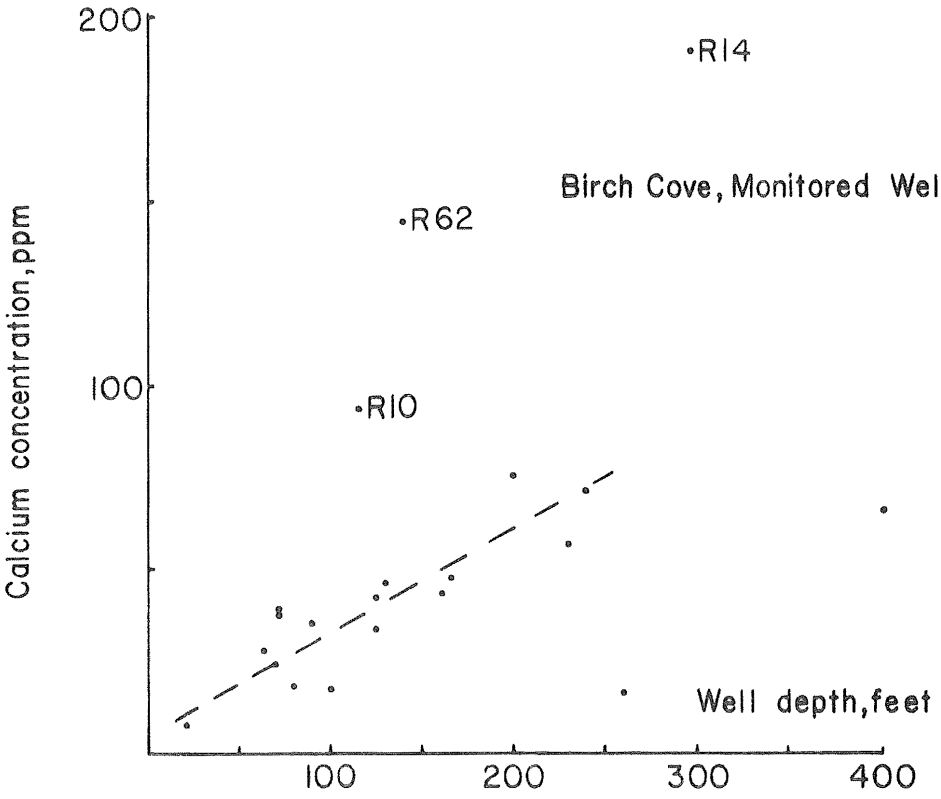


Figure 5.20 a. Calcium concentration in groundwaters versus well depth, Birch Cove.

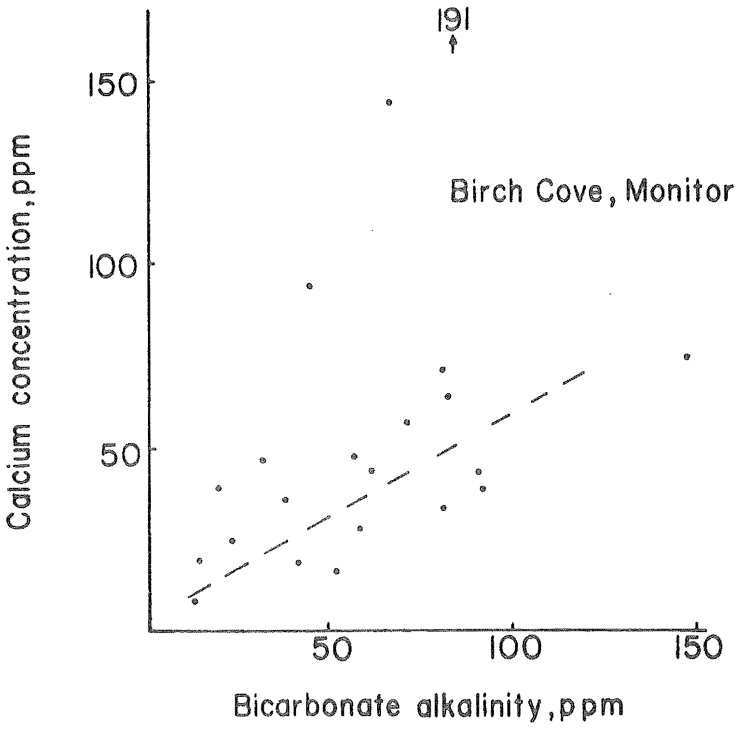


Figure 5.20 b. Calcium versus bicarbonate alkalinity concentrations in groundwater, Birch Cove.

	Conductance	pH	Sodium	Potassium	Calcium	Magnesium	Iron	Manganese	Alkalinity	Sulphate	Chloride	Nitrate
Conductance	1.00	-.32	.90*	.82*	.89*	.63*	.08	.10	.21	.74*	.99*	.44*
pH		1.00	-.37	-.37	-.10	-.21	-.08	-.18	.39*	-.32	-.34	-.36
Sodium			1.00	.77*	.63*	.29	.05	.09	.02	.82*	.90*	.35
Potassium				1.00	.66*	.56*	.16	.18	.13	.58*	.80*	.54*
Calcium					1.00	.72*	.04	.05	.46*	.59*	.86*	.37
Magnesium						1.00	.19	.20	.19	.17	.63*	.48*
Iron							1.00	.65*	-.06	.05	.09	-.02
Manganese								1.00	.14	.00	.10	-.10
Alkalinity									1.00	.14	.09	.14
Sulphate										1.00	.68*	.36
Chloride											1.00	.39*
Nitrate												1.00

* Refers to a significance level of .01 or better

TABLE 7 PEARSON CORRELATIONS ON AN AREAL BASIS, BIRCH COVE

Seasonal Fluctuations in Groundwater Chemistry

Seasonal variations in Na, Cl, and conductance (figs. 5.21 to 5.23) show essentially the same pattern in most of the monitored wells. Significant correlations between Na and Cl are found in all wells except wells R3, 60, 63 and 62 (appendix I). The former three wells may have other Cl types beside Na since there is evidence of septic tank contamination. The latter well is a Ca - Cl type water of unusual composition. These anomalies will be discussed further in chapter 7.

From fig. 5.22 it appears that wells with high mean Cl concentrations have a pulse type response, with the two peaks being a result of salt contaminated recharge in the springs of 1972 and 1973. The second peak is much lower. Three possible explanations for this, on the basis of table 8 and appendix 2 are: firstly, the more rapid warming in air temperature from January to April 1973 resulted in earlier infiltration of snowmelt recharge than in 1972, hence the slightly earlier peak of Cl in 1973; secondly, the large amount of precipitation during the water year 1972-73 (6" more than the previous water year and 9" above average) resulted in more recharge to the groundwater system and hence more dilution; and thirdly, the higher snowfall during the water year 1971-72 necessitated the use of more road salt (appendix 2).

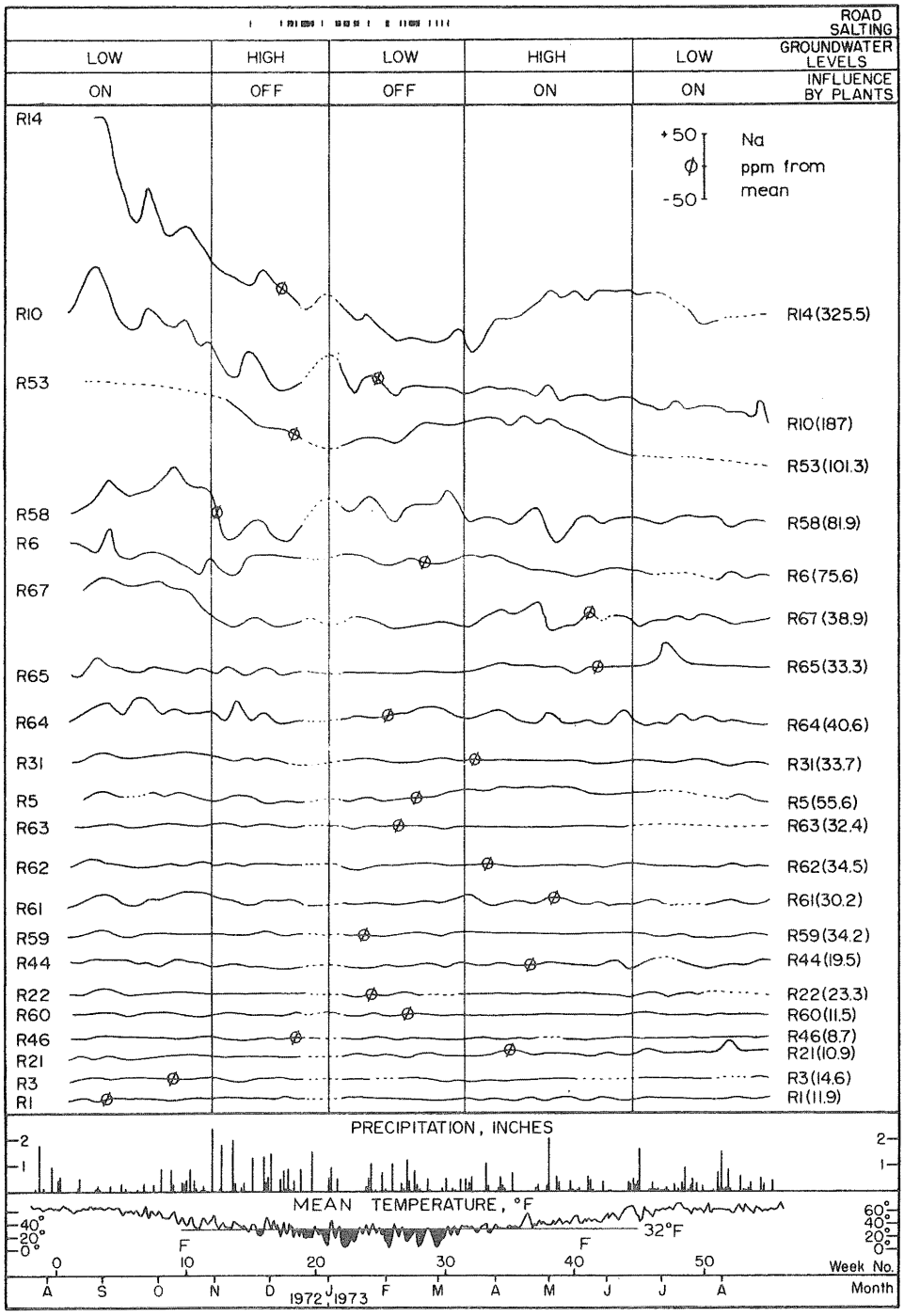


Figure 5.21. Time variations in sodium concentration, Birch Cove.
NOTE: On this diagram and others of similar format, Ø refers to the mean value of the parameter illustrated. The mean value is given in brackets after the well number on the right hand side of the plot. F refers to frozen ground conditions.

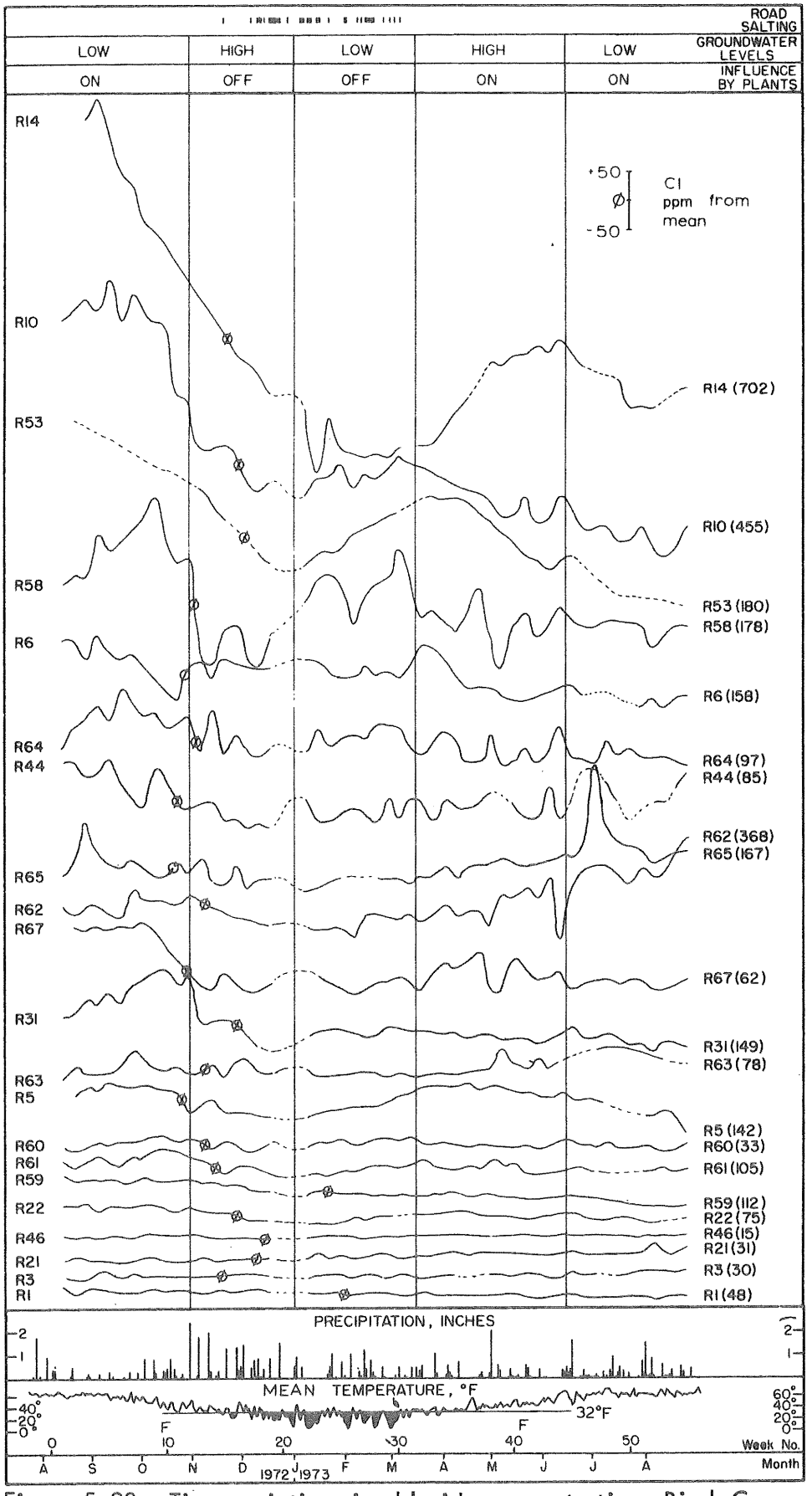


Figure 5.22. Time variations in chloride concentration, Birch Cove.

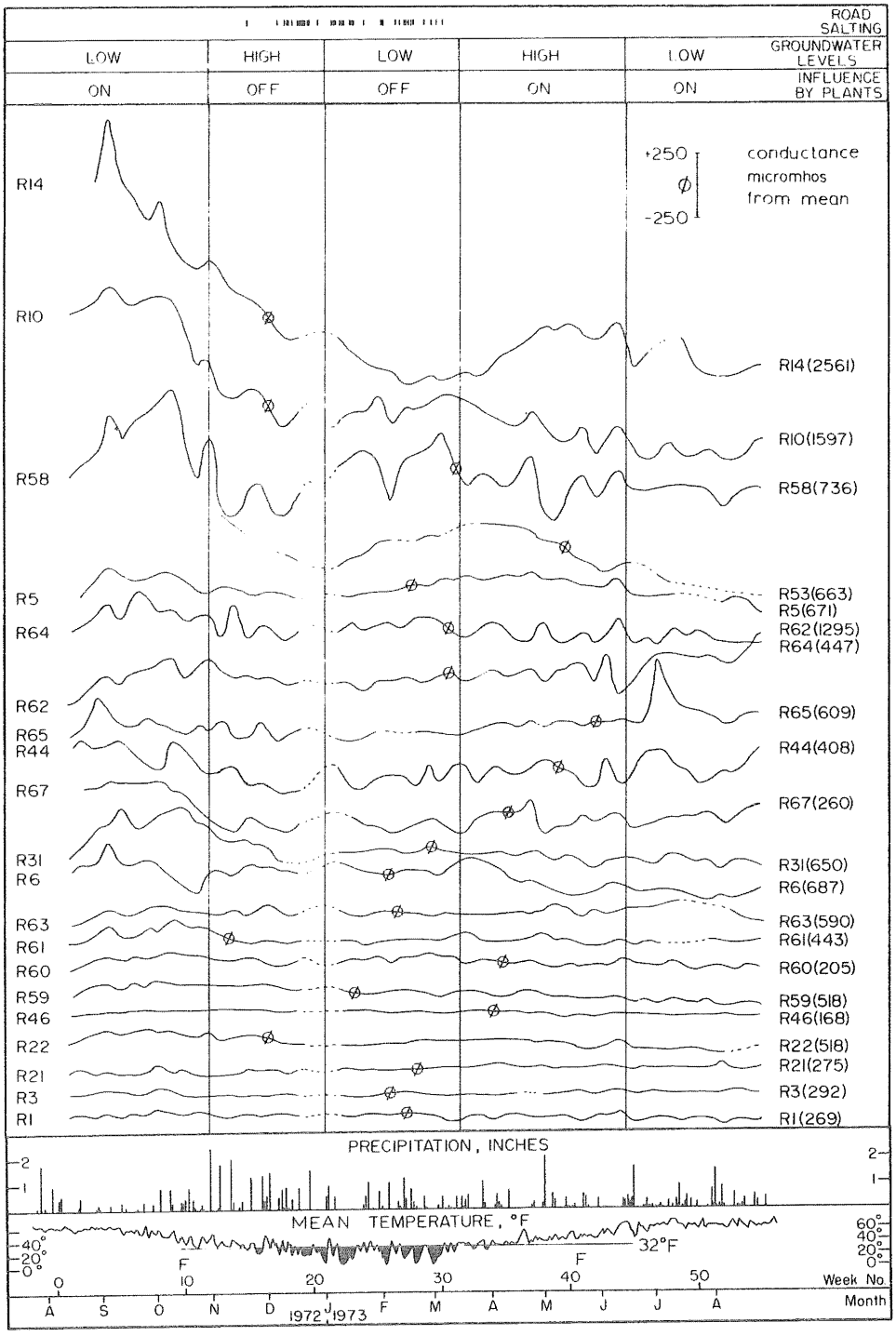


Figure 5.23. Time variations in conductance, Birch Cove.

TABLE 8

CLIMATIC DATA FOR WATER YEARS 1971-72 and 1972-73

Water Year 1971-1972
(Oct. 1, 1971 - Sept. 30, 1972)

Month	Mean Temperature °F	DPM*	Total Precipitation Inches	DPM*	Total Snowfall Inches	DPM*
O	50.9	+1.1	2.65	-1.81		
N	38.8	-2.1	6.65	+0.67	2.0	-0.7
D	26.7	-3.3	3.75	-2.09	12.8	-2.9
J	23.4	-1.8	6.29	+0.49	26.5	+7.8
F	20.5	-3.9	5.40	+0.32	19.8	-1.2
M	27.7	-3.0	8.98	+4.58	13.5	-2.3
A	35.4	-3.8	4.74	+0.59	32.9	+28.2
M	47.5	-0.7	6.44	+2.13	6.2	+5.8
J	55.9	-0.8	4.54	+1.19		
J	63.4	-0.2	3.26	-0.36		
A	63.5	-0.6	2.80	-0.90		
S	58.7	+0.1	1.55	-2.16		
Total			57.05"		113.7"	

Mean Temperature
42.7 °F

Water Year 1972-1973
(Oct. 1, 1972 - Sept. 30, 1973)

Month	Mean Temperature °F	DPM*	Total Precipitation Inches	DPM*	Total Snowfall Inches	DPM*
O	45.7	-4.1	7.41	+2.95	3.4	+3.3
N	36.1	-4.8	8.85	+2.87	5.5	+2.8
D	26.4	-3.6	7.55	+1.71	16.3	+0.6
J	24.1	-1.1	4.37	-1.43	11.7	-7.0
F	22.5	-1.9	5.34	+0.26	29.4	+8.4
M	32.1	-1.4	4.68	+0.28	6.1	-9.7
A	39.2	0.0	5.30	+1.15	2.5	-2.2
M	46.3	-1.9	4.00	-0.31		
J	58.6	+1.9	4.85	+1.50		
J	65.6	+2.0	6.36	+2.74		
A	64.7	+0.6	3.93	+0.23		
S	57.1	-1.5	0.95	-2.76		
Total			63.6"		74.9"	

Mean Temperature
43.2 °F

* DPM = Departure from 30-year mean, as given by the Atmospheric Environment Service.

Cold air temperatures during the winter of the 1971-72 water year likely prevented much active infiltration of precipitation, but the lower melting point temperature of salty roadside brines could make their entry into the groundwater system possible. In the winter of the water year 1972-73, in contrast, the large number of rainfall events combined with the highly fluctuating air temperatures resulted in several thaws during the winter, thus allowing large amounts of uncontaminated recharge to dilute the infiltrating brine solutions. Active infiltration during the winter of 1972-73 is evident in the plots for wells R10, 53, and 58 (fig. 5.22) which show an almost immediate increase in chloride following the start of road salting around week 18 or 19. As an example of the effect of salt application in relation to precipitation, a 10% decrease in the amount of salt applied, along with an 11.5% increase in precipitation during the water year 1972-73 over the year 1971-72 resulted in a decrease in the peak Cl value of 50%, 40%, and 73% (for wells R14, 10, and 53 respectively). The greater decrease in well R53 likely indicates a higher permeability in the vicinity of this well. Thus chloride concentrations are responding not only to the annual rate of salt application (Toler, 1974), but also to the amount of recharge.

To obtain an idea of the time lag between salting and change in water chemistry, week 19 (mid-December) was taken as the start of fairly continuous salting and the time taken for the peak Cl value to occur was noted:

TABLE 9

TIME LAGS FOR CHLORIDE ION CONCENTRATION

IN SELECTED WELLS, BIRCH COVE

Well	Time Lag, weeks
R10, 58	8.5
R5, 53	16
R67	18
R14	25

These values for time lag should represent a minimum lag for chemical response in the groundwater system since Cl is a highly mobile ion and can serve as a tracer. The time lag depends on factors such as permeability, source of Cl, position of the well in the flow system, and mixing or dilution phenomena. Well R58 showed a noticeable immediate effect in Cl concentrations as well as a delayed effect. This indicates the entry of surface runoff into the well, perhaps as a result of faulty well construction (the homeowner reported water discoloration after heavy rains).

Wells such as R44, 62and 65 show a slight overall increase in Cl over the year of monitoring, but no definite pulses. This could indicate a periodicity of the peaks greater than one year (due to low permeability or position in the flow system) and/or a dilution-concentration effect. The latter effect is the most

likely since these wells show essentially the same concentrations of Cl at the start and finish of the water year 1972-73 implying that changes in storage could be causing the concentration changes.

The lowest total dissolved solids concentrations (reflected by conductance, fig. 5.23) in most wells occur during mid-winter from the end of December to middle of January. This is a function of recharge at the start of the water year in October, when water levels start to rise, the soil moisture deficit is satisfied, and salt from the previous winter is past its maximum value. Hence the fall recharge should have lower conductance than spring recharge and the time lag from this input to the mid-winter low is about 3-4 months, which is compatible with the time lags estimated for Cl in table 9.

Within experimental error a given percent increase in sodium concentrations corresponds to the same percent increase in Cl concentration, further supporting a NaCl source for the Cl. Terry (1974) suggests that some Na from salt may be retained in the soil. This is not the case for most wells in Birch Cove, although well R53 appears to show a time lag of one week between Na and Cl peaks. Hence the thin glacial till cover is not effective in retaining Na, possibly because of its sandy nature and high permeability, its thinness, or its limited capacity for base exchange.

To group the wells, a plot of percent conductance was used (calculated

by averaging conductance values in each well, then taking each individual value divided by the average and multiplied by 100). On the basis of the relative smoothness of seasonal fluctuations, three groupings were found: 1) highly fluctuating response (wells R6, 44, 58, 60, 64, 65, 67); 2) intermediate response (wells R1, 10, 21, 31, 53, 61, 62, 63); and 3) smooth damped out response (wells R3, 5, 14, 22, 46, 59). A discriminant function analysis was performed on these groupings (with variables well depth, topographic elevation and water table elevation). The results indicated well depth to be significant at the 0.05 level, with deeper wells showing damped out responses. A well depth of 150-175 feet separates response types 1 and 3, while type 2 has well depths greater and less than these depths. This result has several implications. Firstly, type 1 response could represent wells in local flow systems with nearby sources of recharge and type 3 represent wells in an intermediate system with a recharge area at the Birch Cove High (fig. 5.2). Type 2 wells would then represent transitional zones between these flow systems or a mixing of different water types. Secondly, type 3 wells could simply indicate the effect of permeability decrease with depth or a longer travel time for recharge water to reach the well - the water source for these wells could then be very local, as for type 1 wells. Thirdly, the results indicate that seasonal fluctuations in chemistry can be used to make some deductions regarding flow systems, even in areas with salt contamination in which areal variations in chemistry are suspect. The second interpretation is the most likely, and favors local flow systems.

Based on the overall shape of the curves in fig. 5.22, there are three types of curves: 1) stable type, with little or no variation (e.g., wells R1 and 46); 2) dilution–concentration type curves (e.g., wells R44, 62 and 65); and 3) pulse type response as a result of road salting (e.g., wells R10 and 14). Well R31 is of the latter type but shows only one peak, indicating that the well is receiving enough recharge to damp out the second, lower peak.

The wells with high chloride values and pulse type response show a large number of high significant correlations between different variable pairs (e.g., appendix 1, tables 1-E and 1-F). This is a result of the increase in solubility of other ions caused by high salt concentrations. Also, the lower mean pH in salt contaminated waters (pH$<$ 6) would increase the solubility of components such as Fe and Mn.

Calcium and magnesium ions (figs. 5.24 and 5.25) are significantly correlated with each other in all the wells because of their geochemical similarity. About 60-65% of the wells have a significant Na-Mg and Na-Ca correlations with the former at a higher level. Magnesium may be more sensitive to salt concentration than Ca since it is slightly more mobile than Ca in the soil. Time lags for Ca and Mg are the same as Cl, indicating a major input of these ions in spring recharge or an increase in their solubility at this time due to salt in the water.

Bicarbonate composition (fig. 5.26) is relatively stable, with most fluctu-

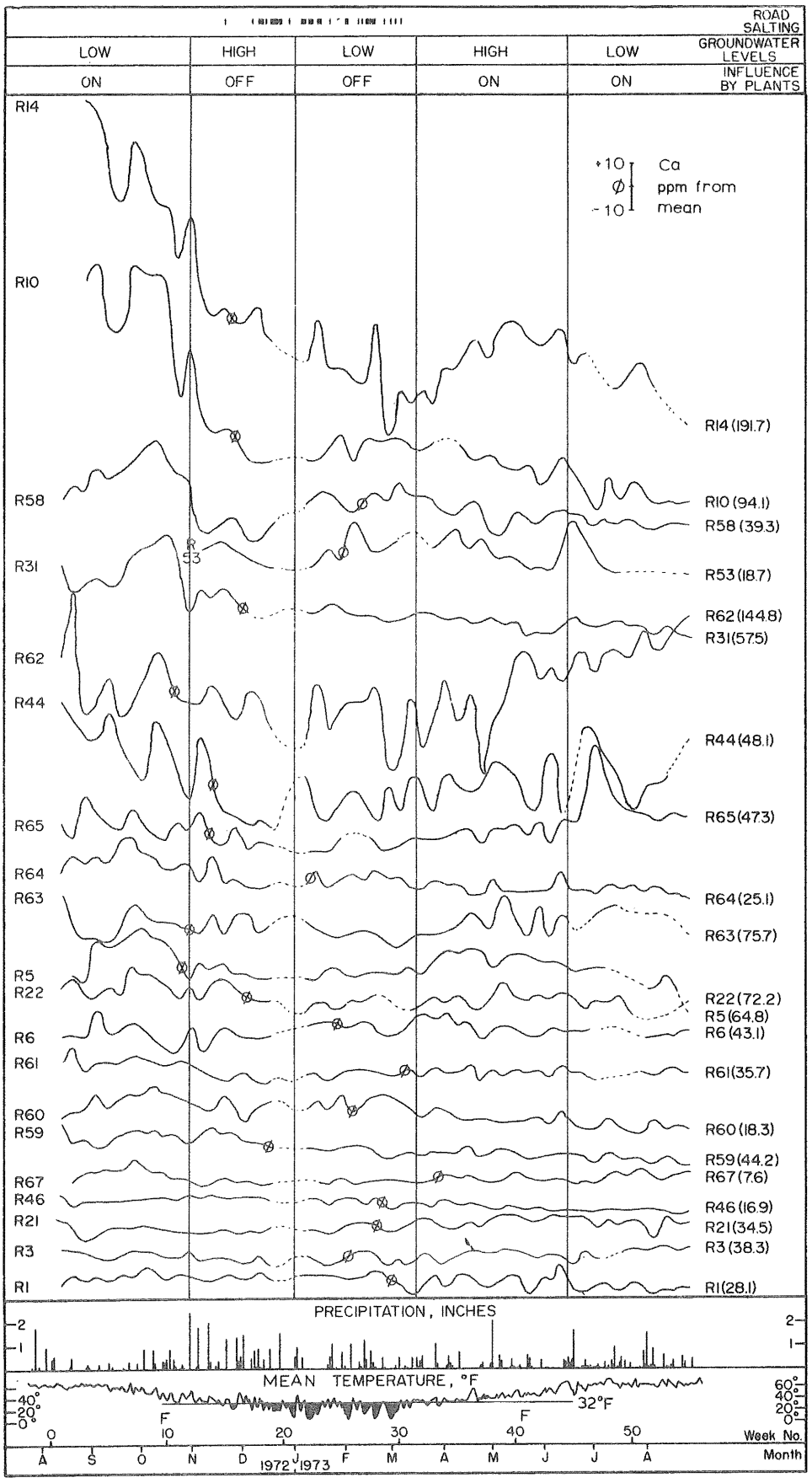


Figure 5.24. Time variations in calcium concentration, Birch Cove.

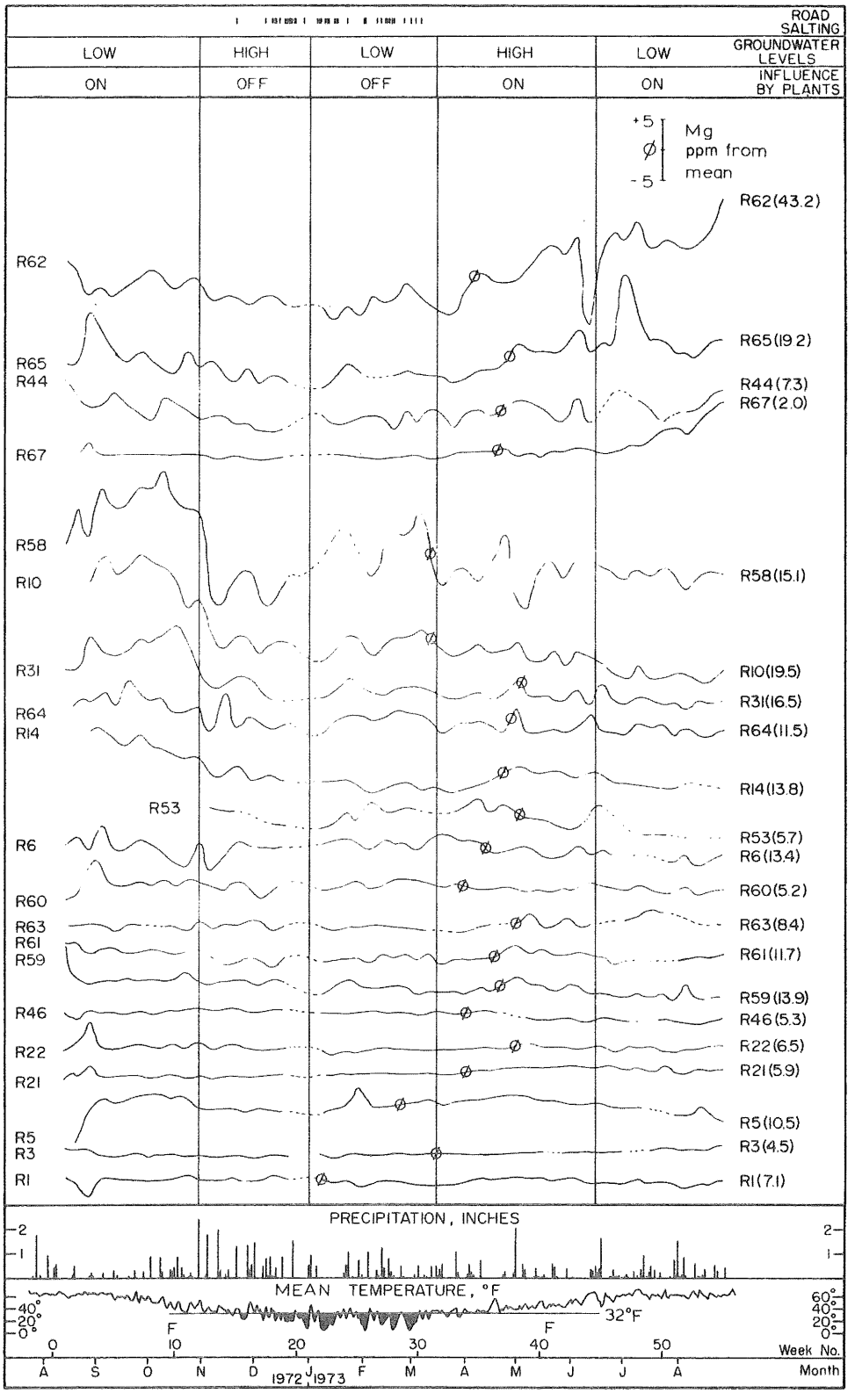


Figure 5.25. Time variations in magnesium concentration, Birch Cove.

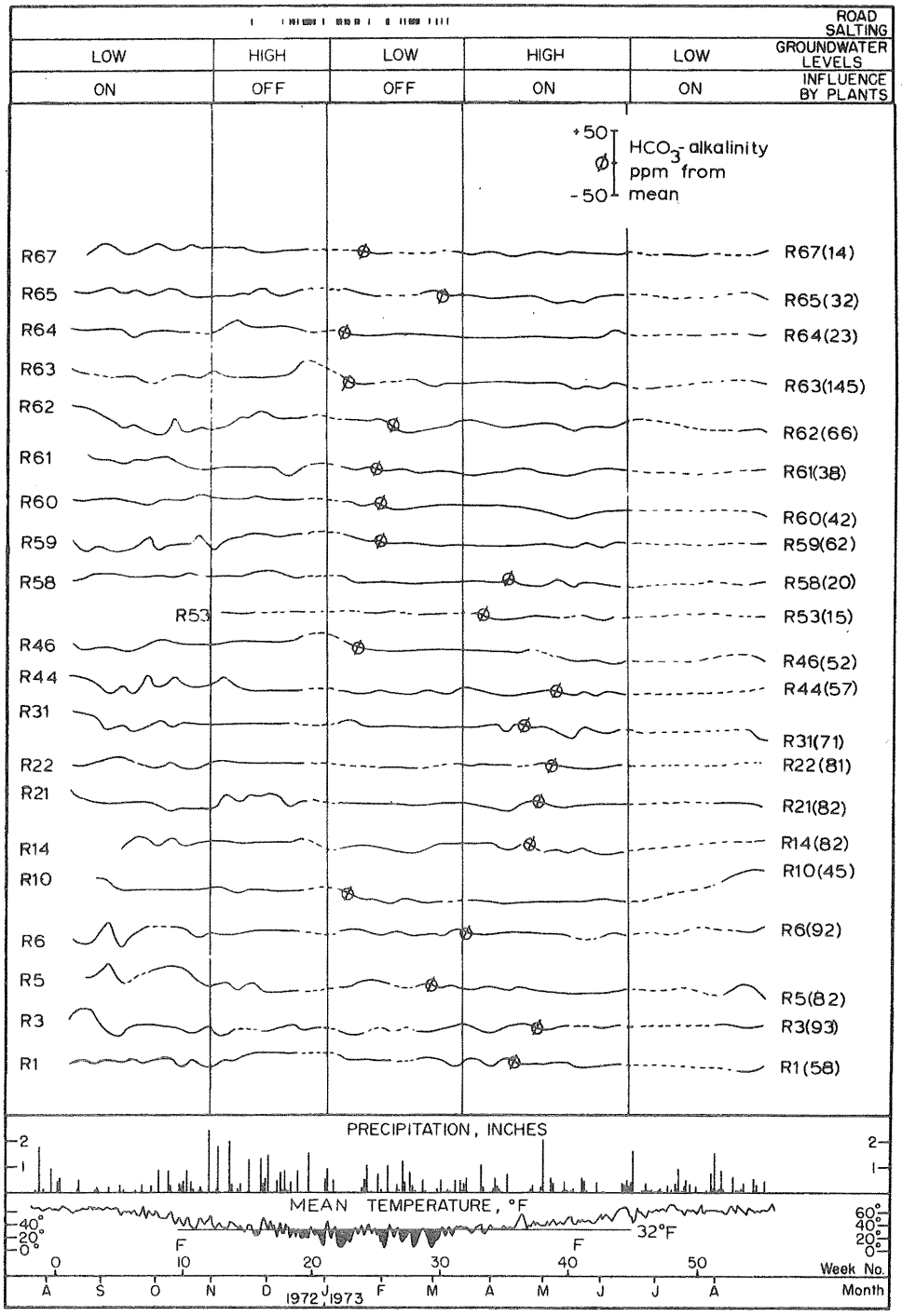


Figure 5.26. Time variations in bicarbonate alkalinity concentration, Birch Cove.

ations occurring in late fall and spring. A significant HCO_3 -Ca correlation (in wells R1, 3, 5, 14, 44, 46, 60, 61) indicates a calcite source in soil or bedrock for some of the HCO_3 in these wells. The large Ca fluctuations in well R44 may indicate biological influence since this well is likely recharged in a forested area. Significant HCO_3 -Na correlations (wells R14, 44, 46, 62, 67) could be due to weathering of plagioclase fledspar. Significant HCO_3 -Fe correlations (wells R10, 21, 22, 64) could reflect the influence of organic decomposition in the soil, e.g.,

$$4CH_2O + 4O_2 \rightleftharpoons 4H^+ + 4HCO_3^-$$

$$2Fe(OH)_3 + 4H^+ \rightarrow 2Fe^{++} + 5H_2O + 1/2O_2$$

(Langmuir, 1969).

Potassium variations (fig. 5.27) are small in most wells. Late fall fluctuations may reflect biological influence (Likens et al, 1967). Since K is highly correlated in most wells with Na, Ca or Mg, it is likely mobilized during the spring. Significant K-Mn correlations (wells R5, 6, 10, 22, 31, 53, 58 and 59) may reflect increased weathering of minerals containing these ions by high salt concentrations, or an organic source. A significant K-NO_3 correlation (wells R1, 44, 53, 67) likely indicates an organic origin for the K; these wells all have forested areas immediately upgradient.

Sulphate and Nitrate (figs. 5.28 and 5.29) are significantly correlated in about 50% of the wells (R5, 10, 14, 21, 22, 44, 58, 62, 64). This could

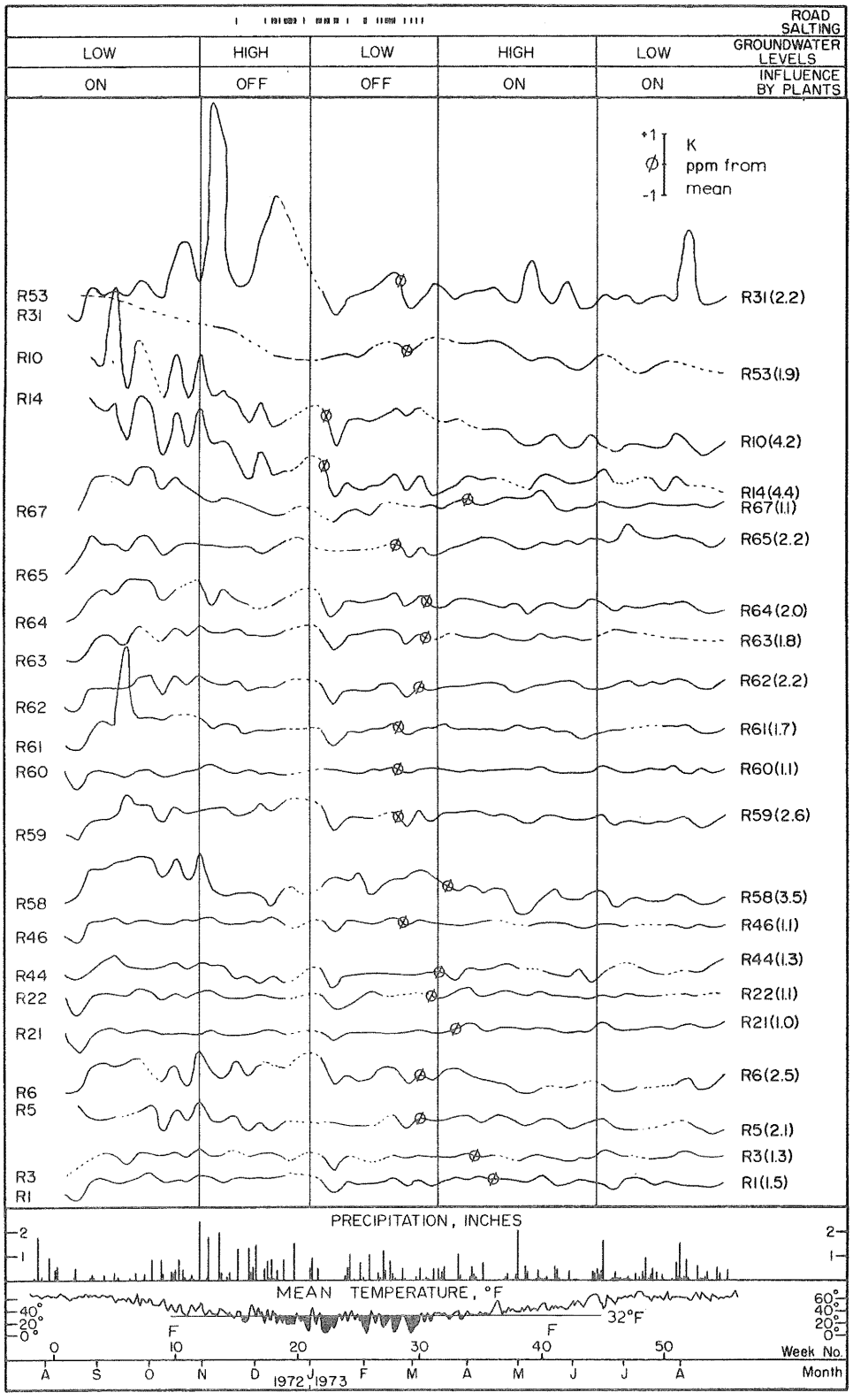


Figure 5.27. Time variations in potassium concentration, Birch Cove.

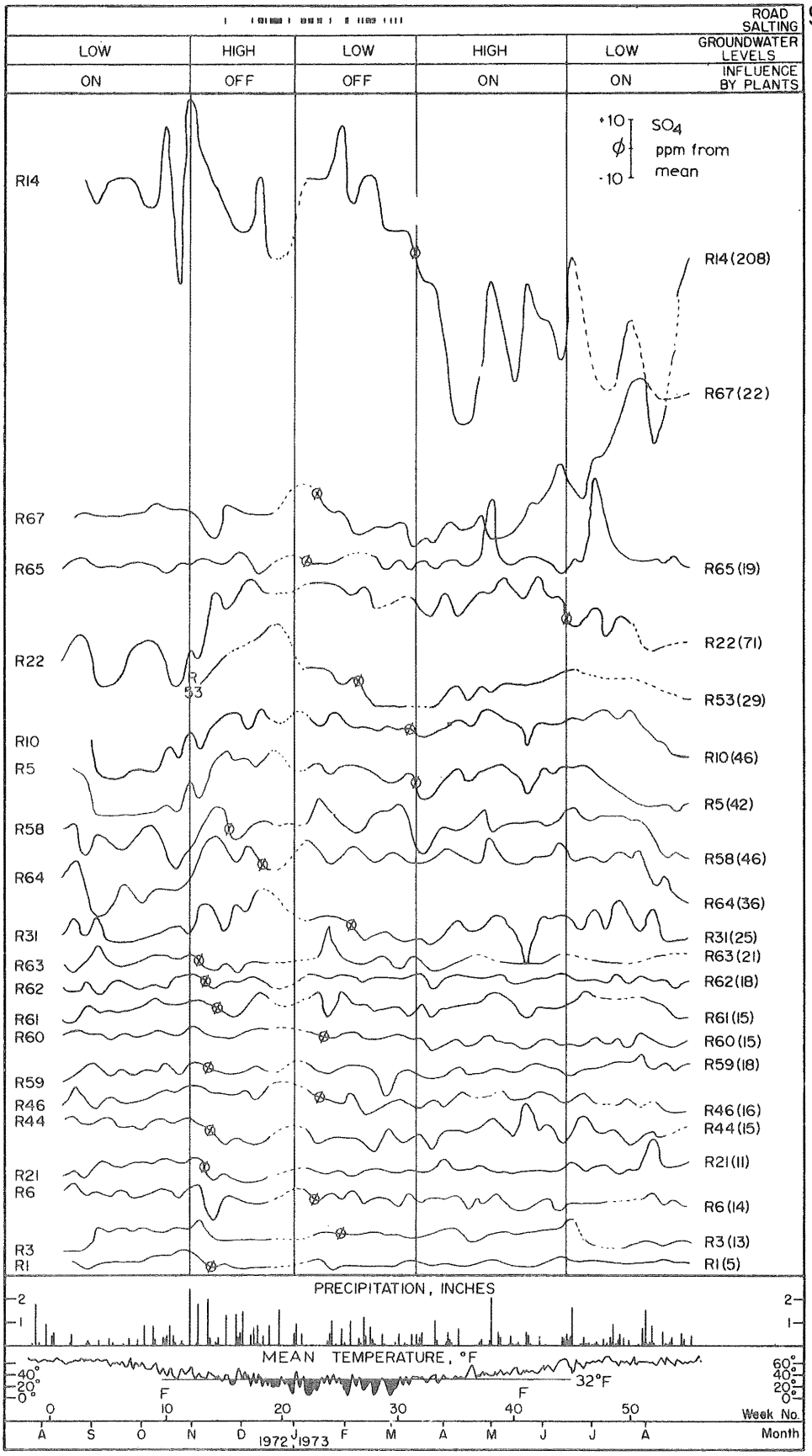


Figure 5.28. Time variations in sulphate concentration, Birch Cove.

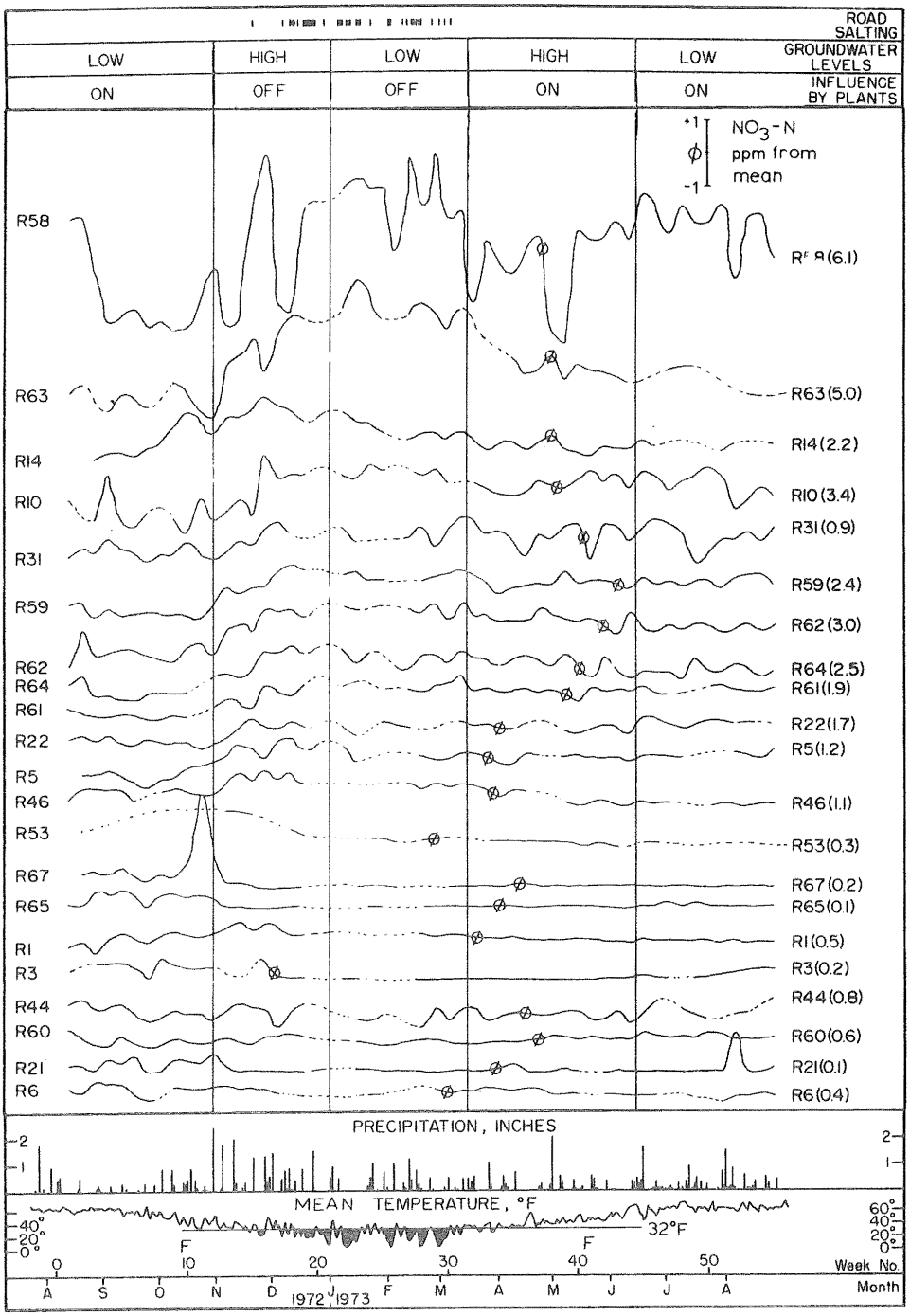


Figure 5.29. Time variations in nitrate-nitrogen concentration, Birch Cove.

represent an organic origin for some of the SO_4 - either by production of H_2S and subsequent oxidation or by increase of CO_2 during organic breakdown and thus increase of SO_4 (for example, see the above equations) or, by desorption of SO_4 from organic complexes. Four of the wells listed show a significant HCO_3-Fe correlation which supports the latter example. Sulphate and Cl are significantly correlated in wells R21 and 44, indicating SO_4 input in the spring. Lowering of the pH by salt and subsequent oxidation could release SO_4 from pyrite in the bedrock. Where SO_4 is correlated with NO_3 it likely represents a time lag of 6 months or more; in other cases an almost immediate response may be possible since SO_4 is often high in groundwaters in the winter when precipitation contains more of this ion. The reason for the increase in SO_4 in wells R65 and 67 towards the end of summer 1973 is uncertain.

Nitrate input reaches a maximum in the spring when the decomposition products of organic matter can enter the groundwater flow system. Hence the peaks in NO_3-N in many wells in winter (fig. 5.29) are likely the result of input from the previous winter, representing a time lag of about 7-8 months. Feth (1964) and Parizek et al (1967) also found lags of a similar order of magnitude for NO_3. Plant use of nitrogen may accentuate the time lag. If the response were a dilution concentration effect, a peak in NO_3 would be expected in August as well as in December-January when the least amount of groundwater is in storage. This was not the case.

Significant negative NO_3-Cl correlations (wells R5, 10, 22, 31, 59, 60, 61, 63, 64) support the possibility of delayed infiltration of NO_3 due to organic or soil processes, especially since many of these wells also showed a significant NO_3-SO_4 correlation. Significant positive NO_3-Cl correlations may indicate rapid infiltration (e.g. well R67, a dug well with a shallow groundwater supply, shows this) or faulty well construction.

Manganese is significantly correlated with Cl in wells R1, 6, 10, 53, 58, 59, 61, 65. This could be a result of Mn input in spring (Mn is released from decaying vegetation during the winter and also mobilized from the bedrock by low pH humic acids) by natural means, or by increased solubility of Mn in the bedrock due to the lower pH and higher ionic strength of salt contaminated waters. Control of Mn by pH is evident in wells R1 and 53, which show a significant negative correlation between pH and Mn, and suspected in wells R6, 31, 46, and 60 (appendix I).

Groundwater temperature variations are shown in fig. 5.30. The changes are gradual and appear to lag 5-6 weeks behind air temperature changes. Groundwater temperature is affected because of the change in recharge water temperature; the time lag is due to mixing effects and flow. Temperature fluctuations decrease with depth, hence wells R5, 31, and 44 should theoretically represent deeper groundwaters. However, R31 and 44 were classified as shallow waters on the basis of percent conductance. This anomaly can be explained if high Ca variations (fig. 5.24) and high K variations (fig. 5.27) in wells R44 and 31, respectively, are affecting the conductance.

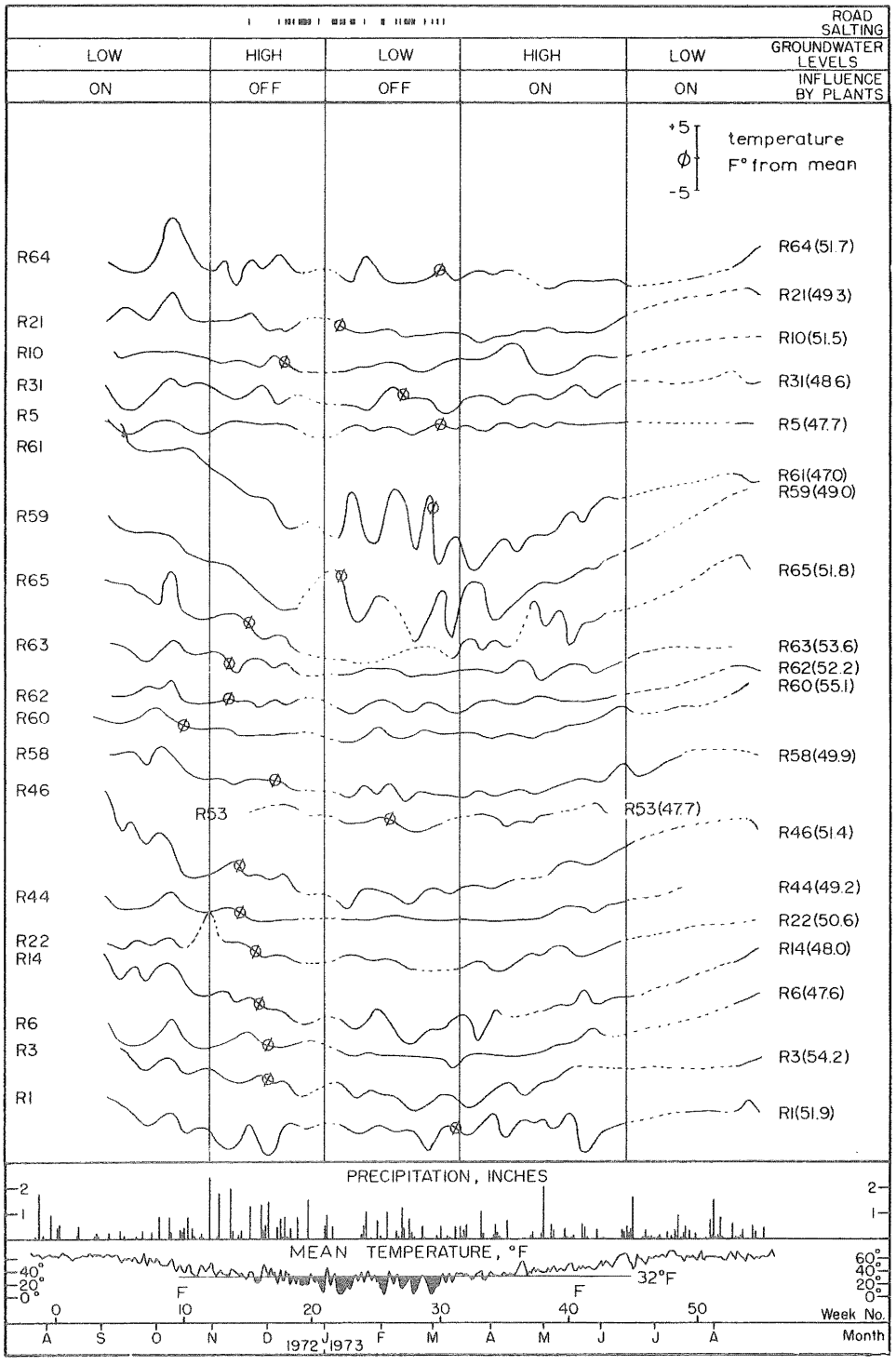


Figure 5.30. Time variations in groundwater temperature, Birch Cove.

High temperature fluctuations indicate a shallow groundwater (wells R59, 61, and 65). Well R59 is classified as a deep water - possibly mixing of groundwater types of similar chemistry and different temperatures is occurring. The position of wells R59 and 61 near shear zones supports the idea of rapidly moving groundwater in the shear zone mixing with slower moving groundwater in less permeable areas adjacent to the shear zone. In well R61, it appears that waters of different composition are being mixed since the conductance varies greatly. Wells R14 and 53 show lower temperatures than many of the other wells and this appears to be related to high salt concentration by active infiltration of cold salt-contaminated roadside brines or meltwater.

Summary

Groundwater flow in Birch Cove is controlled mainly by topography and geologic structure, with little or no influence by glacial till deposits. The undulating bedrock topography is a function of geologic structure , and favors the development of local flow systems. High fracturing in the vicinity of the Birch Cove anticline axis results in some channelling of groundwater towards the axis, thus accentuating the effect on flow of the northeast striking joint set. High yield wells are located near the anticline axis and shear zones; the granite-quartzite contact may also conduct large volumes of groundwater. Irregularities in the water table may be associated with shear zones.

Results of areal variations in groundwater chemistry support the idea of the predominance of local flow systems in Birch Cove, originating on small topographic highs. The influence of road salt, due to the lack of appreciable glacial till cover in the area, masks the true chemical variations to some extent. The main water types are HCO_3-Cl or Cl-HCO_3. Waters with a high salt content are often Cl-SO_4 type.

The area shows relatively high groundwater turnover rates, with the waters being in equilibrium with the weathered products of minerals in the quartzite. Total dissolved mineral content increases towards sea level, either as a result of increasing age of groundwater and/or the cumulative effect of urban salt input to the system. From the data it is difficult to determine whether one or both effects are operative. The linear increase of calcium with well depth indicates that weathering proceeds below the water table in this area; hence water movement through the fractures must be rapid enough that its aggressiveness is maintained for a considerable length of time.

Seasonal variations in groundwater chemistry can be used to obtain some idea of time lags for various ions. An average of 15 weeks was estimated for Cl, with Ca, Mg, Na, and K showing similar responses. Nitrate has a time lag of 6-8 months, with sulphate in many cases showing a similar result. In Birch Cove, salt contaminated wells show high significant correlations among many of the

variables, which can be attributed to the effect of salt on pH and on solubility of other ions. Salt contaminated wells also show generally low temperatures during winter, likely reflecting active infiltration of snowmelt recharge. Wells proximal to shear zones, such as well R61, may show unusual temperature fluctuations.

Wells with a shallow groundwater source, such as R67, show both immediate and delayed responses to water chemistry and water level fluctuations. This is likely a result of rapid input through a local or highly permeable zone, followed by an input of water which has travelled through less permeable zones in the aquifer or from a more distant source.

The time lags for chloride ion as determined from seasonal fluctuation data can be used to estimate the permeability in the vicinity of a well. When the source of the Cl is known, velocity can be calculated and Darcy's Law applied to determine the permeability. For well R14, a permeability of 0.5 ft/day (4.1 gpd/ft^2) was calculated. This value is relatively low as compared to the range of 2.9×10^{-5} to 28.5 ft/day (10^{-2} to 10^{-8} cm /sec) given by Snow (1965) and implies that the well may be in a zone of low permeability, thus explaining the relatively long time lag for the well. Also, it indicates that the smooth nature of the percent conductance curves for the deeper wells is likely a reflection of time and/or lower permeability rather than a distant source and a regional flow system. This supports the idea of mainly local flow systems in the area at the

aquifer depth ranges penetrated by the domestic wells studied. The chemical results, which imply a vertical permeability greater than the horizontal, also support the idea of local flow systems.

The hydrologic budget estimate in chapter 3 indicates that much of the available groundwater recharge in the area is presently being utilized and that groundwater mining could occur in dry periods or with increased demand.

Chapter 6

DISCUSSION OF THE RESULTS IN THE SACKVILLE AREA

The topography and geology of the regional study area are shown on figs. 6.1 and 2.2 respectively. Monitored well locations in Maxwell Subdivision are shown on fig. 6.2.

Movement of Groundwater in Sackville

Drillers' logs (fig. 2.9) were used to prepare a piezometric surface (fig. 6.3) and a contour map of the bedrock surface (fig. 2.8). Lakes and swamps were also included in the surface because their altitudes were similar to the water levels in the nearby wells. The groundwater and surface water divides coincide in the central part of the area (fig. 6.3) but do not in the southern part of the map area near First Lake - this might be due to insufficient well data in this locality.

Comparison of the bedrock map and piezometric map (figs. 2.8 and 6.3, respectively) shows that the main recharge areas east of Springfield Lake and south of Webber Lake coincide with bedrock highs. Local recharge areas occur over some bedrock highs (e.g., south of Duck Pond) and over drumlins (e.g., east of Webber Lake, north of Barrett Lake, and southwest of First Lake). A regional flow system is possible in the bedrock from the water divide on the west to the regional

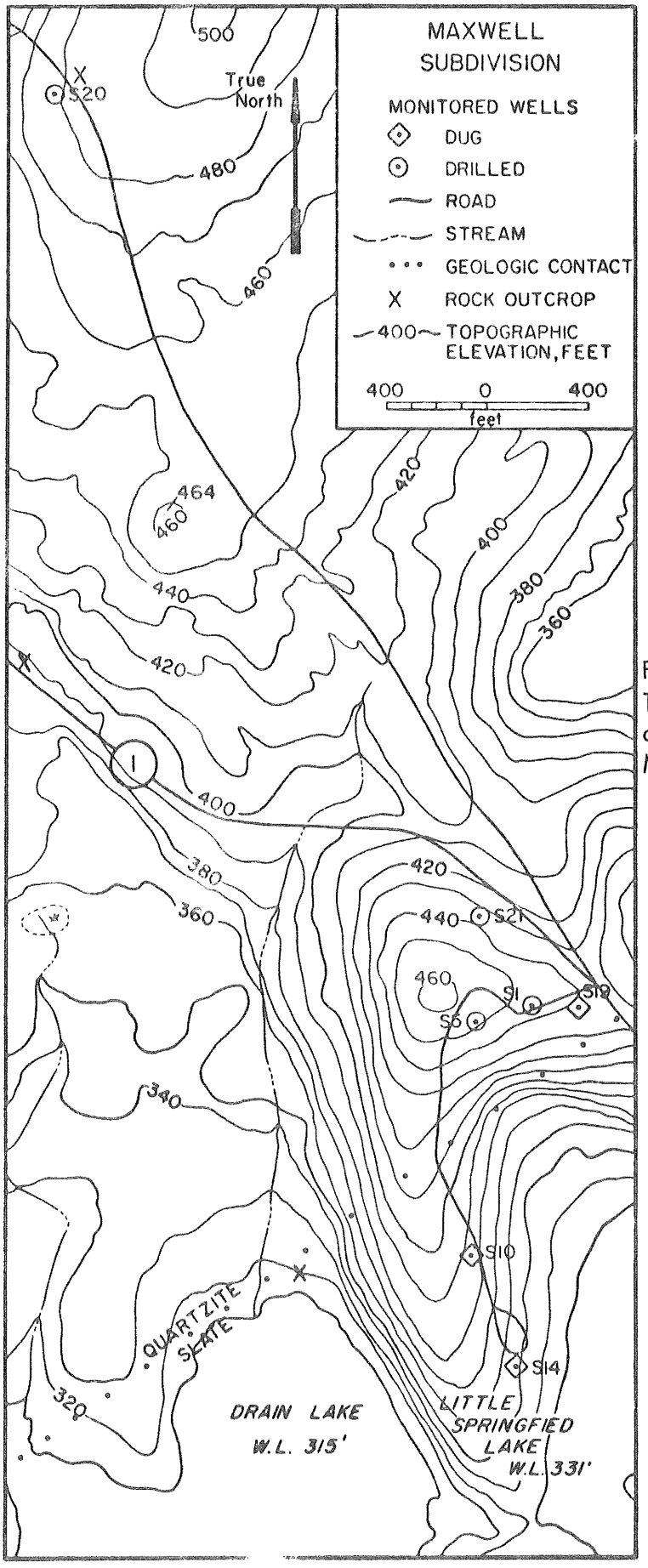


Figure 6.2.
Topography and location of monitored wells, Maxwell Subdivision.

discharge area on the east (Lakes Kinsac and Fletcher in this area) with an average hydraulic gradient of 0.016 to 0.020 ft/ft. This is supported by the piezometric map (fig. 6.3) which shows a general east-northeast flow of groundwater controlled basically by the bedrock topography. Intermediate type flow systems are possible but the data is insufficient to clarify this point. There is a north-south line of local recharge areas along the Beaverbank Road (fig. 6.3) which result in a local discharge line running north-south through Fenerty, Wilson, and Feely Lakes.

Yield of bedrock wells varies from 1-5 gpm. Locations of wells with reported yields greater than 5 gpm are shown in fig. 2.2. The majority of these wells are located within 1/4 - 1/2 mile of either the north or south slate-quartzite contact, where high fracturing is possible. Evidence for high fracturing is the low groundwater potential along the contact near Springfield Lake (fig. 6.3) reflecting rapid dissipation of potential here. Well-developed bedding planes may conduct significant quantities of groundwater. Wells near the granite-slate contact on the west side of Kinsac Lake also show high yields; this contact may have been faulted, thus producing highly fractured zones.

The elevation of water levels in bedrock wells corresponds closely to those in dug wells where such data is available, with the levels in dug wells sometimes higher. This indicates a communicating sequence, with waters in the bedrock in hydrostatic equilibrium with the overlying waters (Gretener, 1969) and with a small component of downward flow in some areas. Hence the till-bedrock contact must

be relatively permeable to groundwater movement as discussed by Knutsson (1971). Groundwater in the bedrock occurs under water table conditions in the recharge areas but under artesian conditions where the bedrock is covered by glacial till.

The glacial till samples from Sackville are composed of sandy silt or silty sand (fig. 6.4). They show a wide variety of specific yield values (as compared to fig. 6.4a, from Johnson(1967)) but generally less than 25%. Permeability also varies widely, as shown from data from 14 testpits in the Beaverbank area (courtesy of Mr. M. Jackson), but is directly related to median grain size (fig. 6.5). The mean value of 7.0×10^{-6} cm/sec or 1.2×10^{-1} gpd/ft^2 lies within the range of permeabilities for tills of 2.0×10^{-4} to 9.0×10^{-1} gpd/ft^2 found by Norris (1963) and is relatively low as compared to the bedrock: however, on a regional basis, leakage through till could contribute significant amounts of recharge to the bedrock if it enters the regional flow system. High pumping rates in a bedrock well could induce leakage from the till.

That permeable lenses or joints exist in the till in Sackville is shown by two lines of evidence: 1) the logs from the testpits document perched groundwater flow up to 2-4 gpm from sandy lenses: this caused caving in some of the pits; and 2) the rapid responses of dug well S14 to changes in water level and water chemistry (see later) indicate a good hydraulic connection of this well to the surface. This is not a direct surface runoff effect since the well is properly constructed, and also the homeowner reported that 3 springs were entering the well when it was dug (representing discharge from permeable zones in the till). These sandy lenses are not continuous,

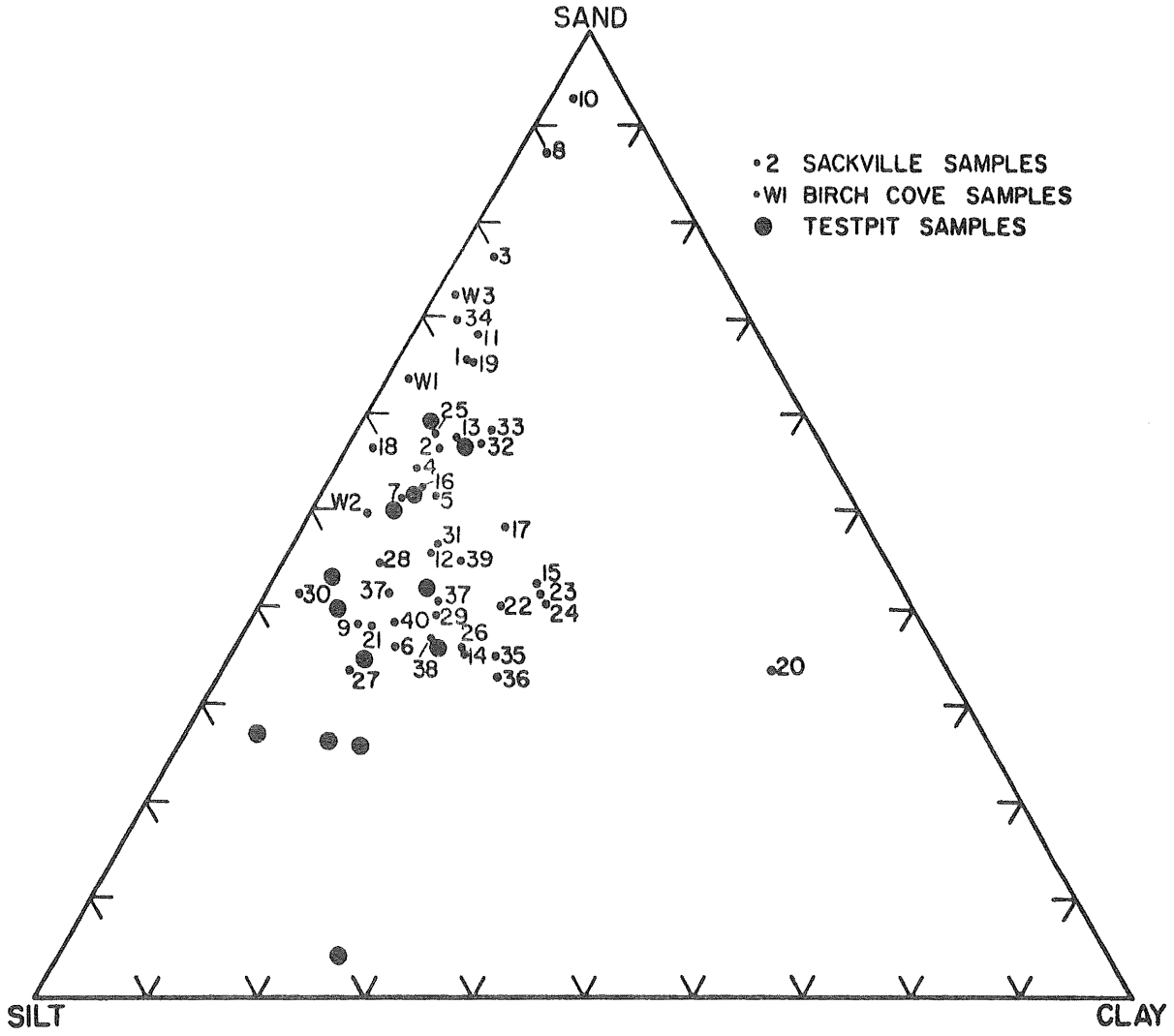


Figure 6.4. Sand-silt-clay percentages of glacial till samples.

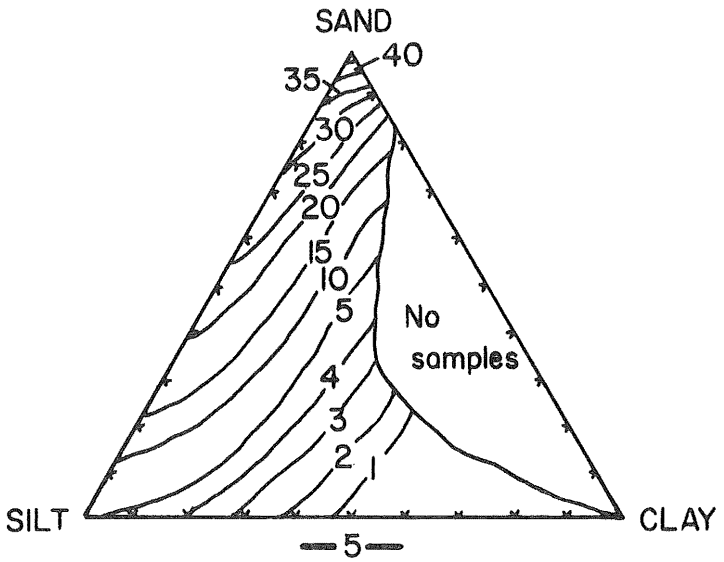


Figure 6.4a. Specific yield of sands, silts, and clays (after A.I. Johnson, 1967).

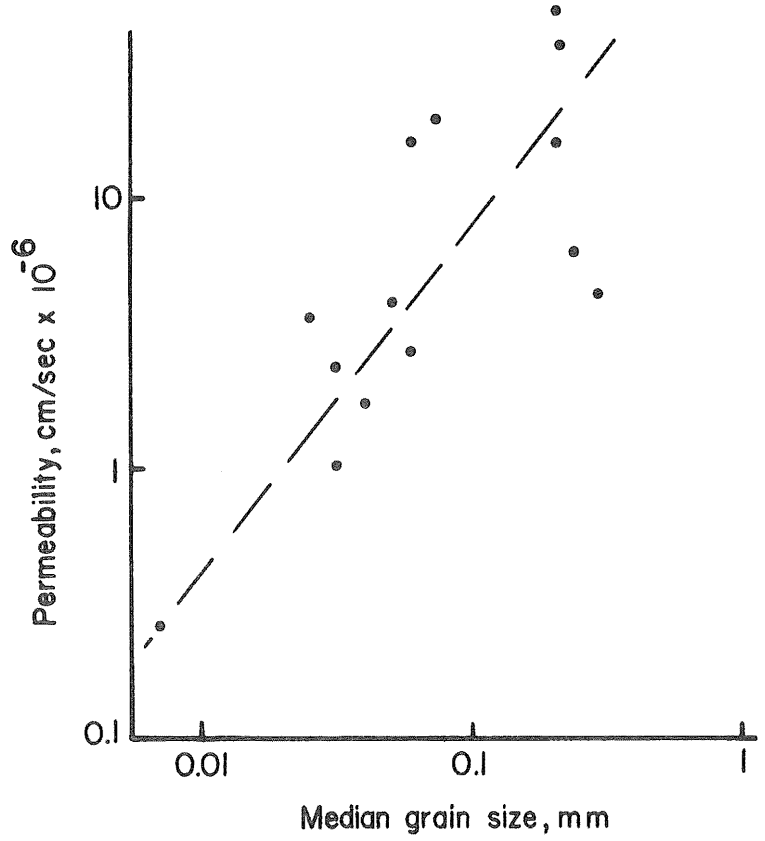


Figure 6.5. Relation of permeability of till to median grain size.

as illustrated by the nonuniform change in fluid potential between dug wells S10 and 14 (fig. 3.4) which are only 200 feet apart. Some idea of the complexity of the till deposits is shown in fig. 6.6, which was interpreted by the author from testpit logs (courtesy of Mr. M. Jackson).

Buried Channels

The location of two bedrock channels in Sackville is shown in fig. 2.8. Wells reporting gravel in their logs are located in figs. 2.2 and 2.8. Where the gravel occurs, it usually directly overlies the bedrock and is more than 10 feet thick. Not all wells with gravel show high yields since they are cased through the gravel and completed in bedrock. In wells S152 and 153, the driller reported a flow of 15 gpm from the gravel layer, with a head above the ground surface of a few feet. Wells completed in this gravel could probably be pumped at a rate much greater than 15 gpm (J.F.Jones, personal communication).

Trescott (1968b) estimates that there might be 50-100 feet of sand and gravel in the deepest part of the Sackville River bedrock valley as far upstream as its junction with the Little Sackville River. Yields up to or greater than 200 gpm from individual wells are possible.

Groundwater Chemistry and Flow Systems

Groundwaters in this area have been divided into confined and unconfined

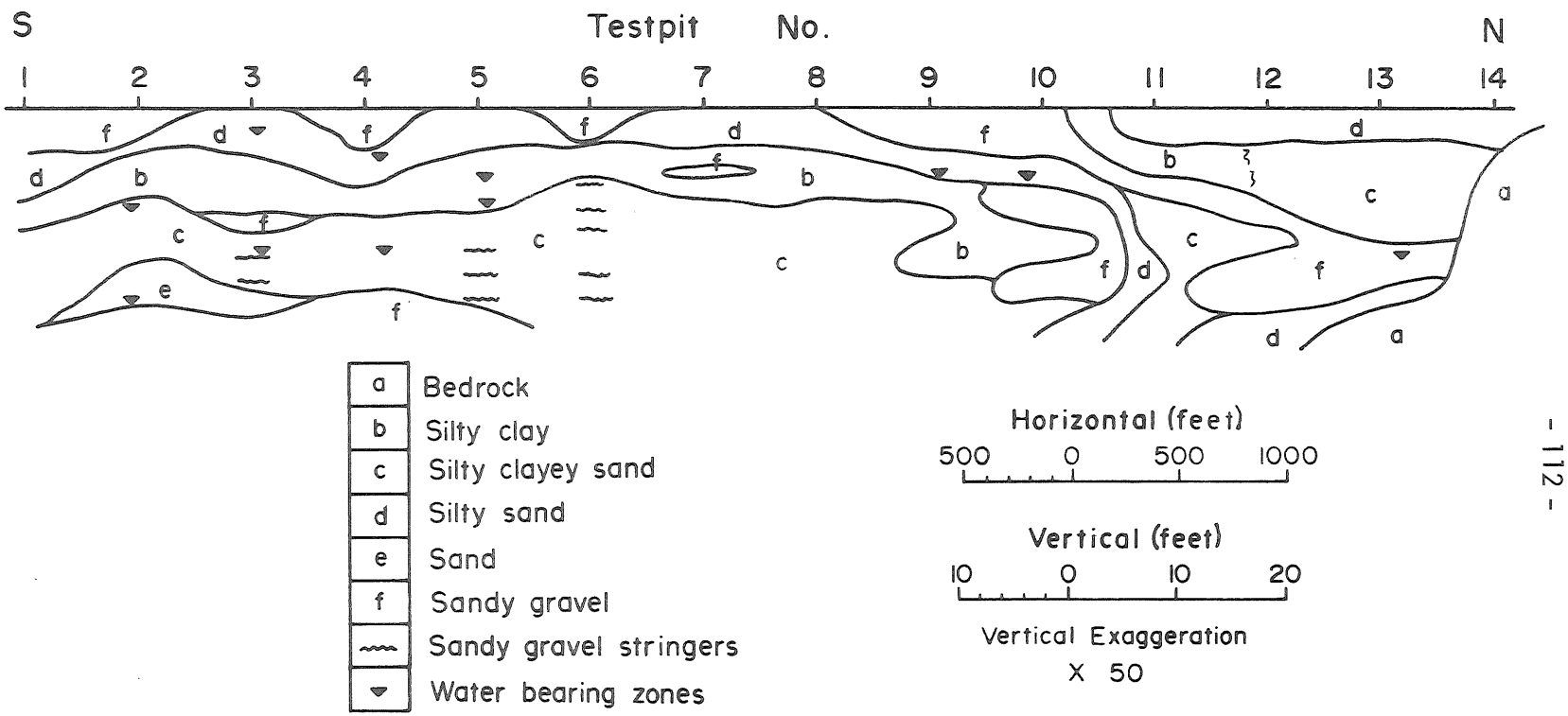


Figure 6.6. An example of till stratigraphy in the Beaverbank area, Sackville.

types (see Definitions). Most drilled well waters are of the former type, most dug well waters of the latter. Confined waters are mainly HCO_3 - SO_4 or HCO_3 - Cl type, with only three samples in the Cl-HCO_3 and none in the Cl-SO_4 groups (appendix 5, fig. 3). Unconfined waters fall mainly into the HCO_3 - Cl or Cl -HCO_3 groups, with minor groups HCO_3 - SO_4 and Cl -SO_4 (appendix 5, fig. 4). The shape of the semilog plots is very similar for similar water types. The mean compositions of the monitored wells are presented in appendix 5, fig. 5, and tabulated in appendix 4. From the areal variation map of the water types (fig. 6.7) it can be seen that HCO_3 - Cl and HCO_3 - SO_4 waters in both confined and unconfined groups are found on or near piezometric highs (fig. 6.3), i.e., recharge areas. Where these types are found in topographic lows, rapid recharge through near surface bedrock or through sands and gravels is indicated. The predominance of the HCO_3 - SO_4 water type in regional discharge areas such as the northern end of Lake Kinsac likely represents the influence of SO_4 from the pyrite-rich slate bedrock masking Cl in the discharge area. The Cl-HCO_3 and Cl-SO_4 water types are not related to position in the flow system and likely indicate salt contamination. Wells of the Cl-SO_4 type especially do have high NaCl concentrations, and are mainly shallow dug wells which are most susceptible to contamination. Evidence for this is illustrated by fig. 6.8.

The predominance of different water types in the confined and unconfined groups implies the presence of two types of flow systems. A regional one is found

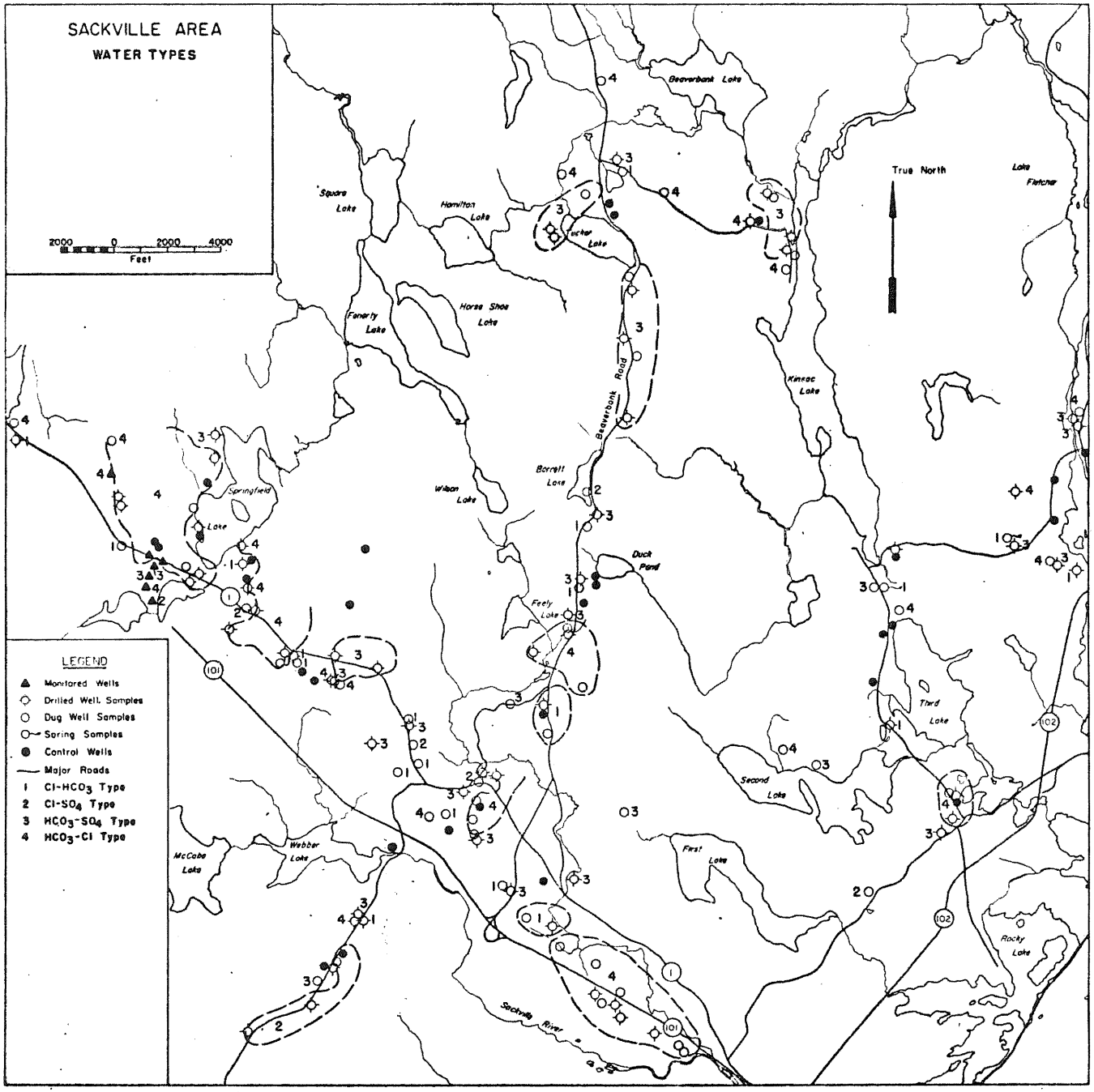


Figure 6.7.
Areal variations in groundwater types, Sackville.

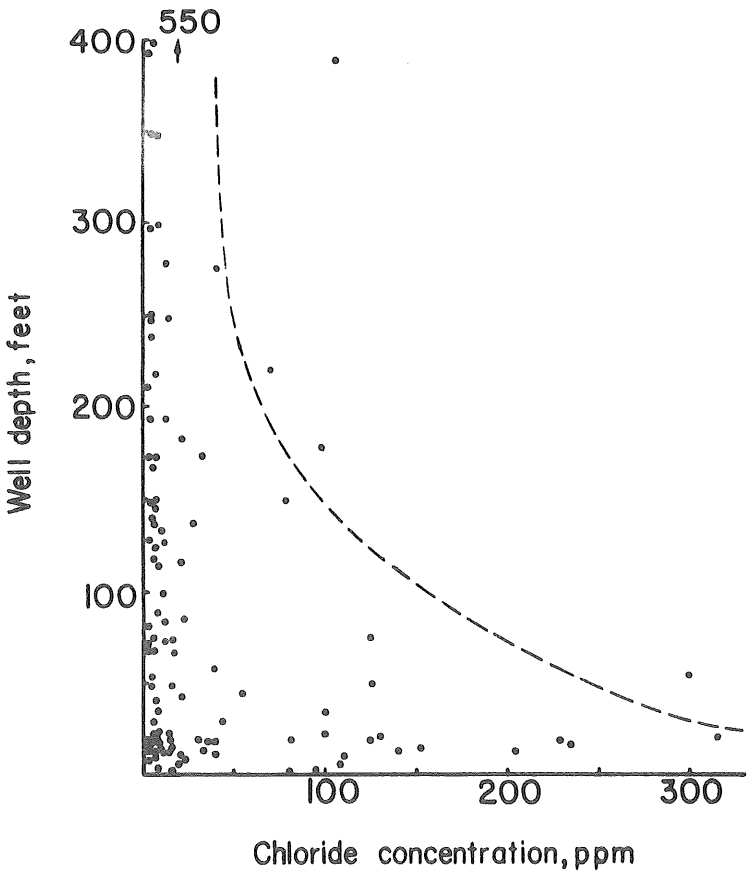


Figure 6.8. Chloride concentration as related to well depth, Sackville.

in the bedrock, and local or intermediate ones where small bedrock highs or drumlins exist. Water types in the regional (confined) flow system progress from HCO_3-Cl in the recharge areas to HCO_3-SO_4 in the discharge areas. The Cl water types in the unconfined system must either be diluted in the regional system or discharged locally without reaching it, since HCO_3 waters dominate. Where thick clayey glacial till occurs, some Cl may be removed by adsorption. This may also represent a membrane effect (Schwartz, 1974): however, further data on the till would be required to determine this, such as clay mineral type and content, carbonate content, and density.

Areal variations in various parameters are illustrated in figs. 6.9 to 6.15.

Iron and Manganese (figs. 6.9 and 6.10)

Variations of Fe and Mn are plotted in relation to the recommended limits given in table 5. The general observation that can be made from this data is that most dug wells have good water quality with respect to Fe and Mn while drilled wells often contain excessive concentrations. This indicates that the bedrock is the most important source for these ions or that dissolved oxygen decrease with depth is causing reducing conditions that increase the solubility of Fe and Mn in the slate and quartzite. The lowest Fe and Mn values seem to occur in waters from local or regional recharge areas where the groundwater would tend to be more oxygenated.

Sodium and Bicarbonate Percents (figs. 6.11 and 6.12)

Since many dug well samples showed some evidence of road salt, only drilled

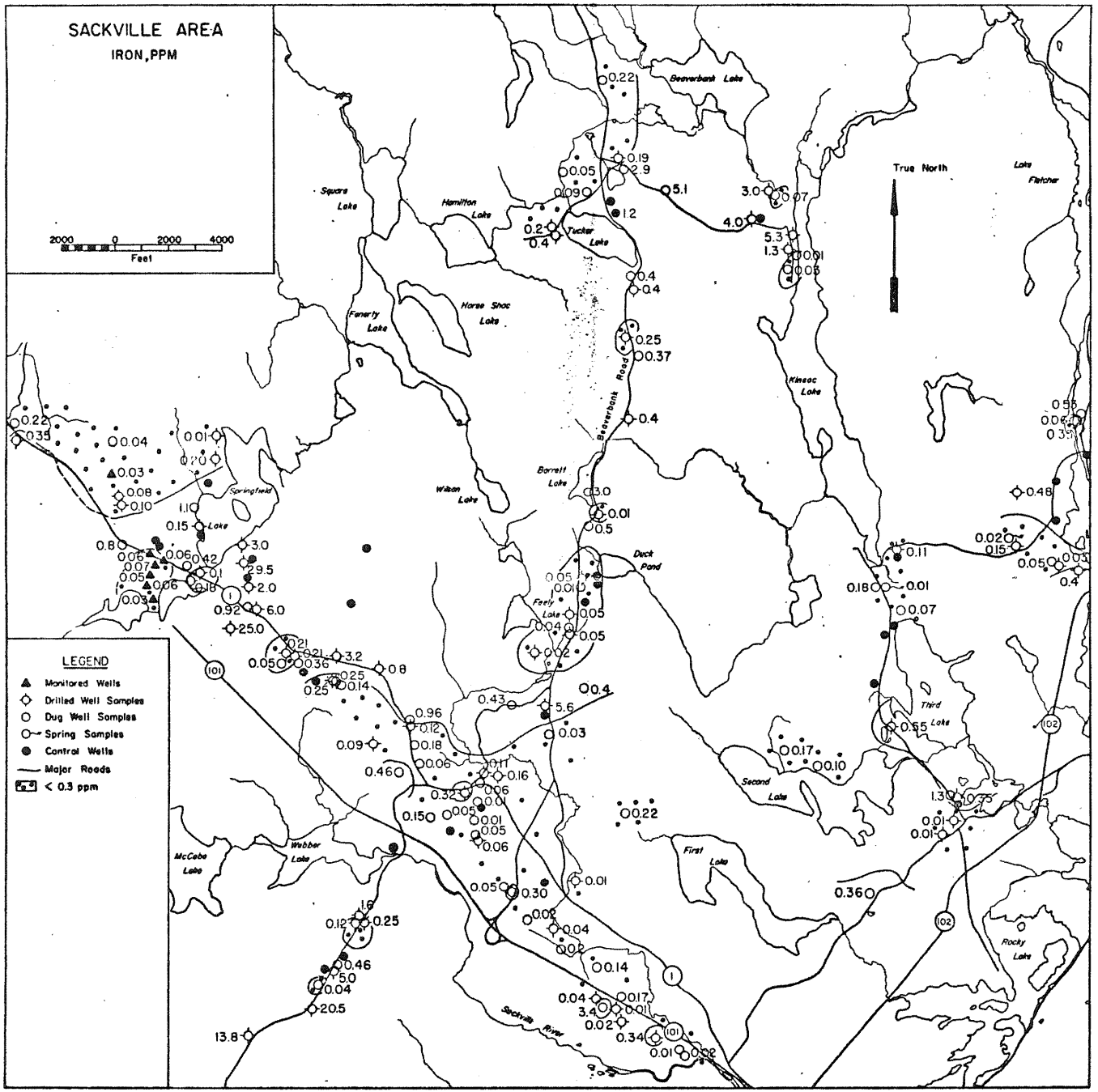


Figure 6.9.
Areal variation in iron, Sackville.

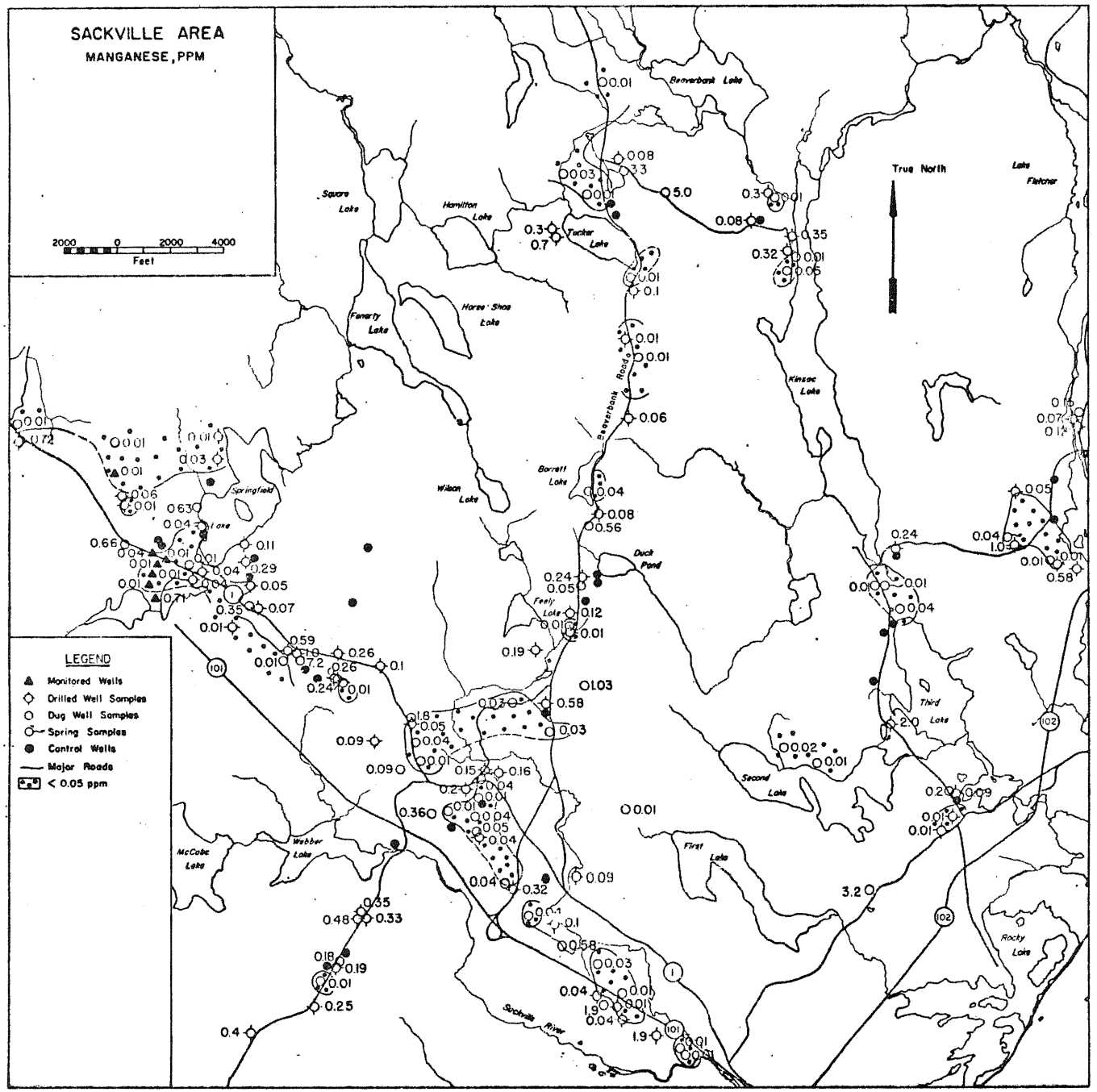


Figure 6.10.
Areal variation in manganese, Sackville.

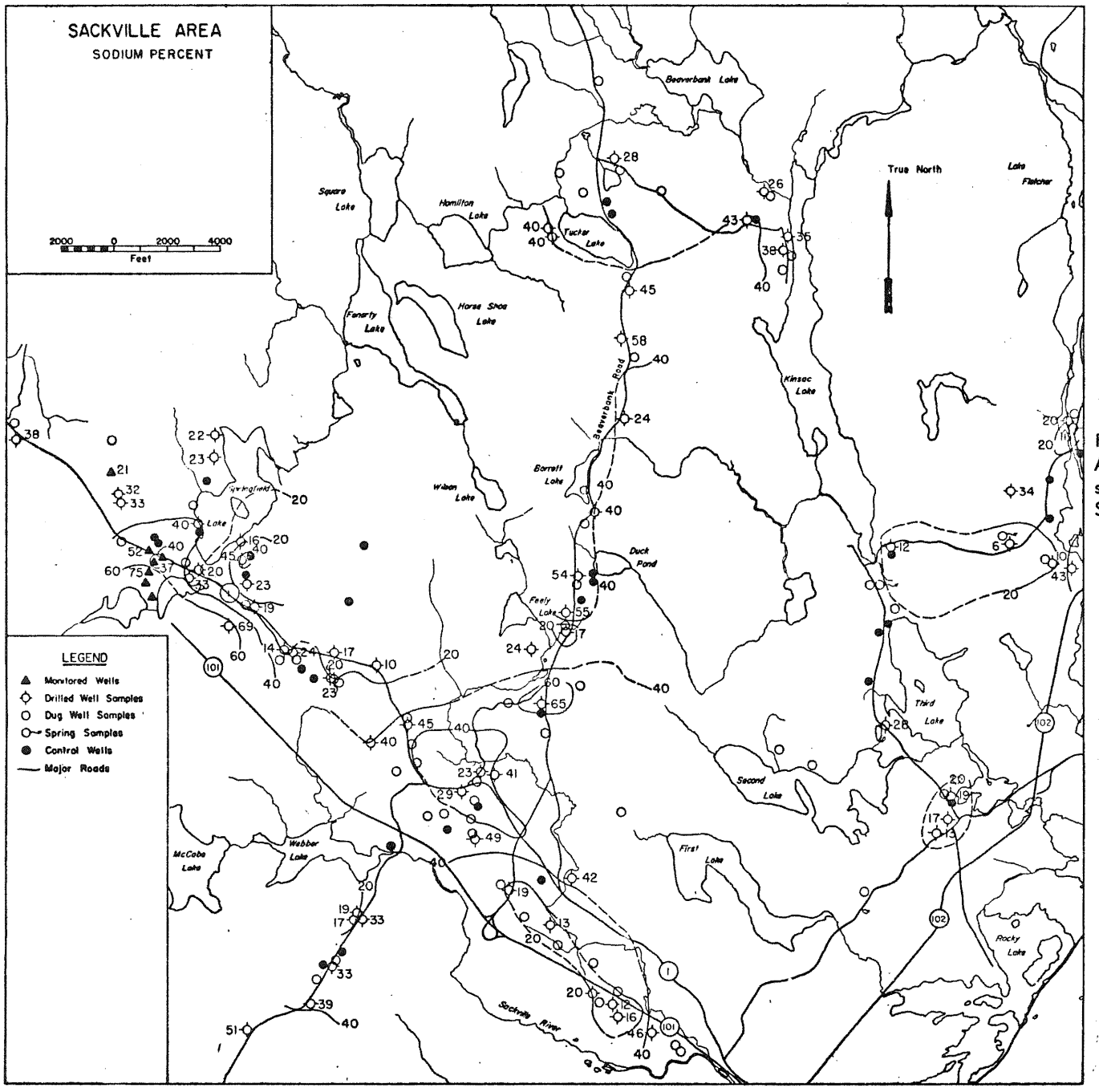


Figure 6.11.
Areal variation in sodium percent, Sackville.

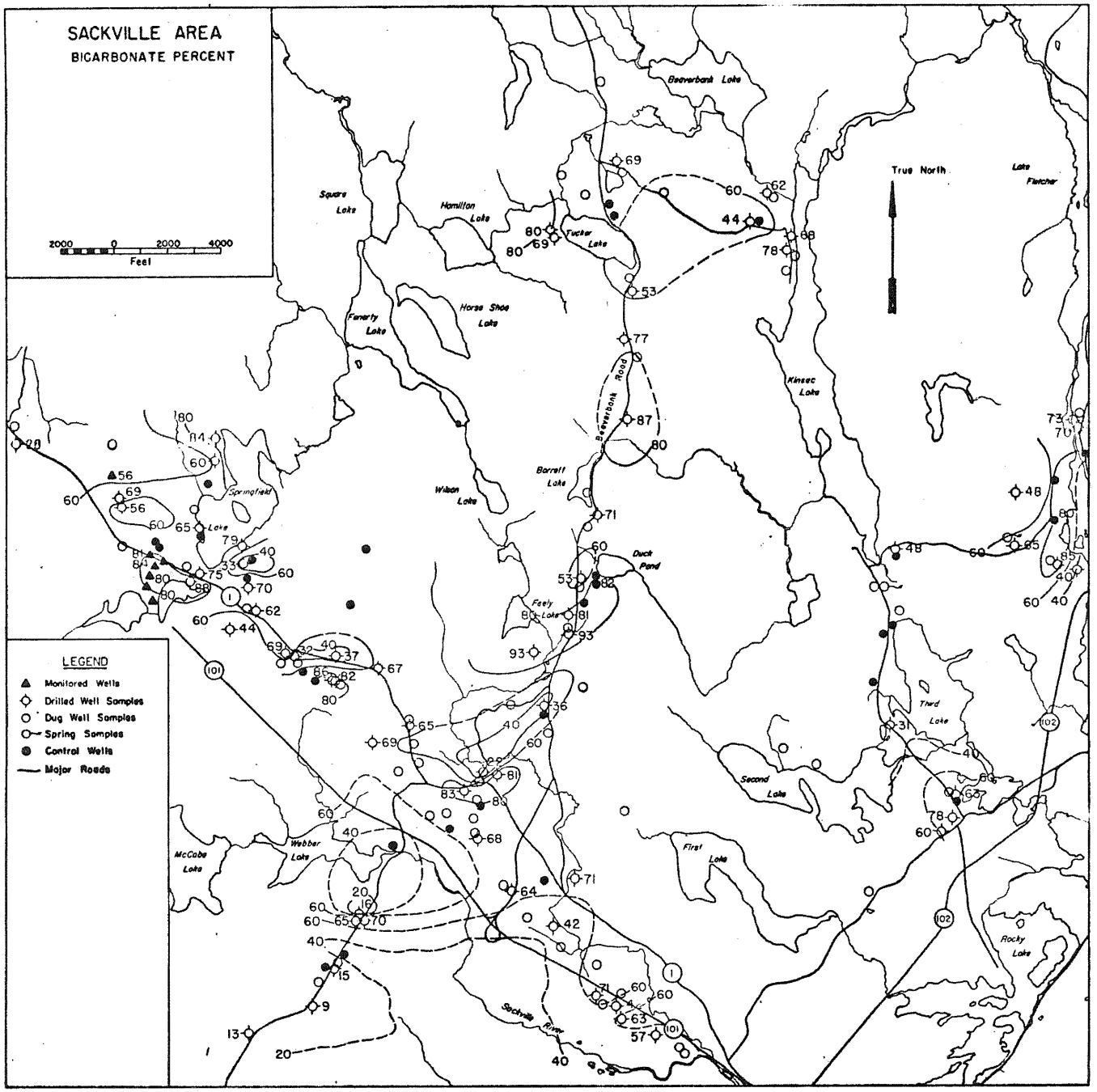


Figure 6.12.
Areal variation in bicarbonate percent, Sackville.

well results were used for these plots. Sodium percent values vary from about 20% in recharge areas to 40-60% in discharge areas, reflecting a regional flow system in the bedrock. The slightly high values of Na% in the recharge areas west of Springfield Lake and south of Webber Lake could represent a small amount of salt contamination since both these areas have a thin till cover.

In general, HCO_3% is highest in recharge areas, especially in those local ones controlled by the presence of thick glacial till (such as east of Feely Lake and northeast of Barrett Lake as indicated in fig. 2.7) where a high pCO_2 occurs. Bedrock recharge areas, such as northwest of Springfield Lake and south of Webber Lake, have a lower HCO_3% (20-40%) as a result of shorter contact time with glacial till and soil air. Well waters in discharge areas covered by thick till, such as in the vicinity of Tucker and Kinsac Lakes, show little or no decrease in HCO_3% from till-covered recharge areas. This indicates a continued input into the system of HCO_3 by waters percolating through glacial till and dissolving $CaCO_3$. Thus some waters from local recharge areas do enter the regional flow system.

Chloride (fig. 6.13)

Results from both dug and drilled wells are shown. Contours are based on the limit set by the author of 50 ppm for uncontaminated water. On this basis, 11% of the drilled wells and 30% of the dug wells show some degree of salt contamination, and thus chloride cannot be used as a chemical facies indicator. Dug well waters with salt are found on the downslope side of roads with respect to groundwater flow,

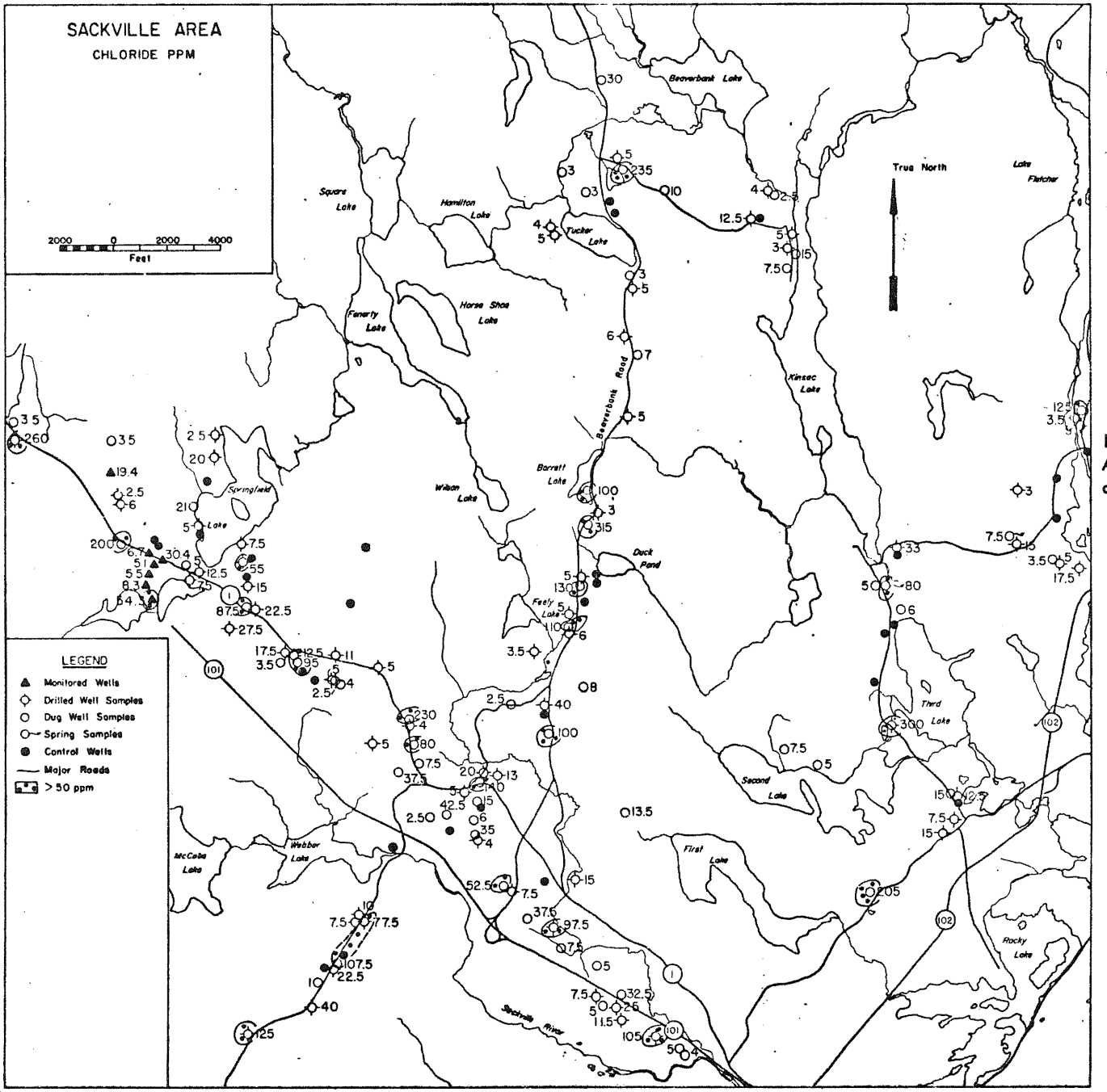


Figure 6.13.
Areal variation in chloride, Sackville.

indicating a probable road salt source. Only local areas appear to be contaminated at present, due to variation in factors such as permeability, till thickness, distance to the source of contamination, and slope of the land.

Calcium to Magnesium Ratio (fig. 6.14)

These ratios in groundwater show a general decrease from 5-6 in recharge areas to 3-4 in discharge areas as a result of the higher solubility of Mg compounds and of the abundance of Mg-containing compounds in the bedrock (such as chlorite).

Base exchange index (fig. 6.15)

Base exchange index should vary from positive in recharge waters to negative in discharge waters (Vandenberg et al, 1969). This relationship is evident in the area indicating that some ion exchange occurs in the bedrock; however, most of the change is likely a result of infiltration of water that has undergone exchange reactions in glacial till. Evidence of the latter is shown by a plot of Ca/Na ratio against depth to bedrock (fig. 6.16). A local discharge area with negative BEI is evident just west of Duck Pond (fig. 6.15); the groundwater flow pattern (fig. 6.3) also indicates a discharge area there.

Mineral Equilibria and Weathering

Stability field plots were made for those well waters with pH and SiO_2 analyses (figs. 5.14 to 5.17 c). Most results fall within the kaolinite field, indicating a well leached aquifer due to instability of the feldspars at the prevailing pCO_2. Samples

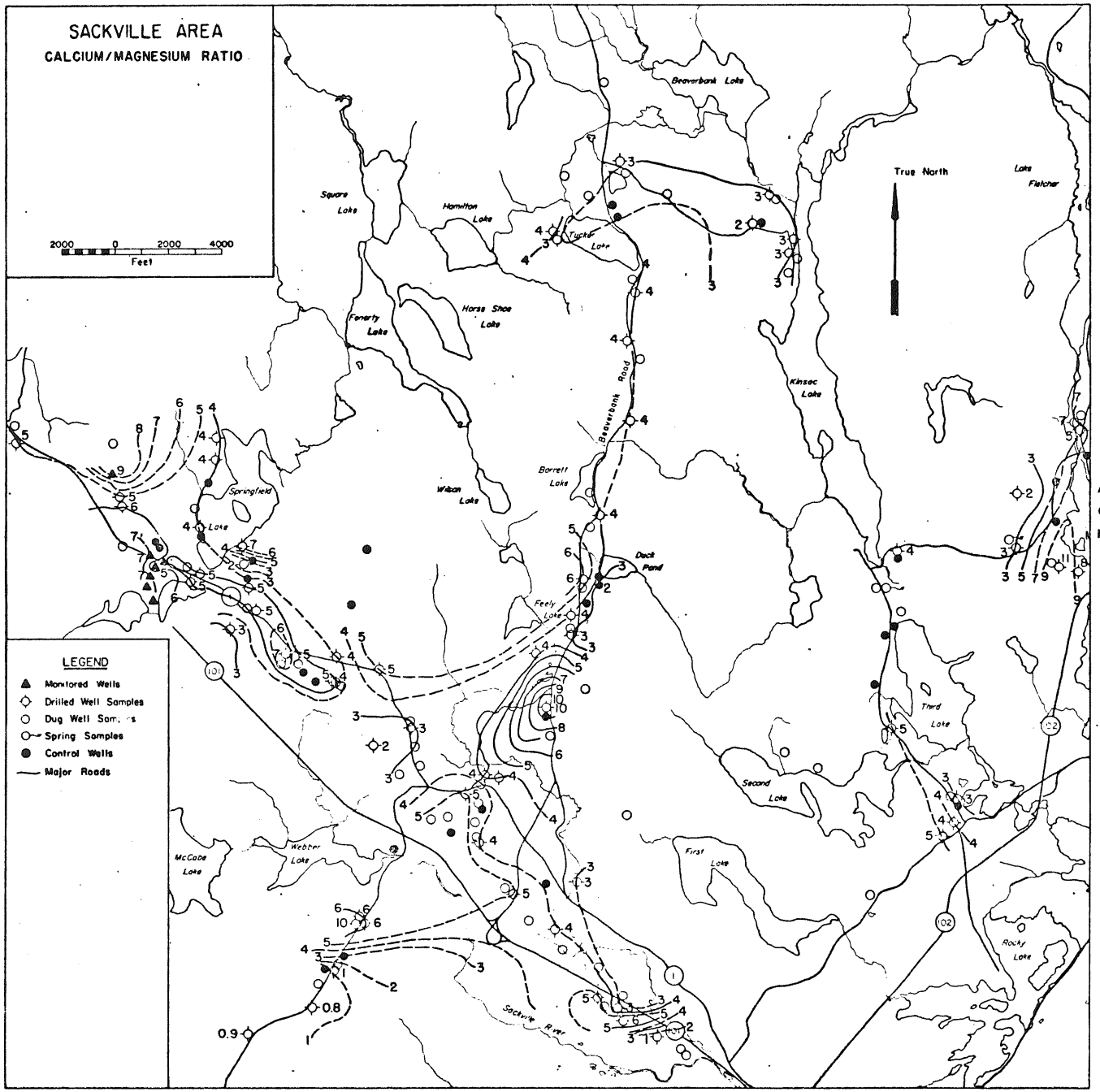


Figure 6.14.
Areal variation in calcium to magnesium ratio, Sackville.

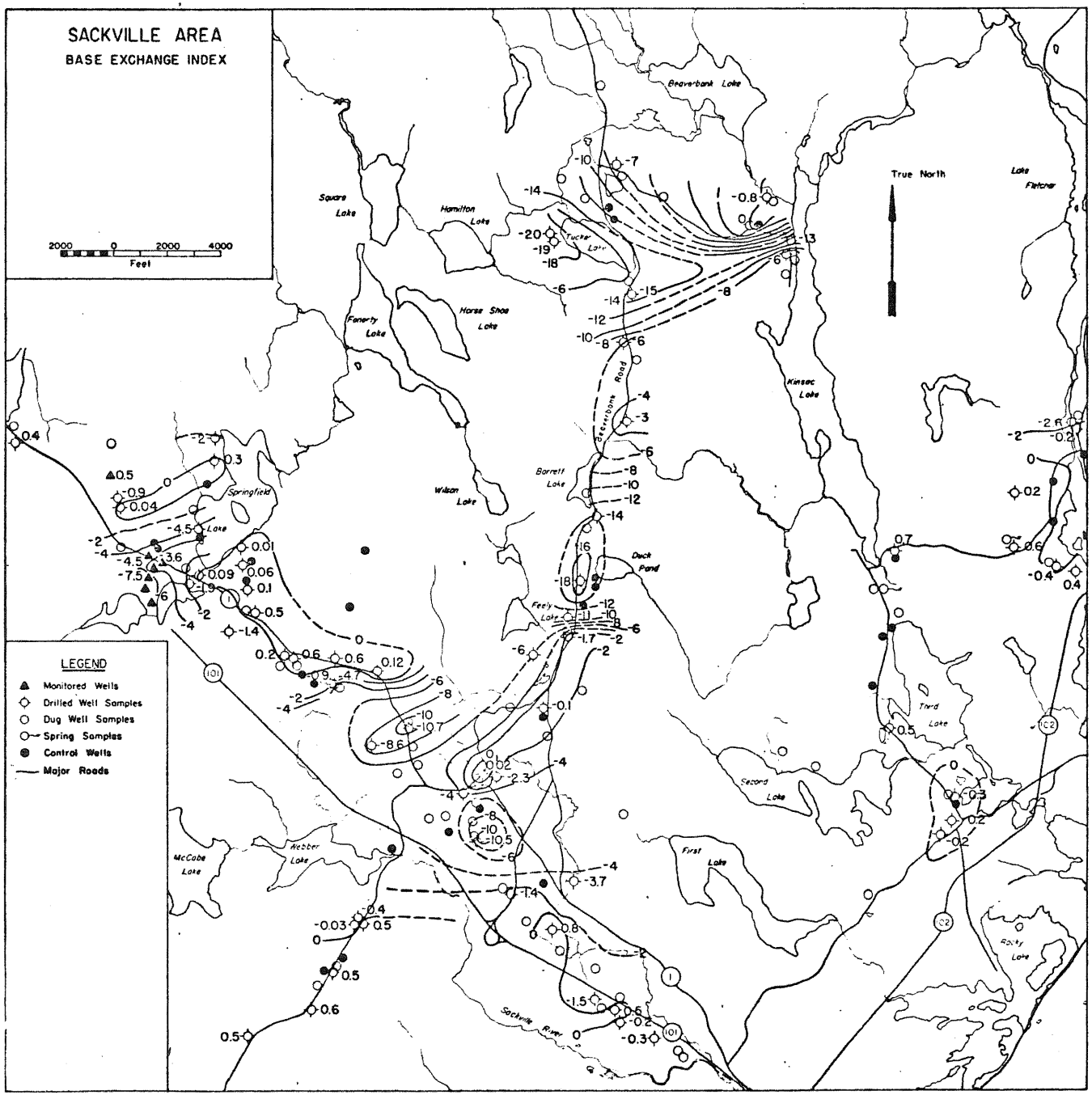


Figure 6.15.
Areal variation in base exchange index, Sackville.

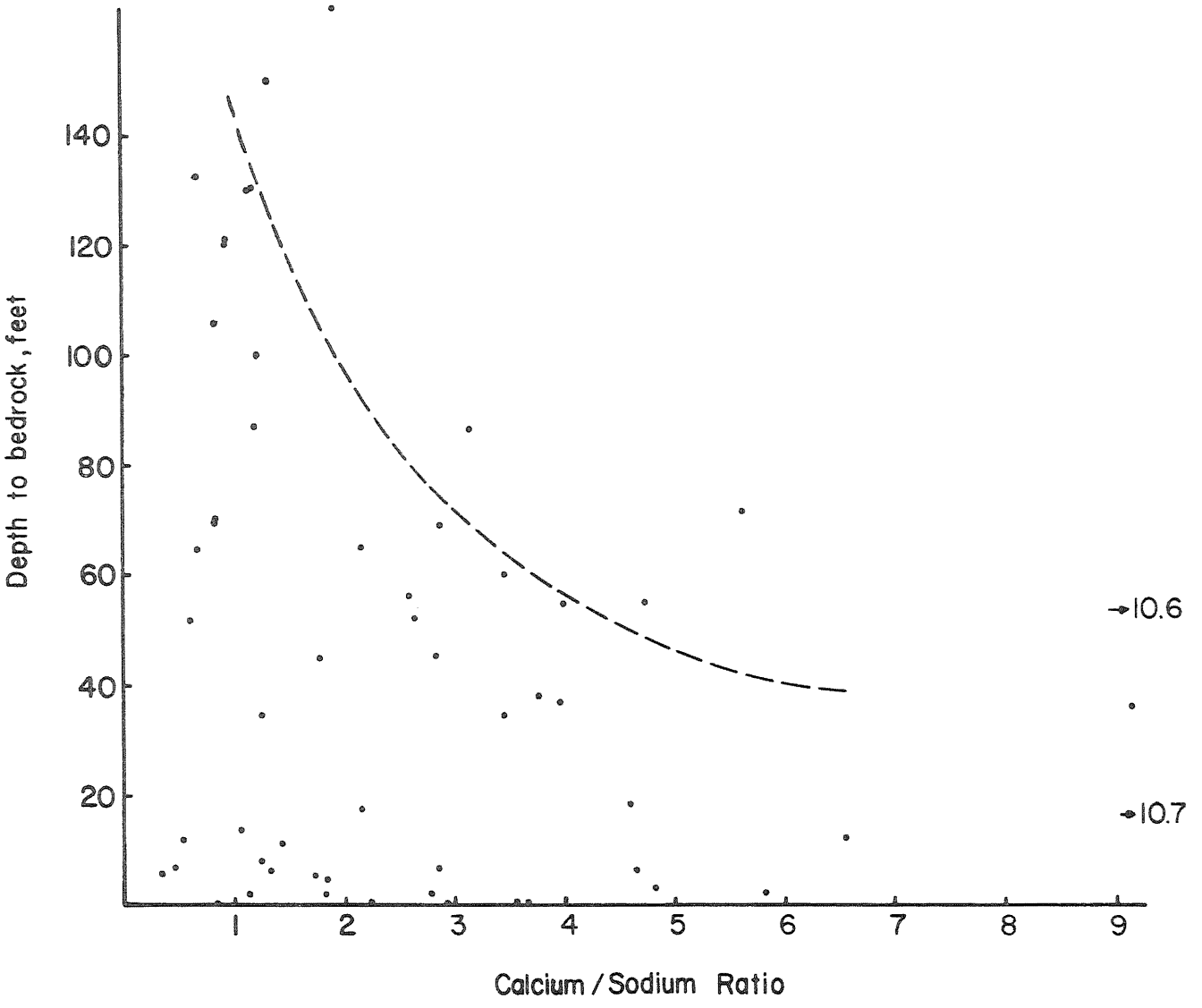


Figure 6.16. Relation of calcium to sodium ratio to depth to bedrock, Sackville.

from two dug wells, S117 and S142, fall within the gibbsite field. Two mechanisms may account for this: firstly, very rapid recharge and/or a very local source for the water (Bricker (1967) has found that gibbsite is produced from initial attack on feldspar, but the reaction is so rapid that it is rarely preserved), and secondly, severe leaching conditions may result in gibbsite production by the following reaction (Garrels et al, 1965):

$$\underset{\text{Kaolinite}}{H_4Al_2Si_2O_9} + 5\,H_2O \rightleftharpoons \underset{\text{Gibbsite}}{Al_2O_3.3H_2O} + 2\,H_4SiO_4$$

At any value of dissolved SiO_2 less than 2 ppm, kaolinite tends to dissolve incongruently by the above reaction to leave a residuum of gibbsite. This "severe leaching" effect could be a result of the first mechanism of rapid recharge of CO_2-rich waters. Both types of feldspar systems are present, as shown by the fact that many of the groundwaters have a pK-pNa value close to 1.0.

Turnover rates were plotted after Jacks (1972,1973). A relatively fast rate is evident for the upper part of the aquifer (fig. 6.17), possibly due to the influence of local flow systems. Data from lower levels falls in a relatively straight line, indicating aggressive leaching at all levels investigated.

Water levels from drilled wells were used in fig. 6.18 which indicates either the effects of increasing groundwater age along a flowline and/or the increase in mineralization with depth associated with a vertical hydrochemical facies. The few anomalously low values of conductance at lower groundwater elevations indicates that these wells either do not penetrate the regional flow system or that recharge from near surface sources is rapid. Addition of Ca and HCO_3 along a flowline by

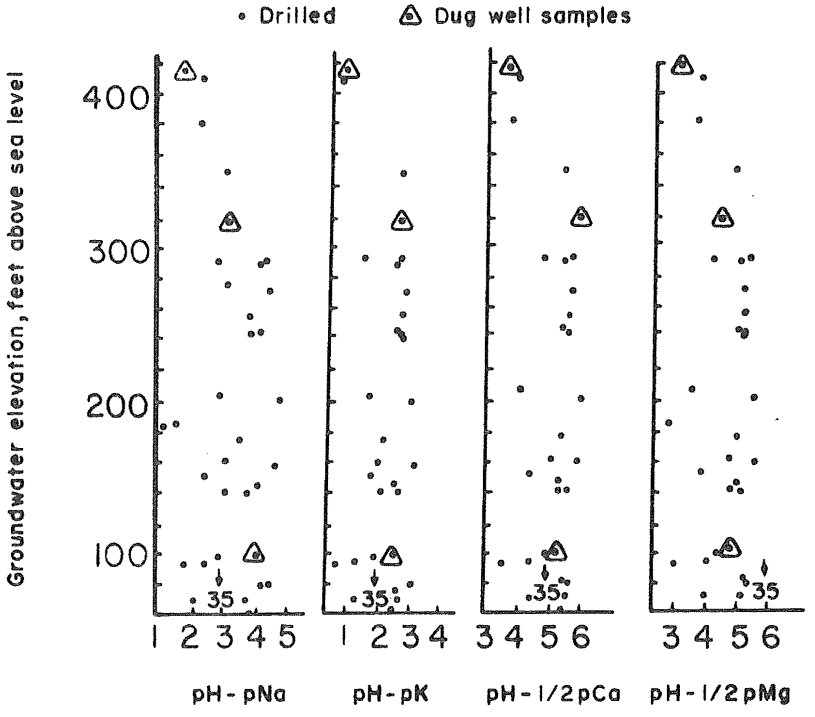


Figure 6.17. pH-pNa, pH pK, pH-1/2 pCa, and pH-1/2 pMg as related to groundwater elevation, Sackville.

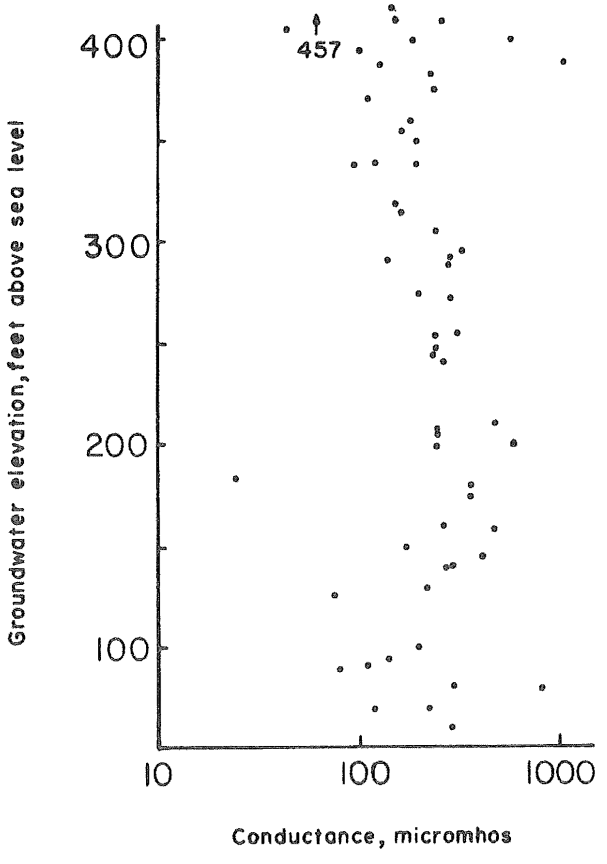


Figure 6.18. Conductance versus groundwater elevation, Sackville.

weathering of $CaCO_3$ (fig. 6.19) may cause this observed increase in conductance. Figure 6.19 shows that even high values of Ca and HCO_3 do not necessarily represent saturation with respect to $CaCO_3$; one possible explanation for this is that the pH is too low as a result of processes such as pyrite oxidation. Most of the saturated waters were obtained from wells which penetrated 50 feet or more of glacial till, indicating that $CaCO_3$ is being locally dissolved in the till and transported into the bedrock. Fig. 6.20 illustrates evidence for Ca input near the surface in dug well waters. The relatively constant Ca concentration with depth in the bedrock indicates either that 1) the water is depleted of CO_2 and the pH is increased by reactions in the till so that it is less unsaturated, or 2) groundwater flow in the bedrock is mainly lateral, as would be expected in a regional system. In some dug well waters, some Ca input could be from road salt; however, most of the dug wells (e.g. wells S39, 50, 51, 61, 70, 72, 73, 81, 94, 128) located in thick glacial till and with Cl less than 30 ppm have a Ca content greater than 20 ppm, indicating dissolution of $CaCO_3$.

Statistics

A discriminant function analysis showed dug and drilled well waters to be different at the 0.01 level with respect to K, HCO_3, and NO_3. The former two ions separate the groups best. The higher K concentrations in dug well waters could be a result of organic contamination by fertilizer and/or weathering of alkali feldspar from granite pebbles found in the till. The higher HCO_3 values in drilled wells probably reflect the influence of high pCO_2 in soil pores through which recharge

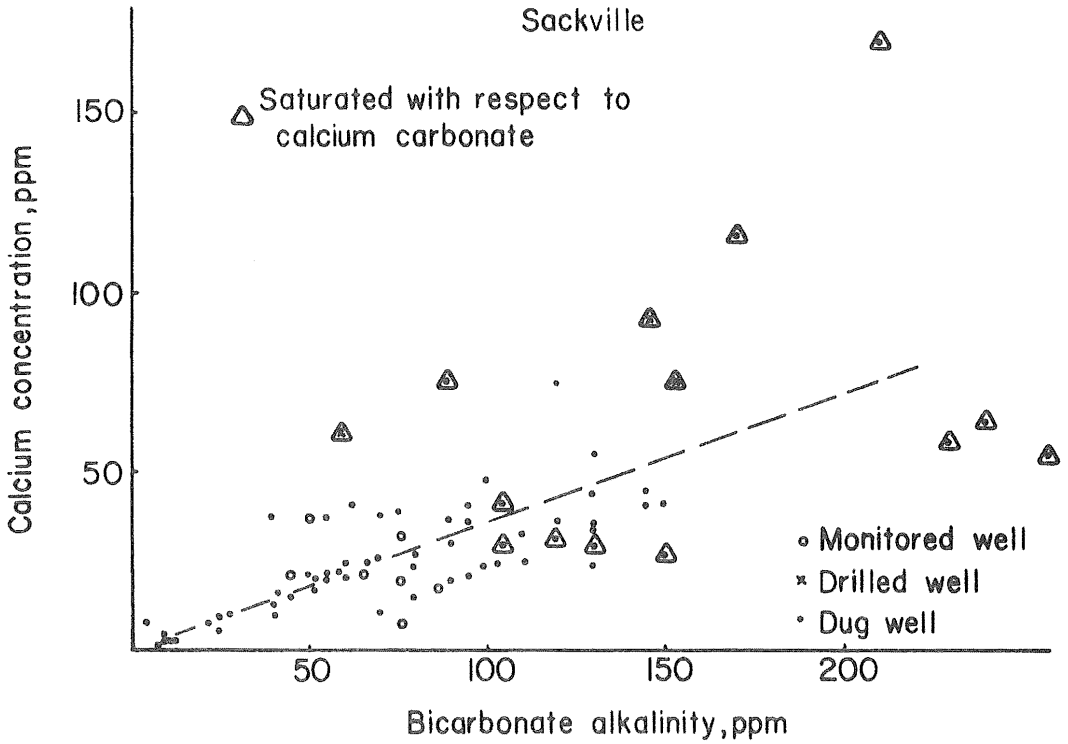


Figure 6.19. Calcium versus bicarbonate alkalinity concentrations in drilled well waters, Sackville.

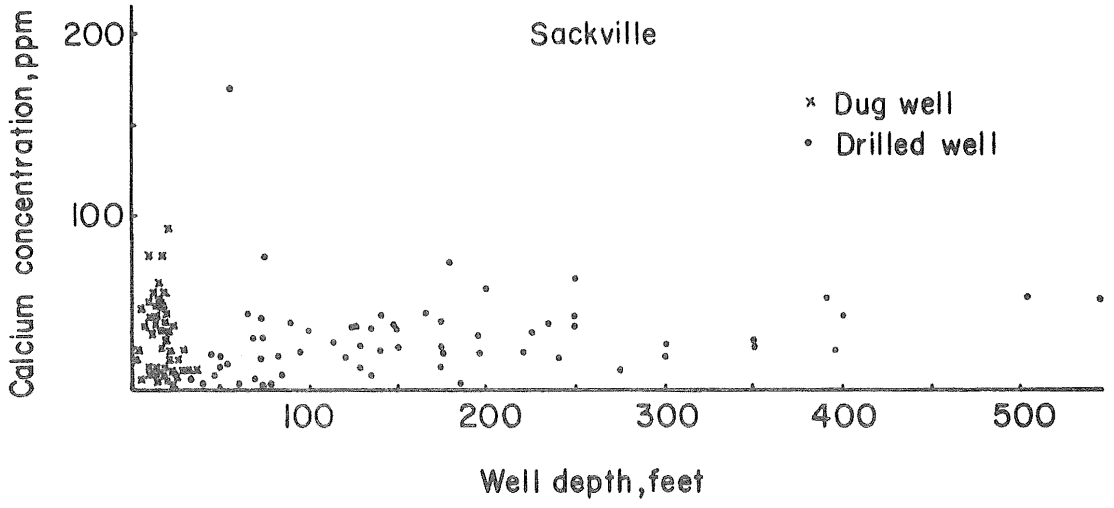


Figure 6.20. Calcium concentration in groundwaters versus well depth, Sackville.

water percolates. The NO_3 in dug well waters is likely the result of contamination by fertilizer or organic material.

Drilled well waters were further separated into those originating from quartzite or slate bedrock. A discriminant function analysis indicated Mg to be higher in waters from quartzite and Fe higher in waters from slate, at the 0.01 level. The high Mg values likely result from weathering of biotite and chlorite. At a less significant level, NO_3 was found to be higher in quartzite waters; this could be a result of the generally thinner till cover overlying the quartzite in this area, thus permitting easier access of near surface water containing NO_3 into the bedrock.

Tables 10 and 11 illustrate the results of a Pearson correlation on analyses from dug and drilled wells, respectively. The higher r values between Na and Cl, and Fe and Mn in dug well waters likely reflects the influence of road salt on the mobility of Fe and Mn in the soil. In the drilled well waters, Mn appears to be influenced more by Cl than pH (high Mn-Cl correlation) while Fe is more pH controlled (a negative Fe-pH correlation is found). In the drilled well waters, where road salt is not a major Na source, the significant Na-Mg correlation could represent the influence of weathering, with Na from feldspar and Mg from biotite and chlorite.

Seasonal Fluctuations in Groundwater Chemistry in Maxwell Subdivision

Variations in chloride and conductance (figs. 6.23 and 6.22) are small in drilled wells S1, 5, and 21. This highly damped out response is attributed to the

	Conductance	pH	Sodium	Potassium	Calcium	Magnesium	Iron	Manganese	Alkalinity	Sulphate	Chloride	Nitrate
Conductance	1.00	.25	.88*	.70*	.68*	.69*	.22	.31	.52*	.50*	.95*	-.08
pH		1.00	.12	.36	.37	.21	-.04	-.17	.43*	-.05	.10	.03
Sodium			1.00	.43*	.28	.33	.20	.22	.45*	.41*	.85*	-.11
Potassium				1.00	.76*	.62*	.13	.13	.50*	.31	.60*	-.01
Calcium					1.00	.82*	.20	.25	.59*	.30	.53*	-.05
Magnesium						1.00	.08	.24	.32	.44*	.65*	.09
Iron							1.00	.54*	.24	.27	.17	-.22
Manganese								1.00	.15	.10	.30	-.19
Alkalinity									1.00	.01	.23	-.20
Sulphate										1.00	.52*	.05
Chloride											1.00	-.05
Nitrate												1.00

* Refers to a significance level of .01 or better

TABLE 10 PEARSON CORRELATIONS ON AN AREAL BASIS, SACKVILLE, DUG WELLS

	Conductance	pH	Sodium	Potassium	Calcium	Magnesium	Iron	Manganese	Alkalinity	Sulphate	Chloride	Nitrate
Conductance	1.00	.22	.89*	.59*	.91*	.86*	-.04	.71*	.71*	.45*	.83*	-.03
pH		1.00	.31	.33	.33	.24	-.51*	-.06	.72*	.37	-.24	-.03
Sodium			1.00	.62*	.68*	.77*	-.08	.60*	.74*	.60*	.63*	-.16
Potassium				1.00	.48*	.59*	-.16	.47*	.57*	.27	.39*	-.06
Calcium					1.00	.78*	-.24	.63*	.69*	.32*	.77*	.06
Magnesium						1.00	-.06	.73*	.76*	.37*	.68*	.03
Iron							1.00	.03	-.31	-.05	.13	-.08
Manganese								1.00	.45*	.19	.69*	-.15
Alkalinity									1.00	.51*	.26	-.04
Sulphate										1.00	.04	-.10
Chloride											1.00	-.02
Nitrate												1.00

* Refers to a significance level of .01 or better

TABLE 11 PEARSON CORRELATIONS ON AN AREAL BASIS, SACKVILLE, DRILLED WELLS

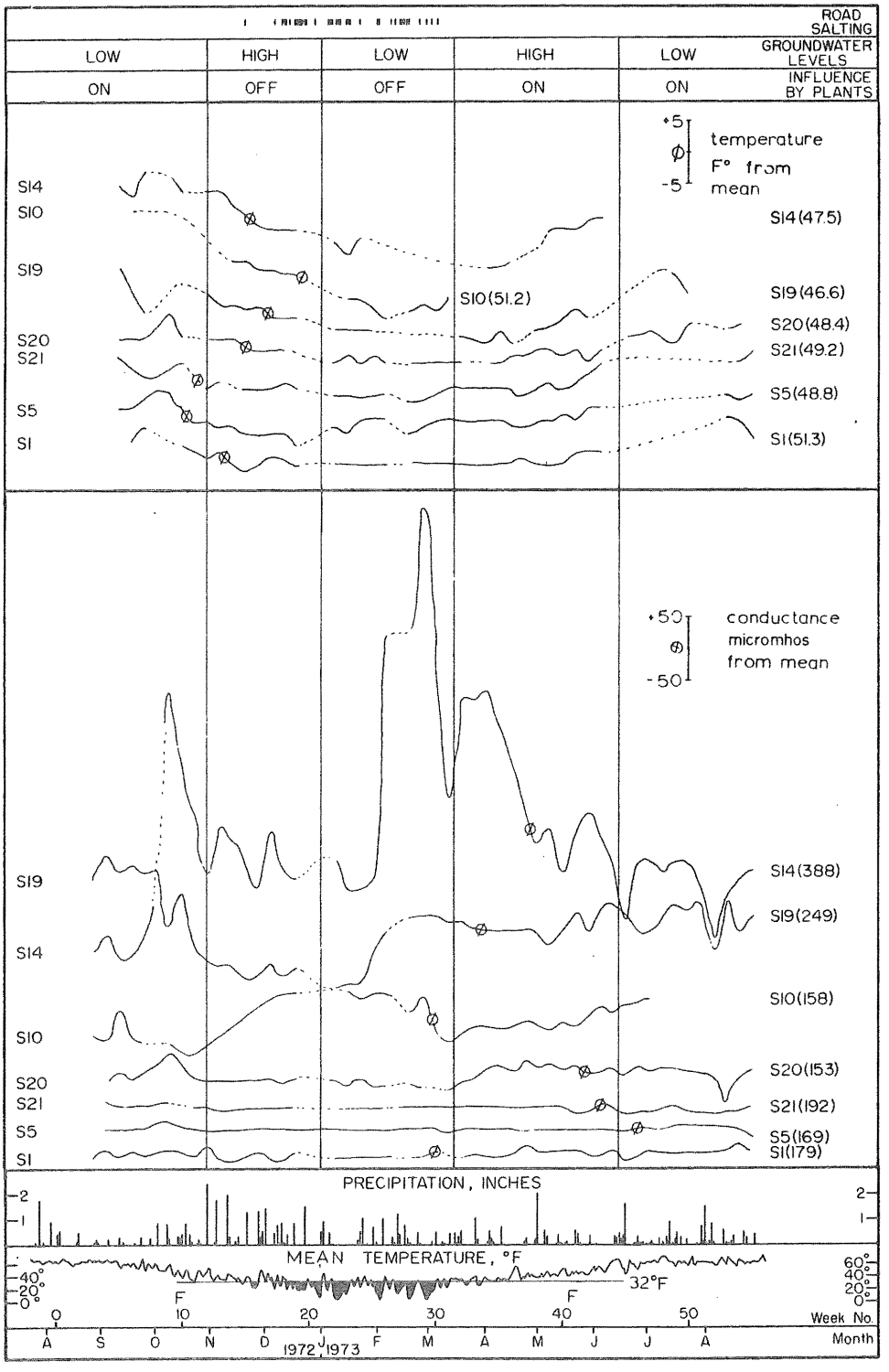


Figure 6.21. Time variations in temperature, Sackville.
Figure 6.22. Time variations in conductance, Sackville.

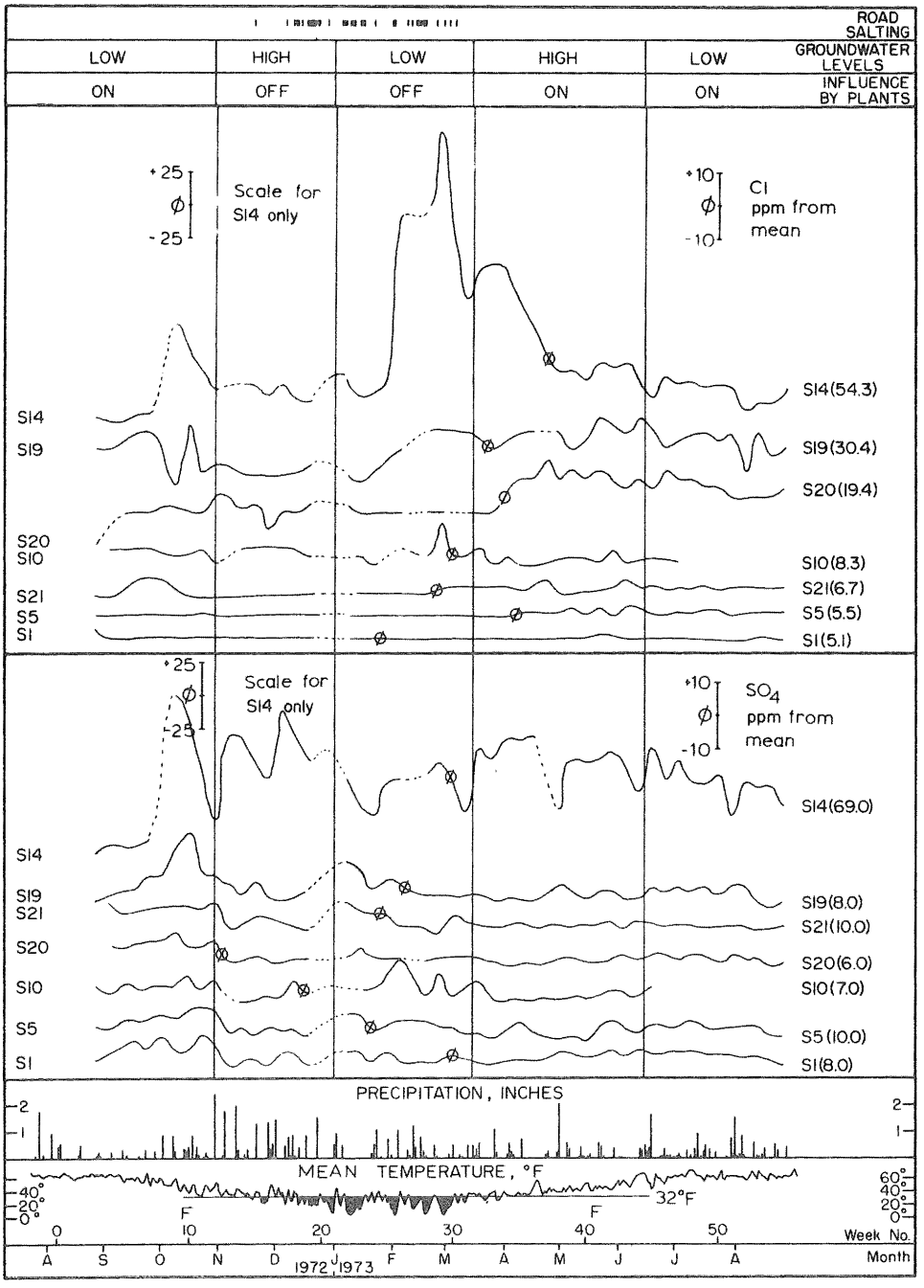


Figure 6.23. Time variations in chloride concentration, Sackville.
Figure 6.24. Time variations in sulphate concentration, Sackville.

thick glacial till cover in the area. Wells S14, 19 and 20 show a similar Cl response to the Birch Cove wells, with low values in mid-winter. Estimated time lags are:

Well No.	Lag, weeks
S14	9
S19	21
S20	17

Well S20, a drilled well, responds in a similar way to Birch Cove wells which are influenced by the thin or absent cover of glacial till. It is probable that this well is being rapidly recharged through an outcrop 80-100 feet away on top of a rock-cored drumlin. In the rest of this section, well S20 will be considered as a dug well.

The time lag for Cl is high in well S10 which is located in a low permeability zone of the till. This lag may be a function both of the low permeability and of slow flushing of salt retained in pellicular water on silt-sized particles in the unsaturated zone (Toler et al, 1974). The large Cl variations in well S14 are a result of permeable sandy or gravelly lenses supplying the well which allow rapid recharge to the well.

Significant correlation between Na and Cl is found in wells S14, 19 and 20. The drilled wells do not show this relationship because Na is increased over Cl by ion exchange processes. Evidence for this is the high Na/Cl ratio (> 4) in drilled wells as compared to dug wells (< 1.5) and the negative BEI in drilled wells. Variations in sodium are shown in fig. 6.26. There is a time lag of about 9 weeks for Na in well S14, and 18 weeks for well S10.

Potassium concentrations are highest in dug wells S10 and 14 (fig. 6.25) and

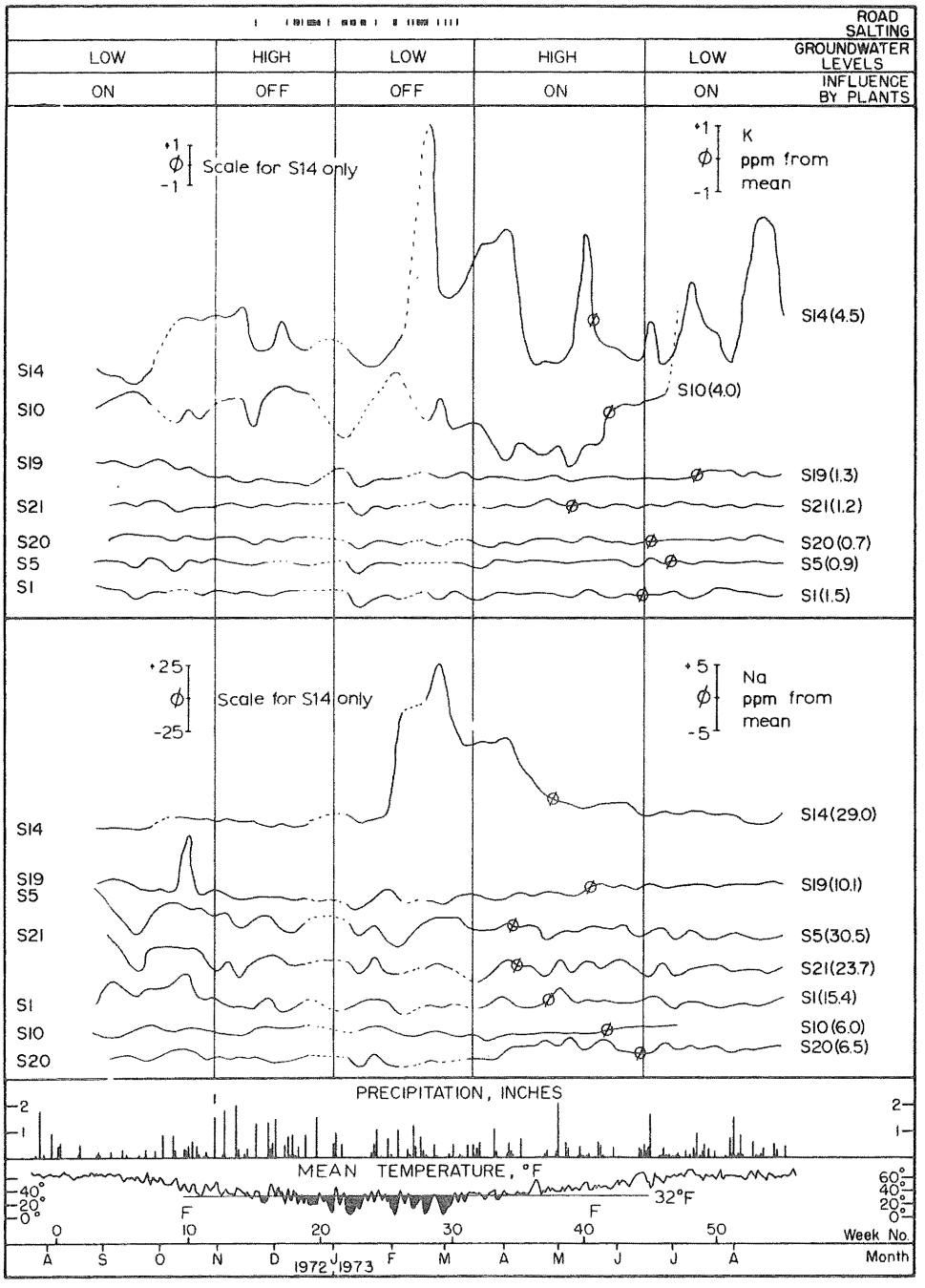


Figure 6.25. Time variations in potassium concentration, Sackville.
Figure 6.26. Time variations in sodium concentration, Sackville.

show a significant correlation with Na and Cl. This could represent a surface water effect as well as increased solubility of K when salt is present or of K impurities in the salt.

Calcium and magnesium variations (figs. 6.27 and 6.28) are significantly correlated only in the dug well waters because by the time recharge waters reach the drilled wells in the bedrock, Ca will likely have been preferentially adsorbed more than Mg. A significant Ca-HCO_3 correlation occurs in wells S10, 19, 20 and 21, indicating weathering of $CaCO_3$ from glacial till.

Peaks in Ca and Mg concentrations occur in the fall and represent a time lag of about 5 months from the estimated input to the system.

Bicarbonate variations are shown in fig. 6.30. A significant positive correlation is found between HCO_3 and pH in well S14, which is expected in the pH ranges encountered in the samples. A negative correlation is found in wells S1 and 5 which might indicate that although HCO_3 is increasing as a result of calcite weathering, the pH is being lowered by some process (such as pyrite oxidation in the bedrock: $2\,FeS_2 + 4\,H_2O + 15/2\,O_2 \rightleftharpoons Fe_2O_3 + 8\,H^+ + 4\,SO_4^{=}$).

Variations in sulphate and nitrate-nitrogen are shown in figs. 6.24 and 6.29. Significant correlations between the two ions occur in wells S5, 14, 20, and 21, possibly representing the influence of breakdown of organic material. If the main input of NO_3 is assumed to be in mid-April, then well S14 shows a lag of 7 months

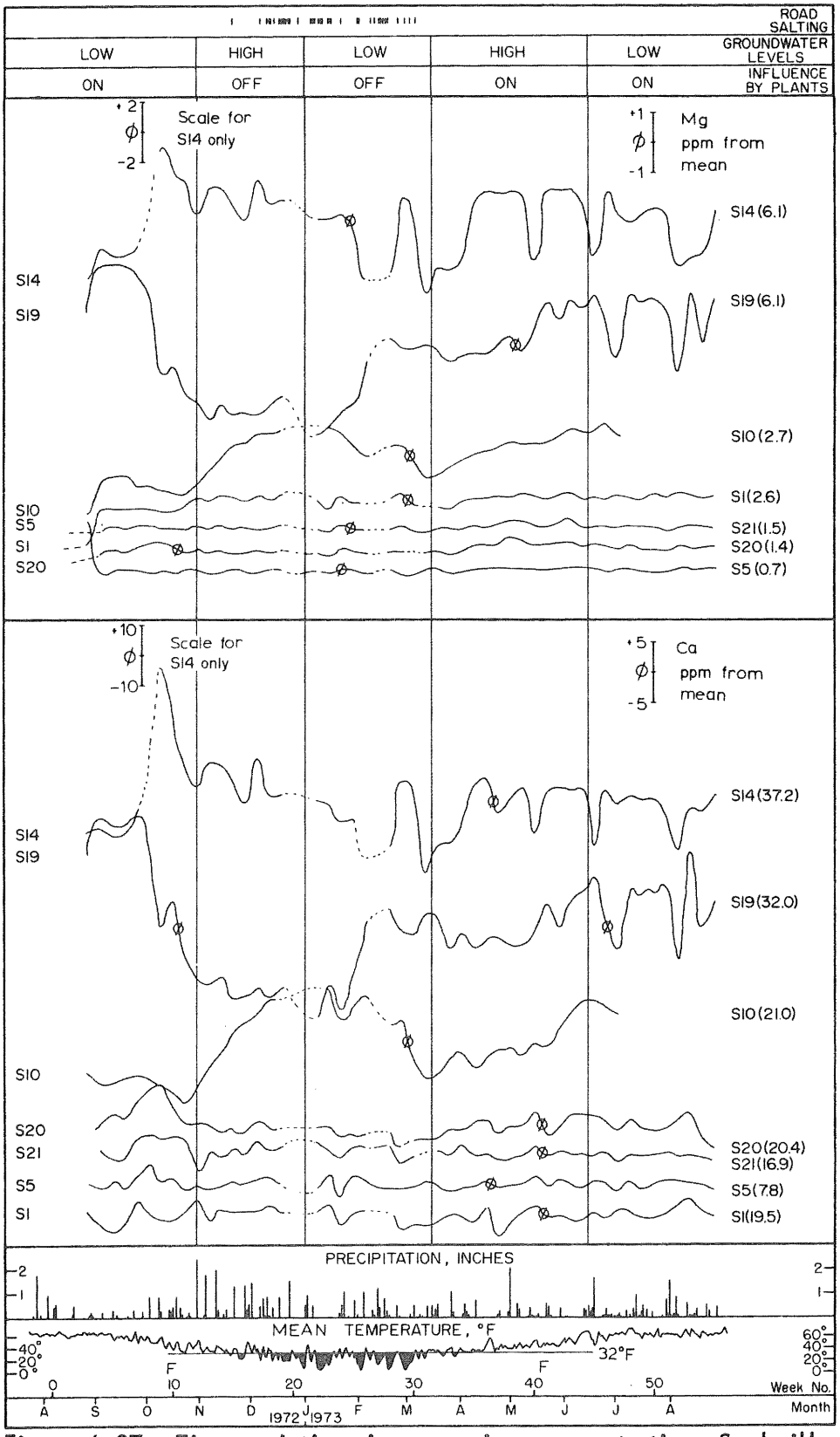


Figure 6.27. Time variations in magnesium concentration, Sackville.
Figure 6.28. Time variations in calcium concentration , Sackville.

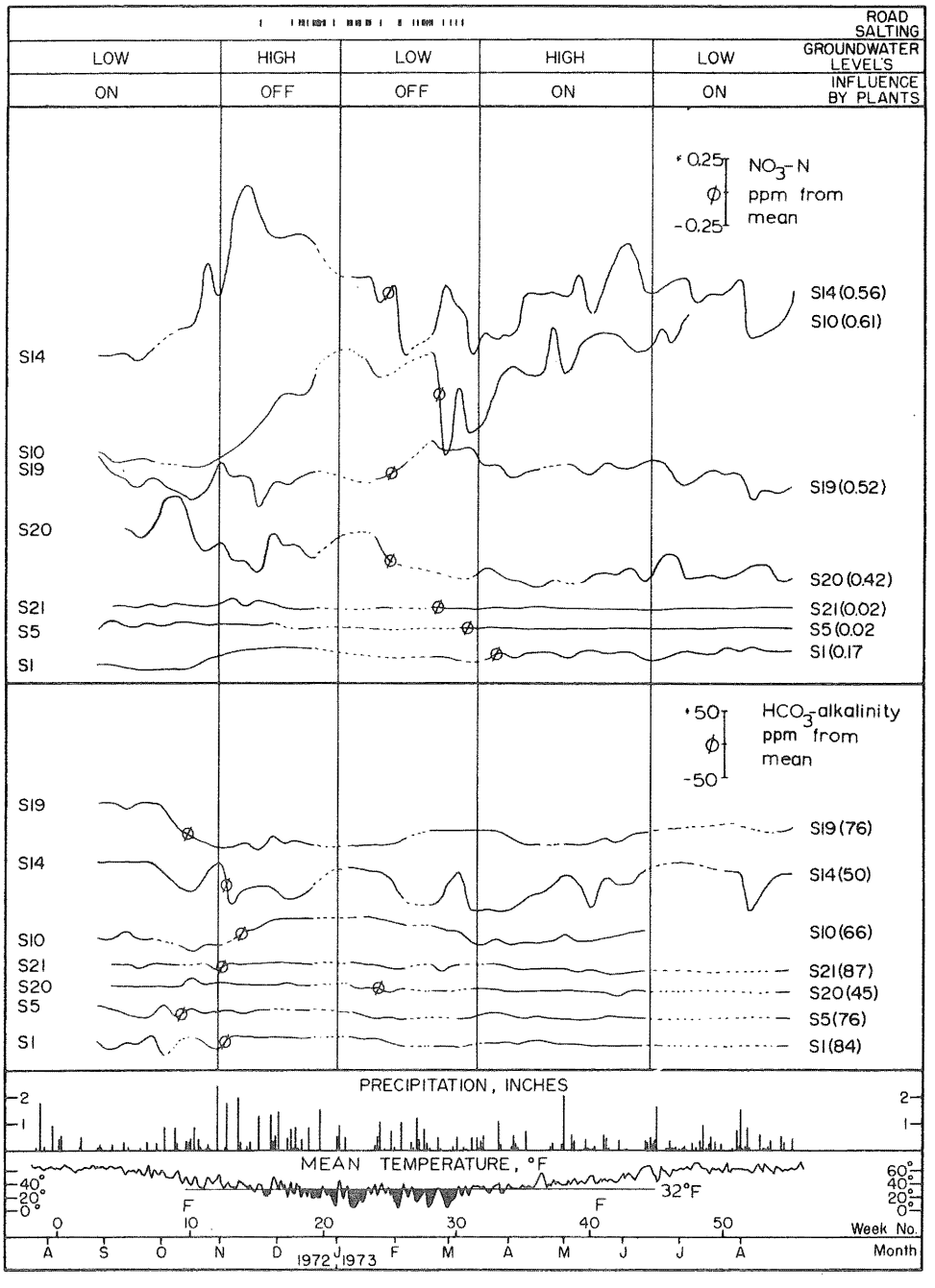


Figure 6.29. Time variations in nitrate-nitrogen concentration, Sackville.
Figure 6.30. Time variations in bicarbonate alkalinity concentration, Sackville.

and well S19 a lag of about 10 months. Well S10 showed a continuous increase until sampling stopped (the homeowner sealed off the dug well and switched to a drilled well). The two NO_3 peaks evident in well S14 could represent a rapid primary response to spring recharge by a permeable path and a delayed secondary response by movement through more silty or clayey zones in the till.

Variations in groundwater temperature (fig. 6.21) are much more damped out in drilled wells as compared to dug wells as a result of the thick glacial till cover.

Summary

Groundwater flow in Sackville is mainly controlled by the bedrock topography and/or the major joint sets in the area (the resultant direction of flow imposed by the major joint sets is the same as that imposed by the topography of the bedrock surface, hence the two effects cannot be separated). A regional type flow system exists in the bedrock. The main effect of glacial till is to superimpose local flow systems on the regional one with the two systems being in hydrostatic equilibrium. High yield wells are associated with geologic contacts, possible shear zones, and buried sand and gravel deposits.

The regional variation in water chemistry supports the postulated groundwater flow patterns, especially since most of the waters from bedrock wells are uninfluenced by road salt. The main confined water type in the area is HCO_3-SO_4,

likely due to the influence of pyrite-rich slate bedrock. Water types Cl-HCO_3 and Cl-SO_4, especially the latter, appear to represent road salt contaminated waters.

The high values of potassium in dug well waters represents either the influence of glacial till or organic material. The latter is unlikely because of the low correlation of K with NO_3 (table 10). Glacial till also appears to contain reasonable amounts of $CaCO_3$.

Relatively high groundwater turnover rates are found, with most of the waters being in equilibrium with kaolinite. The dissolved mineral content increases with decreasing piezometric elevation, probably as a result of the existence of a regional flow system.

In Maxwell Subdivision, the time lag for chloride varied from 9-21 weeks. The longer lags may be due to retardation of salt dispersion by retention on silt sized material. Drilled wells show very damped out responses to seasonal fluctuations, the result of a thick glacial till cover. The till cover also protects the bedrock aquifer from contaminated surface water and thus the total dissolved solids in the drilled well waters are low. These waters are also affected chemically by base exchange, again a result of the glacial till cover (both the thickness and composition of the till favor this process).

Well S14, with a shallow water source, shows both an immediate and

delayed response to water chemistry fluctuations. This could represent rapid input of water through highly permeable sandy lenses, followed by water which has travelled through less permeable zones in the aquifer.

Using chloride time lag to determine permeability, a value of about 1.6 ft/day (10.0 gpd/ft^2 or 5.7×10^{-4} cm/sec) was calculated for the bedrock in the vicinity of well S20.

Chapter 7

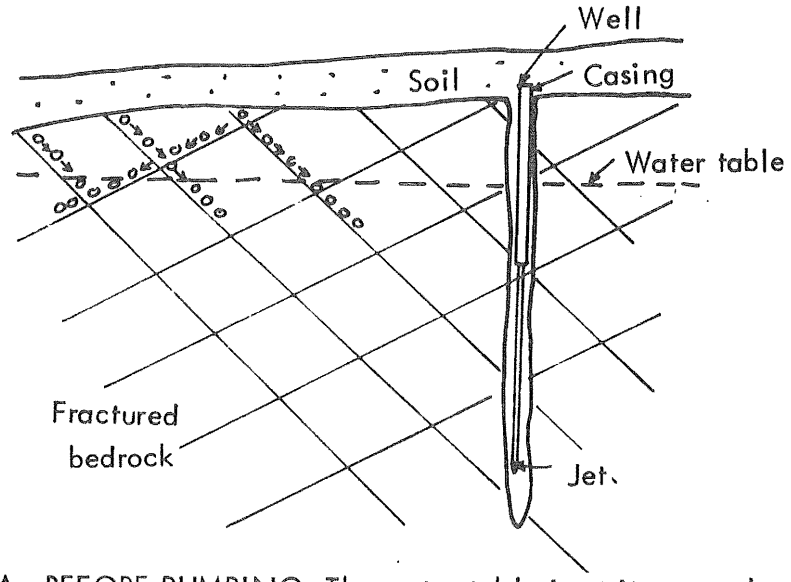
IMPACT OF URBANIZATION ON GROUNDWATER

Introduction

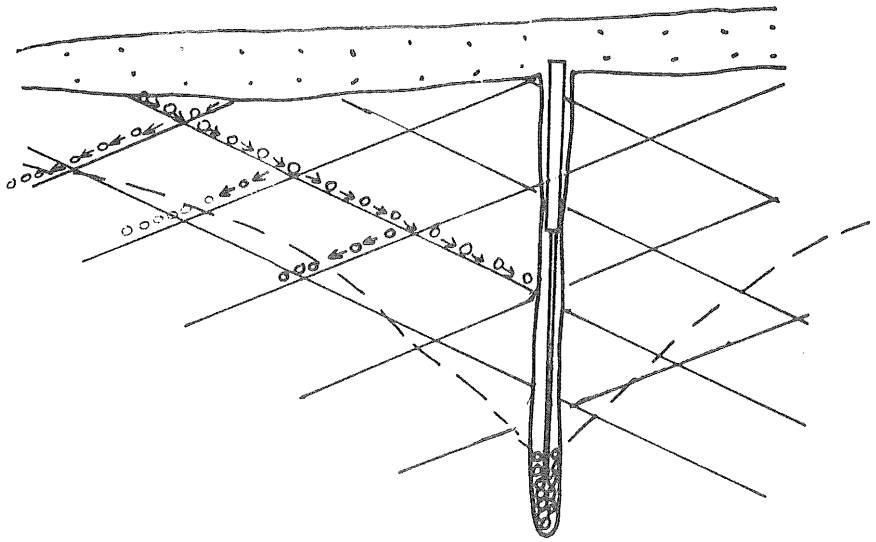
If not properly controlled, urbanization can have deleterious effects on groundwater quality and quantity. The water table can be lowered by such things as well drilling, pumping, land clearing, draining marshes, construction and paving. There is more surface runoff in paved areas, thus reducing the area available for infiltration of precipitation into the groundwater system. Septic tanks may result in development of a recharge mound of contaminated water which might cause local problems. Blasting effects during construction in bedrock areas may either decrease or increase rock permeability and hence change well yields. Generally the extent of these effects is largely unknown; however, one homeowner near Kearney Lake reported that his neighbour's well empties whenever blasting is carried out by the gravel crushing operation on the other side of the lake.

Mechanisms of Groundwater Contamination and Attenuation

Some of the factors important in the movement of contaminants are:1) geologic structure, e.e. fig. 7.1 (courtesy of J.E. Gibb), 2) overloading of the groundwater system with contaminated road salt runoff and septic tank effluent to a great enough extent that natural attenuation is unable to reduce the contaminant to acceptable levels, 3)high pumping in a small area, such as in Birch Cove, which may induce



A. BEFORE PUMPING: The water table is at its natural level and the contaminant is not affecting the well.



B. DURING PUMPING: The water table is lowered at the well, which allows the contaminant to enter the well.

LEGEND

Contaminant running to groundwater

Contaminated groundwater

Figure 7.1. Mechanism of groundwater contamination by pumping in fractured bedrock (after J.E. Gibb).

contaminant movement upgradient into wells, 4) amount of overburden and depth to the water table, an increase in which results in less chance for contamination, since more time is available for filtration, dilution, and ion exchange in the groundwater, 5) regional topographic slope, which affects the shape of the water table, direction and rate of flow, and also the amount of runoff, 6) the amount of topographic relief - in areas of high relief, it may be possible to site a well incorrectly even though it is upslope from a contamination source (e.g. fig.7.2), and 7) the variation of permeability with depth in bedrock aquifers, which results in a more lateral movement of groundwater and thus a more effective areal dispersion of contaminated groundwater.

Once groundwater is contaminated, several mechanisms may cause attenuation. These are summarized in table 12 (from Langmuir, 1972). Dilution and dispersion are the most effective methods for all types of contaminants. Dilution results from diffusion processes in the system due to concentration differences at various points, while dispersion is the spreading out of a contaminant due to differences in fluid velocity throughout the medium. Obviously the nature of the medium determines which processes are operative. Dispersion is most effective in materials with intergranular permeability since the fluid can advance on a broad front, while in fractured rocks fluid movement is confined to fracture planes. Ion exchange processes, which change the composition of a water rather than reduce the total dissolved solids, are most effective in a silty clay medium with intergranular permeability. Oxidation and adsorption are the main methods of natural pollution

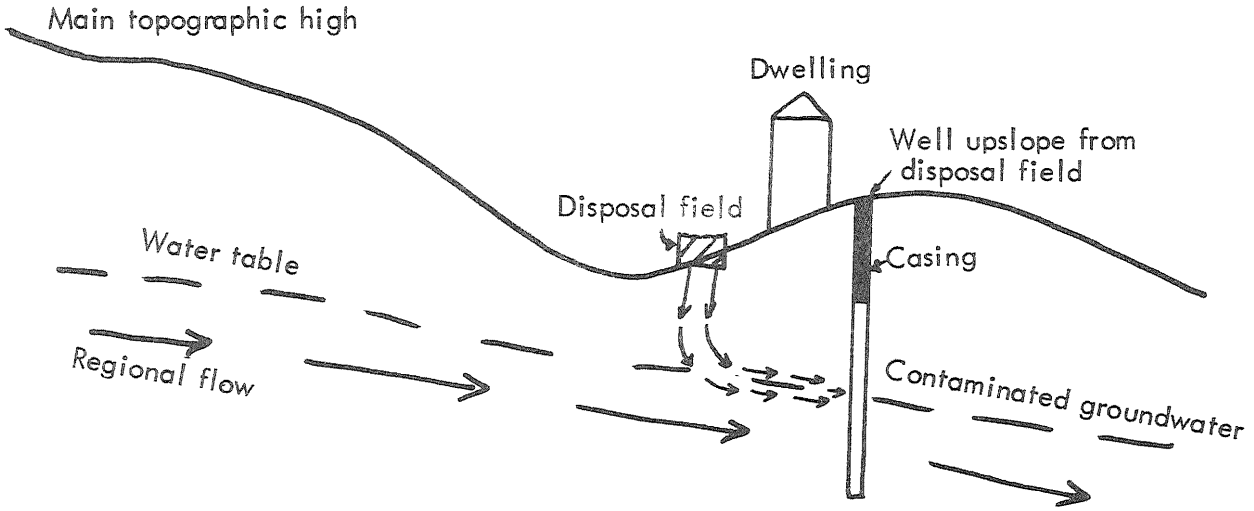


Figure 7.2. Effect of relief on groundwater contamination.

TABLE 12

PROCESSES CAUSING ATTENUATION OF CERTAIN CONTAMINANTS IN GROUNDWATER

Cl	Dilution, dispersion
NO_3	Dilution, dispersion, oxidation-reduction, decay-respiration
SO_4	Dilution, dispersion, oxidation-reduction, decay-respiration, acid-base reactions, precipitation-solution
HCO_3	Dilution, dispersion
Na	Dilution, dispersion, adsorption-desorption
Ca	Dilution, dispersion, adsorption-desorption, ionic strength
Mg	Same as Ca
Fe and Mn	Dilution, dispersion, adsorption-desorption, ionic strength, complexation, acid-base reactions, oxidation-reduction, precipitation-solution
Microorganisms	Dilution, dispersion, filtration, oxidation-reduction, decay-respiration, cell synthesis

control in the zone of aeration, and are most effective in sandy or silty soils. Bacterial removal is best accomplished by percolation through a few feet of fine sand. Romero (1972) suggests 10 feet of sand as the minimum distance required for filtration of bacteria in the unsaturated zone; in non-ideal systems, 50 to 100 feet of travel is desirable.

Water Quality Problems in Relation to Use in the Study Areas

The concept of water quality and acceptable limits for some parameters have been discussed in chapter 4. The following problems will be discussed in this chapter: hardness, iron and manganese, corrosion, bacteria and detergent, and salt.

Hardness

Compounds of Ca and Mg, such as bicarbonates, sulphates, and chlorides are the most common cause of hardness in water, which results in increased soap consumption and incrustation in pipes, tanks, kettles, boilers, and well intakes. Precipitation of $CaCO_3$ occurs when the pressure is reduced or the temperature raised. Temporary or carbonate hardness can be removed by boiling, but other compounds require more complex methods (such as lime-soda treatment).

Hardness as ppm $CaCO_3$ can be calculated from the chemical analyses reported from the study areas:

$$\text{ppm } CaCO_3 = (\text{ppm } Ca^{++} \times 2.49) + (\text{ppm } Mg^{++} \times 4.12)$$

In both areas, the majority of wells show hardness greater than the recommended 80 ppm , especially in Sackville, where saturation with respect to $CaCO_3$ occurs in some wells. This has resulted in the widespread use of water softeners.

Home water softeners normally use NaCl to regenerate the ion exchange unit of the softener - several pounds of salt per week may be required (Manahan, 1972). This may result in deterioration of water quality if many homeowners in a small area are using these units, since they are often not backwashed frequently enough and NaCl is added to the wastewater in this way as well as by ion exchange.

Iron and Manganese

Iron causes red stains in clothing and utensils Iron bacteria (which oxidize $Fe^{\prime}$ may cause a clogging precipitate which is difficult to remove - this is found mainly in cool (less than $65^{\circ}F$) shallow waters with less than 1000 ppm total dissolved solids and high Fe and Mn content (Mogg, 1973). These prerequisites are met in many of the well waters in the study areas.

Manganese causes black stains on clothing and utensils. Black precipitates in tea are caused by reaction of Mn and Fe with tannin. Together, Fe and Mn can pose a serious economic problem since costly treatment units are usually required to remove them.

Chemical analyses of spot samples and monitored wells in Birch Cove indicate that 11% of the waters are over the limit for Fe and 53% for Mn. In the Sackville

area, 35% of the dug well waters were over the limit for Fe and 32% for Mn. In the drilled well waters, 39% were over the limit for Fe and 73% for Mn. Considering both dug and drilled well waters, 37% are over the Fe limit, 54% over the Mn limit. The more severe Fe problem in the Sackville area as compared to Birch Cove is likely a result of the predominance of slate bedrock in the former area. Manganese is equally a problem in both areas.

Corrosion

Corrosive waters usually have a low pH (5.7), low alkalinity (13 ppm), and low hardness (16 ppm) (The Chemistry of Water, UOP Johnson). These conditions apply in wells such as R53 and R67. The corrosion problems are greatest in Birch Cove, where several homeowners reported disintegration of brass fittings and copper piping. This is likely a result of electrochemical corrosion, which may be exacerbated by salt.

Bacteria and Detergent

In Birch Cove, about 70 samples were spot checked on Aug. 13-16, 1972 for Escherichia coli, a nonpathogenic organism found in the intestines of warm blooded animals. This bacteria is an indicator of possible sewage contamination (Canadian Drinking Water Standards and Objectives, 1969). Ten percent of the samples showed a count of more than 2 coliform organisms per 100 ml of sample (2-10 is classified as doubtful, greater than 10 as unsatisfactory). The monitored wells were checked periodically throughout the year: three showed bacteria occasionally (R6, 46, 67).

The latter two of these wells did not show detergent, so are not considered to represent septic tank influence (especially well R46, where the homeowner had pump problems and had to remove the sanitary seal from the well several times). Thus only 1 out of 21 wells is considered to have bacterial problems due to septic tank effluent, i.e. 5%. It is surprising that so few wells have bacterial problems, since there is little or no glacial till cover in the area. Two possibilities which could account for this observation are : 1) filtration of bacteria is occurring as recharge water percolates through near surface joints, perhaps as a result of fine material from runoff or glacial till which has been washed into the joint openings, or 2) the number of samples is not truly representative.

In August 1973, detergent tests were carried out by N.S. Technical College on samples from the monitored wells. The test was for the presence or absence of ABS, a compound added to synthetic detergents. Seven of the wells out of 21 showed the presence of ABS (wells R1, 3, 5, 6, 59, 60, 63), but only one of these (well R6) also had a bacterial count. This reflects the fact that detergent persists for longer periods of time in the groundwater, especially if it is not biodegradable, and also supports the inference that bacteria may be filtered out.

Using the mean values of the chemical parameters measured in the monitored wells as variables, a discriminant function analysis was performed on wells with ABS versus wells with no ABS. For these groups, alkalinity was found to be significant at the 0.05 level, with the higher alkalinities in the well waters containing ABS.

Flynn (1958) also found higher values of HCO_3 alkalinity in detergent contaminated wells. The reason for high HCO_3 is likely due to the fact that both aerobic and anaerobic decomposition of organic matter (which occur in septic tanks and disposal fields) produce CO_2. Groundwater percolating through the leach field or water from the field eventually reaching the groundwater has thus been subjected to high partial pressures of CO_2 and increased HCO_3 content. The alkalinity indicator is valid only in areas with little or no glacial till cover, and hence is not applicable in most of the Sackville area. In the latter area, high HCO_3 concentration is due to passage through thick glacial till containing $CaCO_3$; biological activity in the soil also results in high pCO_2 values.

No detergent tests were carried out for Maxwell Subdivision, but one set of bacterial samples was taken on June 10, 1973. None of the drilled wells showed bacteria, while all of the dug wells showed a bacterial count. Further checking of the dug wells (6 more samples) showed bacteria 100% of the time in wells S10 and 14, and 66% of the time in well S19. However, these bacteria were non-faecal, i.e. did not come from sewage. Surface water is the most likely source, especially in well S10 which was not properly constructed.

Another significant result from these tests was that the wells in the Birch Cove area with detergent in their water did not all show high salt concentrations (notably wells R3 and 63), indicating that septic tank effluent is likely responsible for only a small percent of the NaCl in the waters of the area. Hence the most probable

source of salt in the groundwaters is road salt, as previously mentioned.

Homeowners with bacteria and/or detergent in their water were advised to test their water regularly, and to contact a N.S. Department of Public Health Inspector if the problem persisted.

Impact of Road Salting

Sodium is detrimental to persons on low salt diets, since it can cause problems in the control of conditions such as hypertension and kidney and liver ailments (Terry, 1974). For health reasons, Terry (1974) recommends an upper limit of 20 ppm Na in drinking water. Also, high Na concentrations in water can reduce soil permeability.

The recommended limit for chloride of 250 ppm is based on taste, but the tolerance limit for persons on low salt diets is much lower (Terry, 1974).

Using a value of 20 ppm as a limit for Na, then 62% of the wells in Birch Cove are presently above this limit, at least during certain periods of the year. If an arbitrary limit of 50 ppm Cl is selected as representing groundwaters uncontaminated with salt (Huling et al, 1972, use 100 ppm Cl) then 60% of the wells in Birch Cove are contaminated to some degree; 18% are above the 250 ppm limit suggested by the Canadian Drinking Water Standards (1969). In the Sackville area, 32% of the dug wells and 35% of the drilled wells are above the Na limit of 20 ppm, while

30% of the dug wells and 11% of the drilled wells are above the Cl limit of 50 ppm. The higher Na values in drilled wells reflect the increase of this ion by exchange processes. The overall lower Cl values in Sackville as compared to Birch Cove reflect both the protective influence of glacial till on the bedrock aquifer and the lower housing density.

In the Sackville area, most of the dug wells showing salt contamination are located on the downslope side of the road with respect to groundwater flow. Figure 6.8 shows that most wells with more than 50 ppm Cl are less than 60 feet deep, indicating that it is mainly the shallow groundwater flow systems that are contaminated at present. These appear to be only locally affected as yet, as shown by the patchy distribution of contaminated wells in fig. 6.13.

The rest of this section will deal with the salt problem in the Birch Cove area. Figure 5.4 shows that many wells closer to the road than 50 or 60 feet have salt problems. Salting routes for the area are shown in fig. 7.3, a typical road salt analysis in table 13, and the relative amounts of salt used in appendix 2. Since about 1970, a mixture of 10% salt-90% sand has been used in the area to try and combat well water contamination by road salt (T. Krauch, personal communication).

TABLE 13

CHEMICAL ANALYSIS OF ROAD SALT

95% $\pm$ 1%	NaCl
3.5%	Soluble $CaSO_4$
1.5%	Insoluble $CaSO_4$
0.05%	Moisture

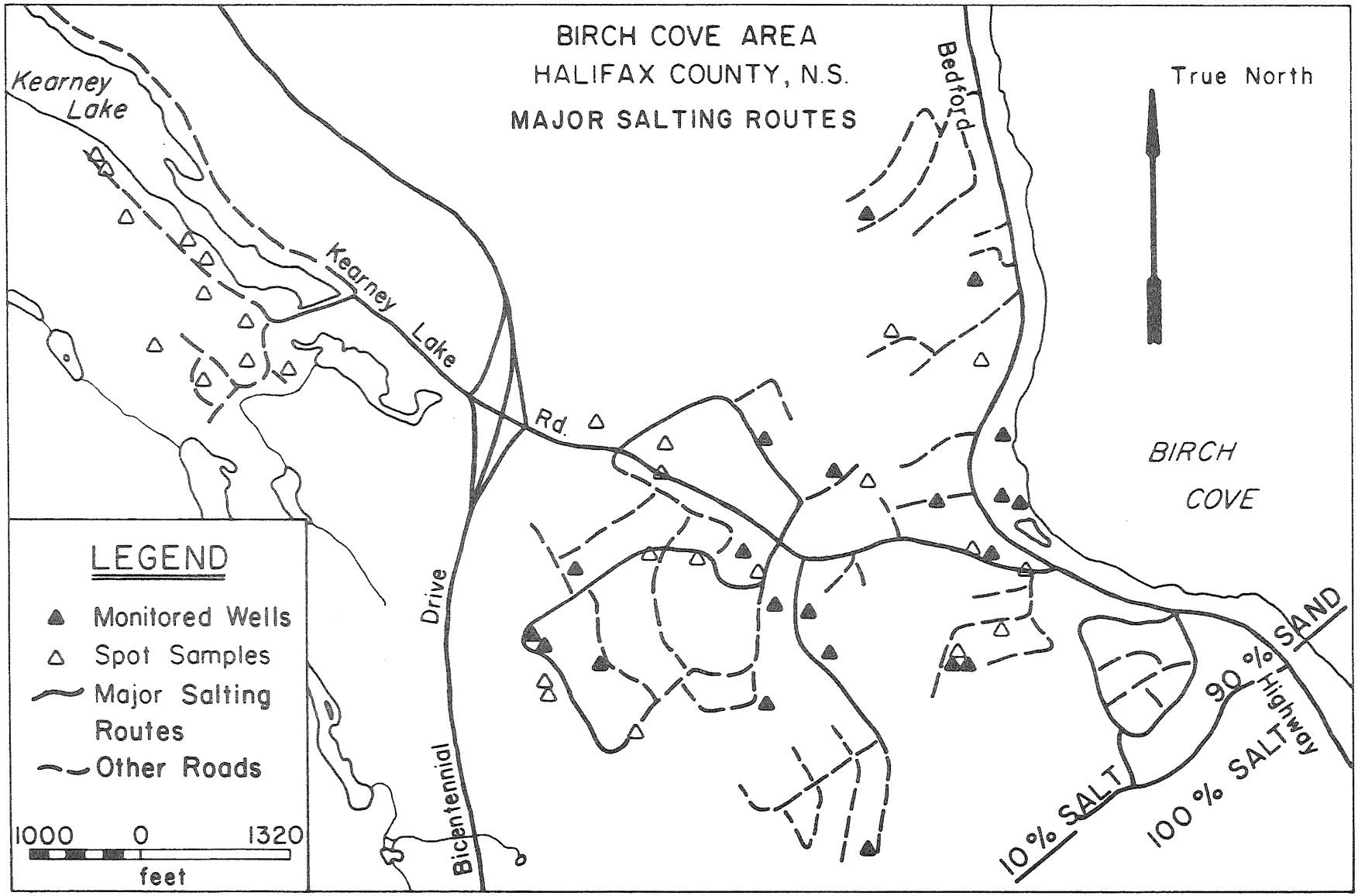
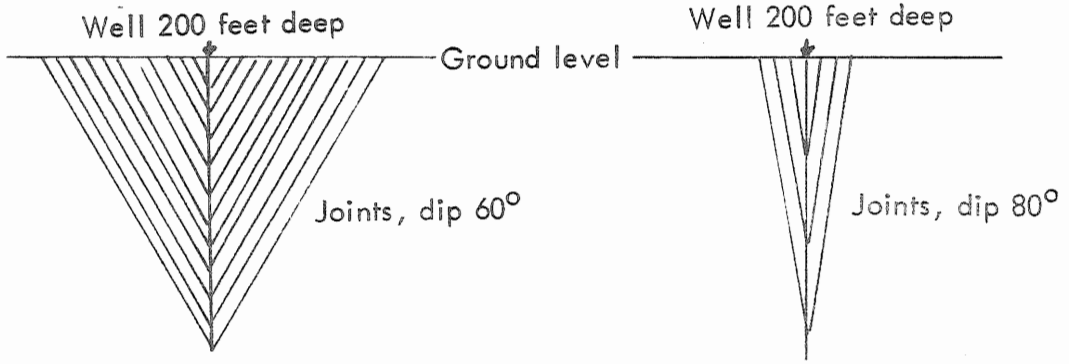


Figure 7.3. Major salting routes, Birch Cove.

A plot of well depth against chloride content (fig. 5.5) shows a wide scatter of data. It is to be expected that other variables will affect the degree of Cl contamination, such as hydraulic connection to the source, hydraulic gradient, permeability, and dilution/dispersion effects. The annual salting rates and distribution of recharge also affect Cl concentrations. Huling et al (1972) found that infiltration of roadside brines occurred both immediately after the winter and during winter thaws - this is likely the case in Birch Cove also. The residence time of salt varies, but was found to be more than a year in Massachusetts (Huling et al, 1972). Depth to the water table and the amount and seasonal distribution of precipitation are also important (Toler et al, 1974). In Birch Cove, a period of at least 8-9 months is required (figs. 5.22 and 7.9) for Cl concentrations after a slug of Cl is recharged to the groundwater system to return to antecedent concentrations. Most wells showed an overall decrease in Cl over the year due to high recharge and low salting rates, but the waters were not flushed out to the extent that uncontaminated values, say 30-50 ppm, were reached. The flushing time of the aquifer is not known, but is likely at least 2 years if no further salt were applied by man.

Figures 7.1 and 7.2 were used to illustrate how pumping may induce movement of near surface contaminated water into a well. The high groundwater use and possible well interference in Birch Cove could produce a similar effect. Figure 7.4 accounts for the joint orientation : for a well 200 feet deep, and joint spacing 10 feet, 22 possible intersections with the well could occur for a dip of 60° and the possible radius of influence is 115 feet (fig. 7.4 a). The chances of some of these



Total possible number of joint intersections = 22
Distance of influence = 220 feet

A casing length less than 20 feet will not be effective in preventing entry of surface water into the well.

Total possible number of joint intersections = 6
Distance of influence = 60 feet

A casing length less than 50 feet will not be effective in preventing entry of surface water into the well.

100 feet Horizontal and Vertical Scale

Figure 7.4. Effect of joint orientation on contamination.

joints being hydraulically connected to a road 50-60 feet away are good. For steeply dipping joints of 80°, which are common in Birch Cove (fig. 2.3), fewer joints intersect the well and the radius of influence is 35 feet (fig. 7.4 b); however, where intersections occur, the steep dip allows the fracture plane to penetrate below the maximum average depth for well casing in the area of 20-30 feet. Hence steeply dipping joints are effective pathways for road salt to enter a well if the well is close to the road and/or deep.

To further support a road salt source for salt in contaminated groundwaters, a detailed sample collection was made in the vicinity of well RI4, which showed the highest salt concentrations of the monitored wells. Sample locations are shown in fig. 7.5. Contours of the Cl concentration show a pattern parallel to the road (fig. 7.6). The conductance also shows this to a lesser degree (fig. 7.7). The relatively low Cl values on the lower west side of the diagram indicate that the small topographic high above these wells (with no roads on it) is likely acting as a local recharge area of uncontaminated groundwater. Bicarbonate alkalinity was also measured on these samples (fig. 7.8) and on the basis of the results discussed in the section on bacteria and detergent, several wells could contain surfactant.

Profiles of the water table and topographic elevations were plotted on the sections shown in fig. 5.2, in order to illustrate the interaction between these factors and some of the wells. A few joint orientations were added to the profiles to give a general feeling for average joint directions.

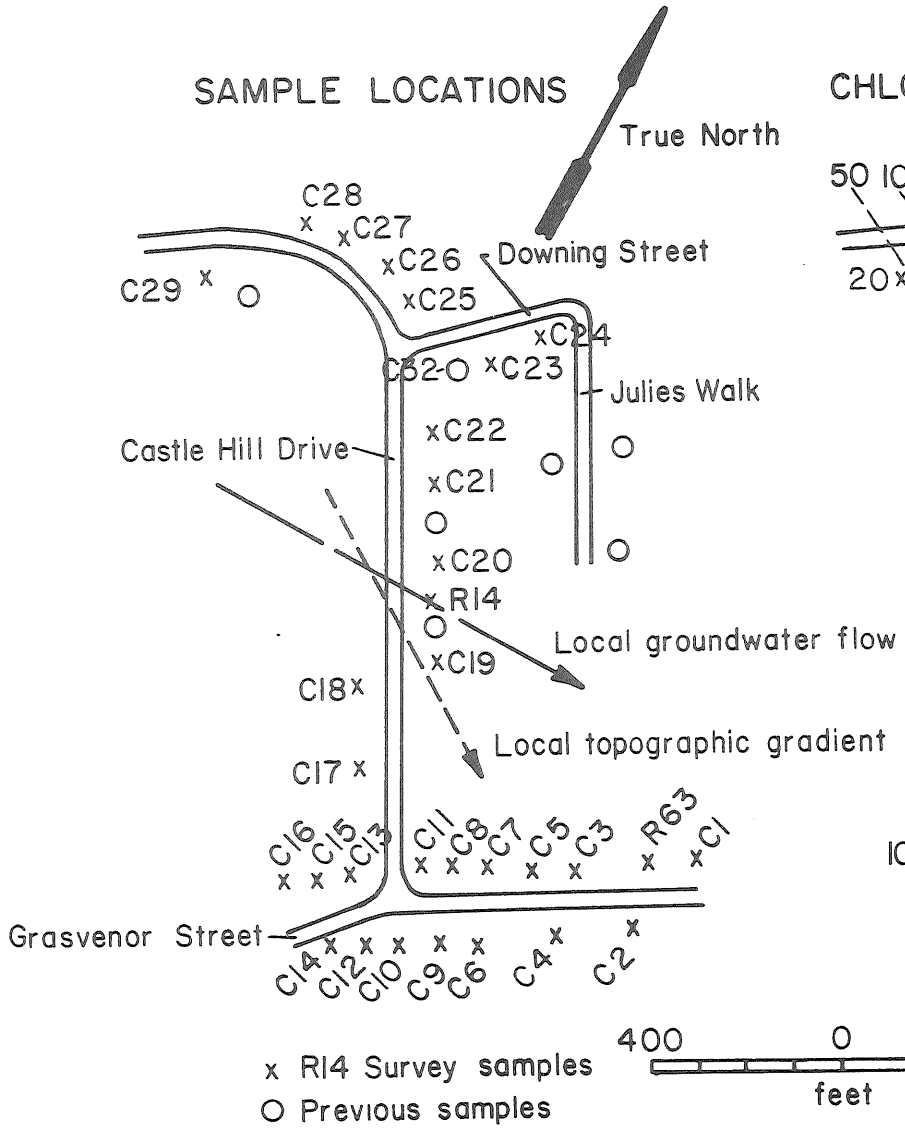


Figure 7.5. Sample locations for Well R14 survey.

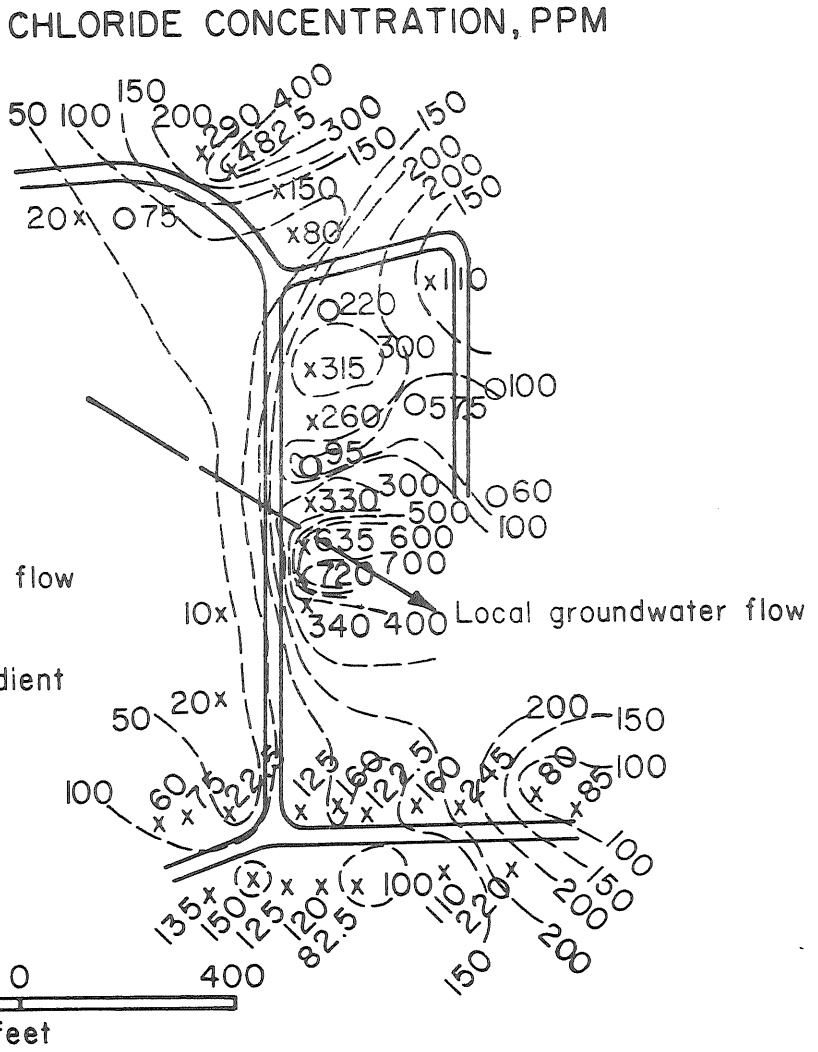


Figure 7.6. Chloride concentrations in the vicinity of well R14.

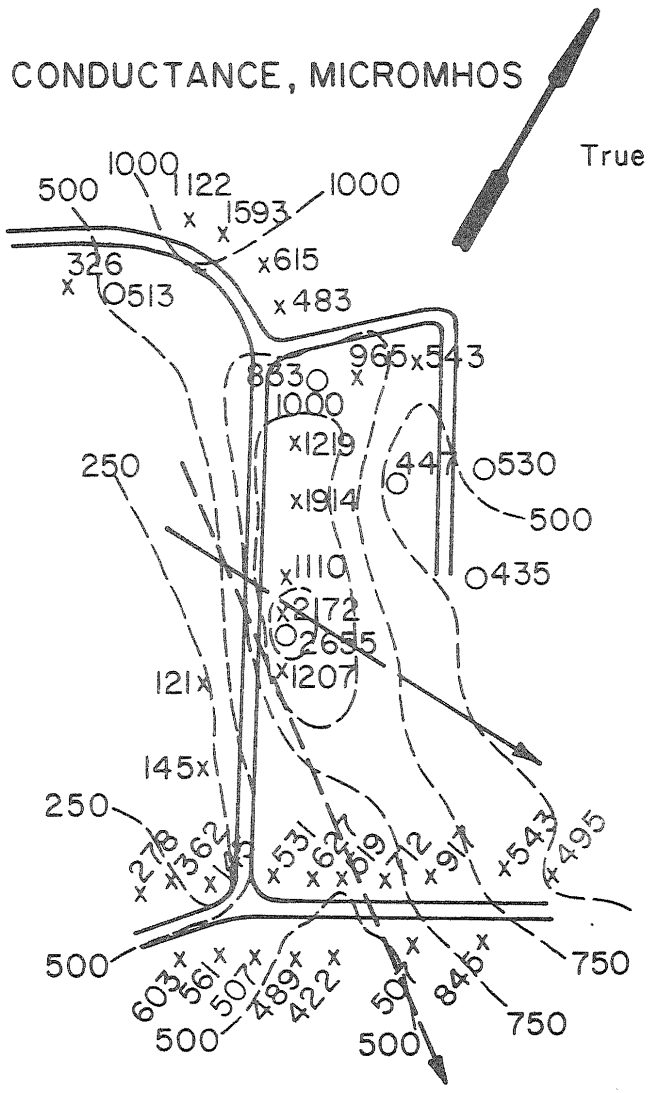


Figure 7.7. Conductance in the vicinity of well RI4.

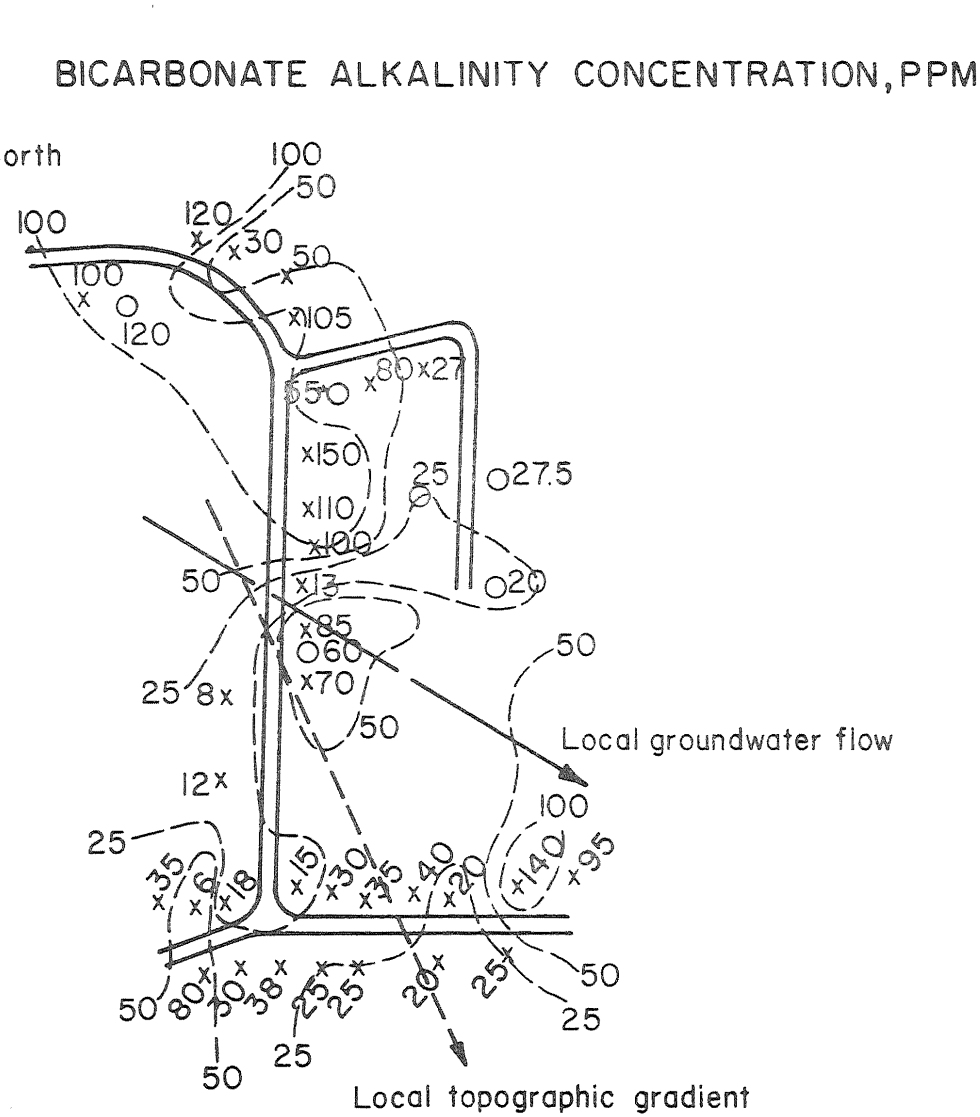


Figure 7.8. Bicarbonate alkalinity concentrations in the vicinity of well RI4.

Profile A-B (fig. 5.2) indicates that well R44 is likely receiving uncontaminated recharge water from the wooded area immediately upgradient and also shows a local influence by the nearby road. Well R67, which shows large variations in water quality, may be receiving varying amounts of recharge from local sources - the forested area upgradient on one side, the road and urban-influenced area on the other. Profile C-D (fig. 5.2) shows roads occurring close to and upslope from wells R14, 64, and 58, all of which have a mean Cl value greater than 100 ppm. The same thing occurs in wells R31, 61, and 62 on Profile E-F (fig. 5.2). The joint orientations are favorable for channelling water from roads above these wells into them. Well R63, with no roads directly above it, shows a mean Cl value of 77 ppm; however, this may be due in part to septic tank effluent since this well contains detergent. Well R46, with a mean Cl content of only 15 ppm, is likely receiving uncontaminated recharge from the wooded area above it (Profile E-F).

The similarity of the responses to most of the chemical variables in wells R5 and 10 indicates a possible hydraulic connection between them. Profile G-H (fig. 5.2) includes these wells. There are four roads in between them, which would account for the higher Cl values found in well R10. In the same profile, well R59 could have a direct connection to the road because of joint orientation; however, the damped out response of this well (see chapter 5) could indicate a less local source for the salt.

Profile I-J (fig. 5.2) indicates that well R22, with a mean Cl content of 75 ppm, is likely close enough to the nearest road to be protected by its casing. Hence the salt in this well likely comes from a more distant source. This profile also indicates that the apparent dip of the joints in this section is almost 0° - this orientation could cause rapid channelling and lateral dispersion of contaminants and again shows the favorability of the joints for propagating contaminants.

Long term Cl data was available for two wells - R53 and 68 (fig. 7.9). Both wells show an overall trend of decreasing Cl levels, possibly due to the use of a sand-salt mixture for the past 3 years and to the large amount of recharge in water year 1972-73.

Well R62 has a very high $CaCl_2$ content (appendix 5, fig. 1) and is located downslope from a city salt box. Well R88 (app. 5, fig. 2), at the same elevation as this box, is also high in $CaCl_2$. Thus there is a possibility that the salt-abrasive mixture may contain $CaCl_2$ as an impurity, or that moisture in the salt may allow a reaction of $CaSO_4$ with NaCl to form $CaCl_2$. The city of Halifax reports that no $CaCl_2$ is added to the sand-salt mixture or sprayed in this area for dust control. Some areas add $CaCl_2$ to salt in order to lower the freezing point of a salt brine solution (Hanes, 1970). It would be interesting to check some of the salt boxes for $CaCl_2$ content, and to find out if some of the homeowners in the area are using $CaCl_2$ themselves for paved driveways.

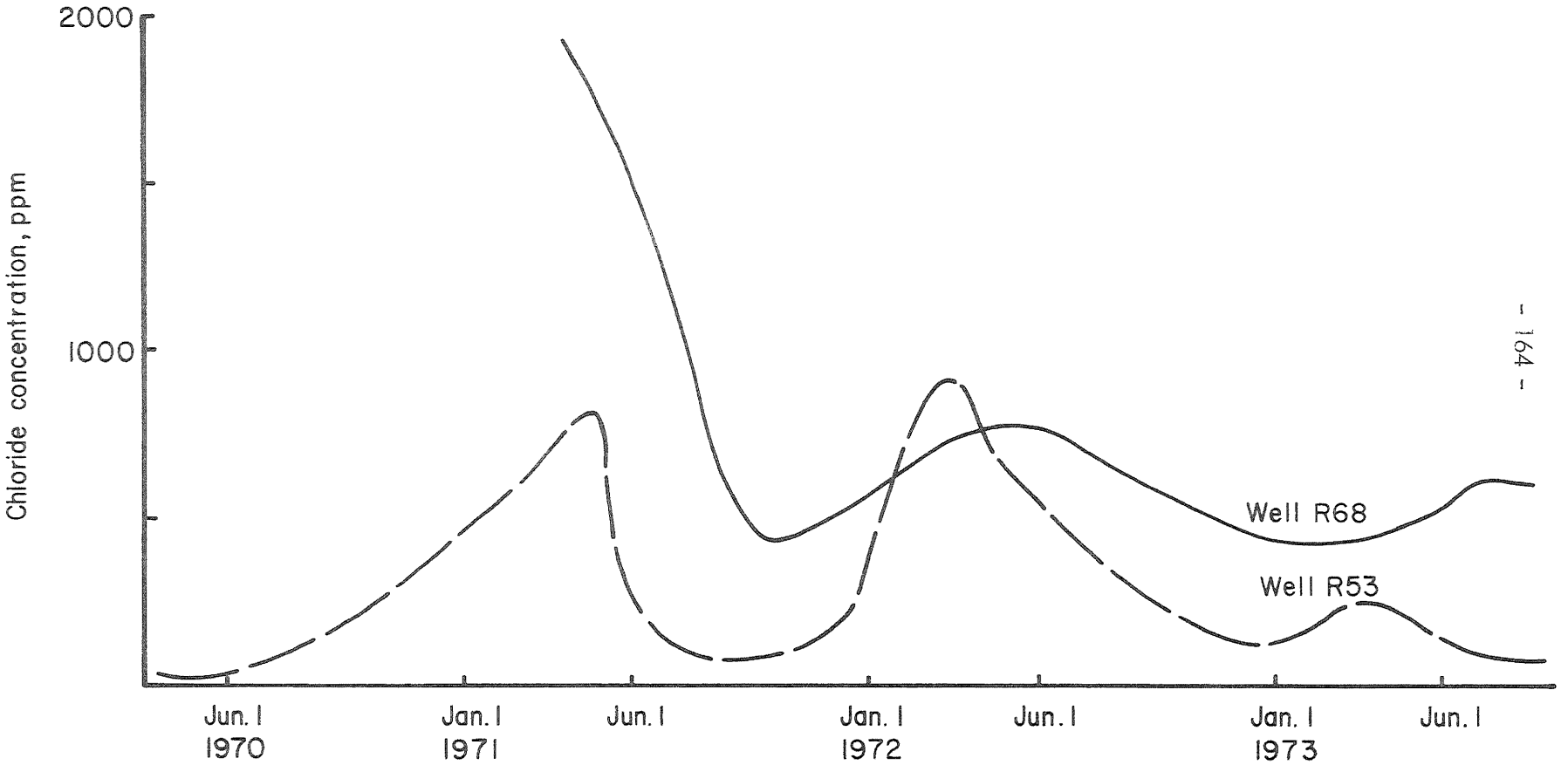


Figure 7.9. Long term chloride data, Birch Cove.

Summary

In the Birch Cove area, the steep dip of the fractures combined with thin glacial till cover and high housing density favors contamination of well water by road salt and other contaminants. Detergent could also pose a future problem in well waters. Excessive Fe and Mn concentrations are found and often have to be treated with costly equipment. Decrease in salt contamination could possibly help reduce the Fe and Mn problems somewhat.

In the Sackville area, the fractures are also steeply dipping, but the generally thick till cover and low housing density results in the protection of the bedrock aquifer from road salt. Local flow systems in the till enhance this protective effect.

From the results of the monitoring for Cl (fig. 5.22) and the longer records (fig. 7.9), it appears that salt levels are generally declining, possibly due to the change from use of 100% salt to 10% salt-90% sand around 1969 or 1970.

Other water quality problems, such as high Ca and Mg (causing hard waters), may be reduced by decreasing salt levels, since the increase in ionic strength caused by salt increases the solubility of other ions.

with K, and Fe with Mn. The Na-Cl relation is likely a result of salt in the groundwater, while the other relations are likely a result of similar geochemical behaviour of the ion pairs.

Both study areas show relatively high groundwater turnover rates and similar weathering effects. Nearly all analyses fall within the stability field of kaolinite, with contents of dissolved SiO_2 ranging between the solubility of quartz and that of amorphous SiO_2. This result is common for most groundwaters and stream waters (Garrels et al, 1971).

The time variation responses of the dug wells in Maxwell Subdivision are similar to that of the drilled wells in Birch Cove. The drilled wells in the Maxwell Subdivision, however, show a very damped out response to seasonal fluctuations as a result of the thick glacial till cover. The till cover also results in modification of drilled well water chemistry by ion exchange processes since base exchange is negligible in Birch Cove where till cover is thin or absent.

There are three main types of seasonal response of the various ions - a pulse response, dilution-concentration response, or essentially no response. The first type is shown by most road salt contaminated wells. Time lags for aquifer response to chemical changes can be determined from the pulse type response, and can also be used to calculate local bedrock permeability if the source of the ion is known. The degree of smoothness of the seasonal variations depends on the well depth, with deeper wells showing a more damped out response, i.e.

short term peaks do not stand out. In Sackville, the response of drilled wells to chemical changes is generally damped due to the glacial till cover. Dug well waters show widely varying chemical responses, both in range and time of response, depending on the permeability of the glacial till in the vicinity of the well. Pearson correlations on a time series basis for individual wells in both study areas indicates that salt contaminated wells have a high significant correlation among many of the variables which can be attributed to the effect of salt on the solubility of other ions.

Road salt contamination of groundwater is the most pressing problem in Birch Cove, with a possible detergent problem in the future. The joint orientations in this area favour the transmission of salty runoff from roads into wells below their protective casings. In Sackville, the problem is more localized at present due to less development and a thick till cover, but further development and road paving could change this situation - many problems have been reported in dug wells in the Kinsac area since that road was paved (J.F. Jones, personal communication). Also, the residence time of salt in glacial tills may be long because of their high silt content, which is favorable for retaining salt, and their generally low permeability. This increases the time required for flushing out of salt. The chloride content of the groundwater is related mainly to distance from roads in Birch Cove and to well depth in Sackville, indicating that shallow dug wells in the latter area are the main type of well that is contamina-

ted with salt at present, and that the bedrock aquifer is apparently protected by the glacial till.

The other main water quality problems of iron, manganese and hardness could possibly be reduced somewhat by lowering of salt levels in the groundwater system. However, these ions can be removed with conventional ion exchange or filtration equipment if the concentrations are not excessive.

Recommendations

Birch Cove

1. Flow patterns in the Birch Cove area should be determined in more detail by the installation of observation wells or use of tracers so that contaminant movement can be more accurately predicted.
2. Wells should be monitored for chemical changes for a period of at least 2 years in future studies of this type, with a 3-4 week sampling interval.
3. Well casings in the area should be a minimum of 50 feet in length, possibly 60-70 feet to help reduce the chances of channelling of salt into the wells by steeply dipping fractures. Cement grouting should be considered in known problem areas.
4. Careful monitoring of salt application rates in the area would be useful so that chemical mass budget calculations could be made of the amount of salt entering the system each year. From this, it might be possible to estimate the time required for flushing out of the salt. Also, it might be profitable to investigate the use of tracers

in the road salt, so that affected wells could be easily identified. This would also facilitate the tracing of groundwater movement patterns. A survey could also be made of the individual homeowner use of salt.

5. Salting should be stopped in at least two areas - the Birch Cove High recharge area and the Castle Hill Drive area.

6. The problem of septic tank effluent influence, especially with respect to bacteria and detergent, should be pursued.

7. A check could be made on the amount of contribution of garden fertilizers and insecticides to the groundwater system.

Sackville

1. Before large developments utilizing groundwater are permitted, a detailed study should be carried out to determine direction, rate of flow, and rate of renewal of groundwater, and effects on existing housing so that the chances of groundwater contamination and overdraft can be minimized.

2. Observation wells and piezometers could be installed in some glacial till areas to determine how much water is contributed to the bedrock through the till - this would be useful in studies such as water budgets and contaminant movement.

3. X-ray diffraction studies could be made to determine the types of clay minerals present in local and exotic glacial tills. The carbonate content of different types of till could also be determined.

4. Hammer seismic or resistivity surveys could be carried out to determine the ex-

tent of possible buried sands and gravels, then verified by test holes to determine the yield and quality of groundwater obtainable from the deposits. The economic feasibility of using screened wells completed in sandy or gravelly lenses in till or in buried channels should be investigated. At present, wells are usually cased through the gravel layers and completed in bedrock.

5. A bacterial survey should be conducted in the area, especially on dug wells. Many of these wells are improperly constructed and susceptible to contamination by surface water runoff.

6. Rusty car bodies on the regional recharge area southeast of Springfield Lake should be cleaned up. Iron leached from these wrecks may be part of the cause of high iron content in the groundwaters discharging on the east side of Springfield Lake. Perhaps a survey of metals in the groundwater which could come from rusting cars rather than slate bedrock could be carried out to test this.

In both study areas, the author feels that observation wells near some of the lakes which are being heavily pumped for water supply should be monitored. Since the results have indicated a good hydraulic connection between the lakes and the groundwater system (by the similarity of water level observations), it is possible that a small decline in groundwater levels could occur near the lakes, depending on such factors as pumping rate, continuity of the pumping, recharge rate, and type of well. For the same reason, draining of boggy areas or dumping of wastes into bogs should not be allowed indiscriminately without a thorough knowledge of groundwater flow in the vicinity. Lake-groundwater interaction could

be checked by monitoring water levels in a lake and nearby wells, by pump tests, and by comparing the water types.

Some of Terry's (1974) recommendations for control of salt contamination in Massachussetts could be useful for the study areas, namely, the setting of strict criteria for proper salt storage, and research toward quantification of the amount of salt to just maintain safe traffic rates and instrumentation on salt trucks to better control the desired amount and spreading rate. The other alternative, reduction of salting, might be difficult to enforce due to public pressure for a bare pavement policy; however, this may be the only solution in some parts of the study areas. Complete stoppage of salting may be necessary in some areas to solve the problem. The bare pavement demand has resulted in the increased use of salt during the last few years and subsequent contamination of many groundwater supplies. The occasional addition of tracers to the road salt being applied would facilitate the separation of natural and manmade effects in the groundwater chemistry in problem areas.

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APPENDIX I

TIME SERIES PEARSON CORRELATIONS FOR MONITORED WELLS

Well RI	Conductance	pH	Sodium	Potassium	Calcium	Magnesium	Iron	Manganese	Alkalinity	Sulphate	Chloride	Nitrate
Conductance	1.00	-.19	.39*	.44*	.89*	.52*	.01	.18	.54*	.32	.73*	.39*
pH		1.00	-.32	.25	-.06	-.40	-.14	-.49*	-.16	-.14	-.57*	.09
Sodium			1.00	.29	.21	.25	-.03	.53*	.21	.23	.70*	.35
Potassium				1.00	.45*	.43*	.03	.05	.34	.05	.29	.37*
Calcium					1.00	.51*	.09	.09	.45*	.18	.52*	.25
Magnesium						1.00	-.11	.08	.36	.30	.44*	.40*
Iron							1.00	.16	.04	-.30	.01	-.02
Manganese		Appendix IA						1.00	.08	.09	.60*	-.05
Alkalinity		* Refers to a significance level of .01 or better							1.00	-.24	.50*	.57
Sulphate										1.00	.28	.02
Chloride											1.00	.39*
Nitrate												1.00

Well R3	Conductance	pH	Sodium	Potassium	Calcium	Magnesium	Iron	Manganese	Alkalinity	Sulphate	Chloride	Nitrate
Conductance	1.00	-.15	.20	.18	.35	-.01	-.38	-.33	.17	.15	.18	.62*
pH		1.00	-.26	.06	.20	.42	.26	.34	.27	-.20	-.10	-.23
Sodium			1.00	.58*	-.16	-.13	-.41	-.38	.08	.31	.19	.48*
Potassium				1.00	-.03	-.15	-.03	-.23	-.14	.27	.44*	.22
Calcium					1.00	.58*	-.25	-.32	.61*	-.37	.10	.30
Magnesium						1.00	-.28	-.32	.68*	-.56*	.04	.10
Iron							1.00	.79*	-.13	.23	-.23	-.65*
Manganese								1.00	-.19	.11	-.29	-.69*
Alkalinity									1.00	-.63*	-.38	.12
Sulphate										1.00	.14	.09
Chloride											1.00	.22
Nitrate												1.00

Appendix 1B

* Refers to a significance level of .01 or better

Well R5	Conductance	pH	Sodium	Potassium	Calcium	Magnesium	Iron	Manganese	Alkalinity	Sulphate	Chloride	Nitrate
Conductance	1.00	.15	.92*	.37	.81*	.66*	- 02	.08	.42*	-.22	.91*	-.52*
pH		1.00	.26	.01	-.21	.13	-.03	.21	-.14	-.06	.22	.01
Sodium			1.00	.35	.74*	.55*	-.04	.08	.34	-.14	.95*	-.49*
Potassium				1.00	.38*	.00	.07	.54*	.42*	-.09	.42*	-.42*
Calcium					1.00	.68*	-.11	-.04	.51*	-.29	.77*	-.57*
Magnesium						1.00	-.06	-.05	.21	-.18	.52*	-.24
Iron							1.00	.09	-.04	.00	-.03	.19
Manganese								1.00	.02	.06	.03	.06
Alkalinity									1.00	-.46*	.39	-.71*
Sulphate										1.00	-.22	.55*
Chloride											1.00	-.60*
Nitrate												1.00

Appendix IC

* Refers to a significance level of .01 or better

Well R6	Conductance	pH	Sodium	Potassium	Calcium	Magnesium	Iron	Manganese	Alkalinity	Sulphate	Chloride	Nitrate
Conductance	1.00	-.28	.89*	.66*	.40*	.80*	-.27	.72*	.04	.46*	.96*	.43*
pH		1.00	-.25	-.41	.29	.08	.18	-.23	.14	-.23	-.29	.15
Sodium			1.00	.54*	.33	.81*	-.17	.62*	.08	.58*	.92*	.36
Potassium				1.00	.13	.37	-.41	.49*	.24	.36	.56*	.23
Calcium					1.00	.71*	-.07	.38*	.19	-.18	.31	-.09
Magnesium						1.00	-.14	.63*	.07	.32	.77*	.21
Iron							1.00	-.12	-.01	-.10	-.23	-.02
Manganese								1.00	.15	.33	.68*	.32
Alkalinity									1.00	.01	-.10	-.20
Sulphate										1.00	.52*	.23
Chloride											1.00	.44*
Nitrate												1.00

Appendix ID

*Refers to a significance level of .01 or better

Well RIO	Conductance	pH	Sodium	Potassium	Calcium	Magnesium	Iron	Manganese	Alkalinity	Sulphate	Chloride	Nitrate
Conductance	1.00	-.02	.95*	.87*	.97*	.98*	-.55*	.92*	.15	-.69*	.99*	-.57*
pH		1.00	-.04	.07	.02	-.01	.42	-.01	-.00	-.24	.01	-.12
Sodium			1.00	.85*	.96*	.93*	-.57*	.93*	.22	-.58	.95*	-.56*
Potassium				1.00	.85*	.85*	-.52*	.89*	.15	-.60*	.90*	-.60*
Calcium					1.00	.98*	-.55*	.92*	.17	-.66*	.97*	-.60*
Magnesium						1.00	-.57*	.90*	.08	-.67*	.97*	-.56*
Iron							1.00	-.54*	.24	.19	-.57*	.31
Manganese								1.00	.25	-.64*	.93*	-.68
Alkalinity									1.00	-.46*	.14	-.36
Sulphate										1.00	-.68*	.59*
Chloride											1.00	-.60*
Nitrate												1.00

Appendix IE

* Refers to a significance level of .01 or better

Well RI4	Conductance	pH	Sodium	Potassium	Calcium	Magnesium	Iron	Manganese	Alkalinity	Sulphate	Chloride	Nitrate
Conductance	1.00	.12	.95*	.88*	.95*	.95*	-.60*	.19	.67*	.39*	.97*	-.07
pH		1.00	.22	.14	.11	.18	.11	.47*	.13	-.23	.22	-.56*
Sodium			1.00	.86*	.94*	.95*	-.62*	.26	.75*	.34	.97*	-.11
Potassium				1.00	.90*	.86*	-.62*	.07	.57*	.50*	.87*	-.00
Calcium					1.00	.95*	-.59*	.11	.65*	.46*	.92*	-.06
Magnesium						1.00	-.58*	.24	.61*	.38*	.96*	-.13
Iron							1.00	.06	-.40	.57*	-.60*	-.25
Manganese								1.00	.01	-.53*	.29	-.63*
Alkalinity									1.00	.31	.65*	-.06
Sulphate										1.00	.30	.47*
Chloride											1.00	-.16
Nitrate												1.00

Appendix IF

*Refers to a significance level of .01 or better

Well R21	Conductance	pH	Sodium	Potassium	Calcium	Magnesium	Iron	Manganese	Alkalinity	Sulphate	Chloride	Nitrate
Conductance	1.00	.09	.58*	.27	.27	.32	-.03	-.11	-.47*	.22	.77*	.04
pH		1.00	.17	.28	.10	.42*	.11	-.09	-.32	.17	.19	.09
Sodium			1.00	.26	-.26	-.05	-.14	-.46*	-.49*	.58*	.78*	.69*
Potassium				1.00	.24	.22	.14	.03	-.23	.33	.36*	.04
Calcium					1.00	.57*	.29	.30	-.17	-.16	.17	-.44*
Magnesium						1.00	.10	.17	-.11	-.27	.36*	-.41*
Iron							1.00	.05	.35	-.15	-.04	-.18
Manganese								1.00	.15	-.27	-.30	-.47*
Alkalinity									1.00	-.32	-.43*	-.07
Sulphate										1.00	.41*	.72*
Chloride											1.00	.25
Nitrate												1.00

Appendix IG

* Refers to a significance level of .01 or better

Well R22	Conductance	pH	Sodium	Potassium	Calcium	Magnesium	Iron	Manganese	Alkalinity	Sulphate	Chloride	Nitrate
Conductance	1.00	-.04	.60*	.27	.67*	.46*	.13	.43*	.30	-.43*	.78*	.61*
pH		1.00	.21	.11	-.15	.22	.06	-.17	-.14	-.22	.08	-.10
Sodium			1.00	.17	.37	.44*	.07	.36	.09	-.62*	.74*	-.59*
Potassium				1.00	.05	.07	.02	.30	.01	-.14	.11	-.09
Calcium					1.00	.48*	.19	.29	.09	-.24	.72*	-.47*
Magnesium						1.00	.10	.04	.06	-.25	.64*	-.41*
Iron							1.00	.48	.41	-.34	.27	-.18
Manganese								1.00	.21	-.34	.32	-.36
Alkalinity									1.00	-.19	.18	.04
Sulphate										1.00	-.67*	.64*
Chloride											1.00	-.69*
Nitrate												1.00

Appendix IH

*Refers to a significance level of .01 or better

Well R44	Conductance	pH	Sodium	Potassium	Calcium	Magnesium	Iron	Manganese	Alkalinity	Sulphate	Chloride	Nitrate
Conductance	1.00	.31	.97*	.73*	.96*	.89*	.07	-.10	.52*	.72*	.99*	.63*
pH		1.00	.31	.40	.30	.37	.23	-.01	.03	.34	.37	.22
Sodium			1.00	.73*	.95*	.85*	.04	-.06	.55*	.72*	.97*	.63*
Potassium				1.00	.71*	.64*	.30	.16	.29	.65*	.69*	.40*
Calcium					1.00	.89*	.08	-.04	.64*	.73*	.97*	.62*
Magnesium						1.00	.12	.02	.45*	.66*	.90*	.51*
Iron							1.00	-.03	.07	.00	.07	.28
Manganese								1.00	.11	.02	-.08	-.19
Alkalinity									1.00	.49*	.56*	.37
Sulphate										1.00	.73*	.39*
Chloride											1.00	.66*
Nitrate												1.00

Appendix IK

*Refers to a significance level of .01 or better

Well R46	Conductance	pH	Sodium	Potassium	Calcium	Magnesium	Iron	Manganese	Alkalinity	Sulphate	Chloride	Nitrate
Conductance	1.00	-.13	.84*	.55*	.85*	.88*	-.68*	-.57*	.84*	.34	.50*	.77*
pH		1.00	.05	.18	-.17	-.15	-.11	.14	-.27	-.18	.29	-.27
Sodium			1.00	.54*	.77*	.84*	-.53*	-.39*	.74*	.29	.53*	.58*
Potassium				1.00	.38*	.47*	-.55*	-.15	.31	.04	.16	.35
Calcium					1.00	.92*	-.45	-.61*	.89*	.36	.58*	.77*
Magnesium						1.00	-.51*	-.67*	.89*	.35	.54*	.80*
Iron							1.00	.39	-.42	-.27	-.30	-.47*
Manganese								1.00	-.59*	-.07	-.18	-.72*
Alkalinity									1.00	.34	.41	.78*
Sulphate										1.00	.19	.26
Chloride											1.00	.18
Nitrate												1.00

Appendix IL

*Refers to a significance level of .01 or better

Well R53	Conductance	pH	Sodium	Potassium	Calcium	Magnesium	Iron	Manganese	Alkalinity	Sulphate	Chloride	Nitrate
Conductance	1.00	-.49	.93*	.89*	.66*	.81*	.51	.89*	-.14	-.32	.99*	.47
pH		1.00	-.55*	-.38	-.29	-.30	-.52	-.42	.03	-.02	-.48	-.17
Sodium			1.00	.82*	.39	.61*	.65*	.84*	-.08	-.25	.92*	.57*
Potassium				1.00	.67*	.75*	.57	.78*	.16	-.18	.86*	.65*
Calcium					1.00	.94*	.18	.51	-.02	-.18	.67*	.16
Magnesium						1.00	.26	.65*	-.07	-.25	.83*	.22
Iron							1.00	.37	.21	-.16	.50	.47
Manganese								1.00	-.18	-.51	.90*	.27
Alkalinity									1.00	.51	-.20	.55*
Sulphate										1.00	-.39	.31
Chloride											1.00	.41
Nitrate												1.00

Appendix IM

* Refers to a significance level of .01 or better

Well R58	Conductance	pH	Sodium	Potassium	Calcium	Magnesium	Iron	Manganese	Alkalinity	Sulphate	Chloride	Nitrate
Conductance	1.00	.19	.95*	.83*	.93*	.95*	-.22	.53*	.15	-.03	.97*	-.09
pH		1.00	.16	.08	.24	.18	.07	-.28	.08	.06	.20	-.36
Sodium			1.00	.81*	.95*	.98*	-.18	.57	.19	-.14	.98*	-.08
Potassium				1.00	.84*	.80*	-.32	.50*	.34	-.17	.83*	-.20
Calcium					1.00	.95*	-.25	.54*	.24	-.17	.97*	-.21
Magnesium						1.00	-.19	.59*	.18	-.11	.99*	-.10
Iron							1.00	-.13	-.09	-.37	-.20	.24
Manganese								1.00	-.05	.01	.60*	.23
Alkalinity									1.00	-.24	.17	.34
Sulphate										1.00	-.12	.40*
Chloride											1.00	-.11
Nitrate												1.00

Appendix IN

* Refers to a significance level of .01 or better

Well R59	Conductance	pH	Sodium	Potassium	Calcium	Magnesium	Iron	Manganese	Alkalinity	Sulphate	Chloride	Nitrate
Conductance	1.00	-.09	.86*	.50*	.84*	.57*	.05	.65*	.15	-.04	.87*	-.57*
pH		1.00	-.07	-.36	-.15	-.14	-.19	-.41	-.53*	.22	.03	-.36
Sodium			1.00	.40*	.76*	.54*	.06	.51*	.17	.03	.81*	-.54*
Potassium				1.00	.34	.11	-.05	.49*	.33	.10	.28	-.14
Calcium					1.00	.74*	.08	.64*	.28	-.04	.87*	-.57*
Magnesium						1.00	.07	.60*	.14	-.25	.77*	-.46*
Iron							1.00	.12	.14	.06	.07	.07
Manganese								1.00	.49*	-.13	.56*	-.10
Alkalinity									1.00	-.01	-.03	.35
Sulphate										1.00	-.07	-.04
Chloride											1.00	-.74*
Nitrate												1.00

Appendix 10

* Refers to a significance level of .01 or better

Well R60	Conductance	pH	Sodium	Potassium	Calcium	Magnesium	Iron	Manganese	Alkalinity	Sulphate	Chloride	Nitrate
Conductance	1.00	.36	.26	.03	.94*	88*	.01	-.81*	.56*	.50*	.94*	-.62*
pH		1.00	.19	.07	.28	.53*	.23	-.21	.09	.04	.35	-.14
Sodium			1.00	.23	.17	.28	.29	.05	.32	.16	.38*	-.01
Potassium				1.00	-.11	.02	-.16	.09	-.12	-.12	.09	-.03
Calcium					1.00	.84*	.15	-.83*	.66*	.56*	.86*	-.59*
Magnesium						1.00	-.02	-.71*	.45*	.42*	.82*	-.57*
Iron							1.00	-.02	.44	.37	.06	.33
Manganese								1.00	-.62*	-.54*	-.66*	.60*
Alkalinity									1.00	.78*	.51*	-.25
Sulphate										1.00	.45*	-.20
Chloride											1.00	-.47*
Nitrate												1.00

Appendix IP

* Refers to a significance level of .01 or better

Well R61	Conductance	pH	Sodium	Potassium	Calcium	Magnesium	Iron	Manganese	Alkalinity	Sulphate	Chloride	Nitrate
Conductance	1.00	.28	.86*	.36	.52*	.40*	.19	.70*	.36	.12	.92*	-.62*
pH		1.00	.38	-.22	.20	.37	.03	.24	.10	.02	.35	-.19
Sodium			1.00	.17	.34	.25	.22	.75*	.26	.19	.85*	-.49*
Potassium				1.00	.20	.04	-.05	.11	.13	.05	.28	-.40*
Calcium					1.00	.70*	.03	.35	.69*	-.31	.60*	-.63*
Magnesium						1.00	.05	.31	.61*	-.31	.50*	-.49*
Iron							1.00	.22	-.12	.11	.14	.07
Manganese								1.00	.12	.14	.78*	-.42*
Alkalinity									1.00	-.29	.39*	-.72*
Sulphate										1.00	.07	.11
Chloride											1.00	-.68*
Nitrate												1.00

Appendix IQ

* Refers to a significance level of .01 or better

Well R62	Conductance	pH	Sodium	Potassium	Calcium	Magnesium	Iron	Manganese	Alkalinity	Sulphate	Chloride	Nitrate
Conductance	1 00	.15	-.35	.53*	.41*	.70*	.35	-.30	-.55*	-.12	.82*	-.20
pH		1.00	.23	.00	.24	.19	.15	.04	-.10	-.07	.20	-.18
Sodium			1.00	-.15	-.17	-.35	-.09	.06	.50*	-.04	-.33	-.19
Potassium				1.00	-.08	.17	-.16	-.38	-.62*	.01	.32	-.15
Calcium					1.00	.69*	.34	.11	-.01	-.40*	.68*	-.35
Magnesium						1.00	.35	.07	-.33	-.24	.91*	-.28
Iron							1.00	.12	.09	-.19	.43	.15
Manganese								1.00	.41*	-.19	-.01	-.38*
Alkalinity									1.00	-.19	-.37	-.02
Sulphate										1.00	-.29	.43*
Chloride											1.00	-.33
Nitrate												1.00

Appendix IR

* Refers to a significance level of .01 or better

Well R63	Conductance	pH	Sodium	Potassium	Calcium	Magnesium	Iron	Manganese	Alkalinity	Sulphate	Chloride	Nitrate
Conductance	1.00	.02	.23	.52*	.55*	.52*	-.01	-.49*	-.06	-.11	.74*	-.22
pH		1.00	.06	.09	-.03	.07	.37	.40	-.12	.11	-.06	-.27
Sodium			1.00	.13	.06	.06	.04	-.14	.40	10	.13	-.32
Potassium				1.00	-.01	.02	-.04	-.04	.02	.06	.21	.05
Calcium					1.00	.76*	-.11	-.67*	.02	-.19	.72*	-.32
Magnesium						1.00	-.22	-.51*	.03	-.18	.74*	-.33
Iron							1.00	.15	-.27	-.02	-.00	.02
Manganese								1.00	-.10	.27	-.60*	-.04
Alkalinity									1.00	-.08	-.13	-.16
Sulphate										1.00	-.27	.13
Chloride											1.00	-.42*
Nitrate												1.00

Appendix IS

*Refers to a significance level of .01 or better

Well R64	Conductance	pH	Sodium	Potassium	Calcium	Magnesium	Iron	Manganese	Alkalinity	Sulphate	Chloride	Nitrate
Conductance	1.00	-.15	.97*	.74*	.93*	.93*	.15	-.35	.18	-.28	.99*	-.57
pH		1.00	-.10	-.19	-.22	-.14	-.02	.01	-.16	-.21	-.16	-.06
Sodium			1.00	.70*	.90*	.92*	.13	-.36*	.26	-.20	.97*	-.52*
Potassium				1.00	.69*	.67*	-.01	-.18	.10	-.31	.73*	-.44*
Calcium					1.00	.95*	.24	-.35	.33	-.36	.94*	-.65*
Magnesium						1.00	.20	-.36	.31	-.36*	.95*	-.60*
Iron							1.00	-.14	.45	-.11	.16	-.17
Manganese								1.00	.05	.03	-.36	.03
Alkalinity									1.00	-.02	.22	-.21
Sulphate										1.00	-.31	.61*
Chloride											1.00	-.60*
Nitrate												1.00

Appendix IT

* Refers to a significance level of .01 or better

Well R65	Conductance	pH	Sodium	Potassium	Calcium	Magnesium	Iron	Manganese	Alkalinity	Sulphate	Chloride	Nitrate
Conductance	1.00	.33	.94*	.23*	.94*	.92*	.25	.58*	-.04	.74*	.98*	.21
pH		1.00	.32	.15	.24	.32	.35	.23	-.09	-.10	.33	.39
Sodium			1.00	.78*	.84*	.82*	.24	.47*	-.15	.74*	.92*	.09
Potassium				1.00	.66*	.60*	.02	.24	-.18	.45*	.70*	-.03
Calcium					1.00	.88*	-.01	.58*	-.04	.69*	.94*	.22
Magnesium						1.00	.20	.55*	-.16	.68*	.93*	.22
Iron							1.00	-.18	-.26	.16	.23	-.15
Manganese								1.00	.08	.38*	.59*	.44*
Alkalinity									1.00	-.31	-.16	.48*
Sulphate										1.00	.74*	-.03
Chloride											1.00	.16
Nitrate												1.00

Aopendix IU

*Refers to a significance level of .01 or better

Well R67	Conduc-tance	pH	Sodium	Potas-sium	Calcium	Magne-sium	Iron	Manga-nese	Alkali-nity	Sulphate	Chloride	Nitrate
Conduc-tance	1.00	.40	.97*	.74*	.63*	.16	.18	.02	.52*	.09	.93*	.36
pH		1.00	.40	.55*	.41	.24	-.24	.09	.34	.12	.42	.38
Sodium			1.00	.79*	.51*	-.04	.15	-.16	.60*	-.10	.97*	.41*
Potas-sium				1.00	.56*	-.06	-.21	-.13	.70*	-.16	.77*	.42*
Calcium					1.00	.66*	- 18	.48*	.34	.57*	.45*	.05
Magne-sium						1.00	-.10	.88*	-.08	.94*	-.16	-.13
Iron							1.00	-.10	-.20	-.11	.21	.15
Manga-nese								1.00	-.17	.82*	-.27	-.15
Alkali-nity									1.00	-.08	.53*	.47*
Sulphate										1.00	-.23	-.12
Chloride											1.00	.36
Nitrate												1.00

Appendix IV

* Refers to a significance level of .01 or better

Well SI	Conductance	pH	Sodium	Potassium	Calcium	Magnesium	Iron	Manganese	Alkalinity	Sulphate	Chloride	Nitrate
Conductance	1.00	.44*	.21	.15	-.09	.12	.17	-.12	-.39	.10	-.08	.01
pH		1.00	.17	-.01	-.13	.22	.53*	-.29	-.52*	.21	-.05	-.14
Sodium			1.00	.17	-.20	-.35	-.49*	.37*	-.07	.38*	-.10	-.71*
Potassium				1.00	.11	-.17	-.13	.27	-.03	-.01	.26	.00
Calcium					1.00	.06	-.04	.20	.17	.10	.11	.34
Magnesium						1.00	.38	-.40*	-.06	-.13	-.54*	.62*
Iron							1.00	-.38	-.30	-.28	.03	.54*
Manganese								1.00	.15	.24	.14	-.39*
Alkalinity									1.00	-.24	-.07	.28
Sulphate										1.00	-.09	-.48*
Chloride											1.00	-.10
Nitrate												1.00

Appendix IW

* Refers to a significance level of .01 or better

Well S5	Conductance	pH	Sodium	Potassium	Calcium	Magnesium	Iron	Manganese	Alkalinity	Sulphate	Chloride	Nitrate
Conductance	1.00	.01	.45*	-.09	.31	.18	-.21	.18	.36	.38*	-.07	.27
pH		1.00	-.18	.09	-.03	-.12	.48	.19	-.43*	.06	.33	-.10
Sodium			1.00	.16	.15	.49*	-.44	.19	.65*	.37	-.33	.62*
Potassium				1.00	-.06	.10	-.09	.21	.21	-.06	-.01	.03
Calcium					1.00	.01	-.38	.32	.30	.28	-.26	.17
Magnesium						1.00	-.23	-.03	.30	-.04	-.01	-.04
Iron							1.00	-.40	-.50*	-.50*	.35	-.57*
Manganese								1.00	.21	.26	-.17	.32
Alkalinity									1.00	.16	-.40	.57*
Sulphate										1.00	-.27	.53*
Chloride											1.00	-.32
Nitrate												1.00

Appendix IX

* Refers to a significance level of .01 or better

Well S10	Conductance	pH	Sodium	Potassium	Calcium	Magnesium	Iron	Manganese	Alkalinity	Sulphate	Chloride	Nitrate
Conductance	1.00	-.29	.42*	.37	.97*	.83*	-.20	-.37	.89*	.06	.12	.55*
pH		1.00	-.30	-.08	-.22	-.18	-.02	-.07	-.43	.16	-.01	-.11
Sodium			1.00	.47*	.40	.42*	-.57*	.13	.45*	.04	.03	.16
Potassium				1.00	.34	.07	-.10	.11	.43*	.45*	.29	-.14
Calcium					1.00	.85*	-.24	-.34	.85*	.06	.08	.59*
Magnesium						1.00	-.19	-.50*	.68*	-.28	-.12	.76*
Iron							1.00	-.18	-.28	.12	-.04	-.09
Manganese								1.00	-.22	.16	.08	-.43*
Alkalinity									1.00	-.02	.16	.29
Sulphate										1.00	.44*	-.54*
Chloride											1.00	-.54*
Nitrate												1.00

Appendix IY

* Refers to a significance level of .01 or better

Well S14	Conductance	pH	Sodium	Potassium	Calcium	Magnesium	Iron	Manganese	Alkalinity	Sulphate	Chloride	Nitrate
Conductance	1.00	-.41	.90*	.44*	.16	.09	.54*	.43*	-.47*	.48*	.97*	-.06
pH		1.00	-.53*	-.50*	.37	.44*	-.28	-.30	.58*	-.18	-.50*	.04
Sodium			1.00	.51	-.26	-.29	.44	.26	-.46*	.18	.96*	-.28
Potassium				1.00	-.20	-.42*	.49*	.39*	-.62*	.30	.48*	-.24
Calcium					1.00	.89*	.09	.23	.13	.56*	-.04	.47*
Magnesium						1.00	-.14	.13	.19	.49*	-.11	.66*
Iron							1.00	.29	-.35	.28	.52*	-.27
Manganese								1.00	-.79*	.84*	.38*	.21
Alkalinity									1.00	-.64*	-.50*	-.08
Sulphate										1.00	.34	.47*
Chloride											1.00	-.16
Nitrate												1.00

Appendix IZ

* Refers to a significance level of .01 or better

Well S19	Conductance	pH	Sodium	Potassium	Calcium	Magnesium	Iron	Manganese	Alkalinity	Sulphate	Chloride	Nitrate
Conductance	1.00	.20	.49*	.76*	.97*	.91*	-.23	-.24	.88*	-.04	.68*	.15
pH		1.00	.43*	.10	.14	.12	.15	-.25	.01	.37	.11	-.08
Sodium			1.00	.44*	.43*	.39*	-.22	-.13	.29	.38*	.41*	-.35
Potassium				1.00	.75*	.59*	-.47	-.09	.81*	.28	.29	-.09
Calcium					1.00	.94*	-.29	-.23	.90*	-.05	.63*	.10
Magnesium						1.00	-.10	-.31	.79*	-.24	.74*	.19
Iron							1.00	-.22	-.31	-.23	.13	.34
Manganese								1.00	-.14	-.08	-.31	-.10
Alkalinity									1.00	-.06	.34	.02
Sulphate										1.00	-.21	-.41*
Chloride											1.00	.47*
Nitrate												1.00

Appendix IAA

* Refers to a significance level of .01 or better

Well S20	Conductance	pH	Sodium	Potassium	Calcium	Magnesium	Iron	Manganese	Alkalinity	Sulphate	Chloride	Nitrate
Conductance	1.00	.45*	.76*	.27	.55*	.78*	-.25		-.12	.22	.66*	.09
pH		1.00	.17	.24	.46*	.38	.00		.12	.57*	-.03	.43
Sodium			1.00	.30	.07	.68*	-.31		-.44*	-.20	.85*	-.35
Potassium				1.00	.33	.32	-.38		.34	.25	.06	.32
Calcium					1.00	.48*	-.12		.42*	.68*	-.04	.66*
Magnesium						1.00	-.37		-.18	.22	.61*	.11
Iron							1.00		.09	-.06	-.25	-.02
Manganese												
Alkalinity									1.00	.50*	-.63*	.68*
Sulphate										1.00	-.33	.72*
Chloride											1.00	-.53*
Nitrate												1.00

Appendix IBB

* Refers to a significance level of .01 or better

Well S21	Conductance	pH	Sodium	Potassium	Calcium	Magnesium	Iron	Manganese	Alkalinity	Sulphate	Chloride	Nitrate
Conductance	1.00	.01	.47*	.02	.38*	.12	.03	-.07	.45*	.41*	-.07	.24
pH		1.00	-.04	-.14	-.24	.29	.12	.04	-.39	.16	.30	-.07
Sodium			1.00	.21	.57*	.17	-.18	-.20	.41*	.52*	-.06	.44*
Potassium				1.00	.09	.29	-.09	.19	.23	-.15	.16	.14
Calcium					1.00	-.16	-.06	-.17	.53*	.32	-.12	.24
Magnesium						1.00	-.32	.11	-.21	-.08	.21	.00
Iron							1.00	-.15	.15	-.15	.06	-.10
Manganese								1.00	-.05	-.24	.08	.01
Alkalinity									1.00	.42*	-.31	.53*
Sulphate										1.00	-.02	.55*
Chloride											1.00	-.15
Nitrate												1.00

Appendix ICC

* Refers to a significance level of .01 or better

APPENDIX 2 AMOUNT AND DATES FOR ROAD SALT IN BIRCH COVE

Data from City Field on Rates of Salting, Tons/mile
Birch Cove Area, as the amount of salt (accuracy ± 25%)

Winter of Water Year 1971-1972*

Jan.	1	0.2	Mar.	1	0.25
	7	1.2		3	0.5
	10	0.2		4	1.0
	11	0.2		5	0.75
	15	0.5		6	0.75
	16	1.5		7	0.13
	17	0.75		9	0.1
	18	0.75		12	0.5
	21	1.5		16	0.5
	26	0.6		22	0.25
Feb.	4	0.75		23	0.5
	5	0.13		27	1.0
	7	0.2		28	0.25
	10	0.5		31	0.25
	20	0.25	Apr.	3	0.5
	21	0.5		4	0.1
	22	1.0		5	0.13
	24	1.0		8	0.5
	25	0.75		9	0.5
	27	0.5		10	0.25
	28	0.25		14	0.5
	29	0.5	May	13	1.0

Winter of Water Year 1972-1973

Nov.	15	.4-.7	Jan.	12	.4-.7
Dec.	5	.8- 2.		21	.8- 2.
	9	.4-.7		31	.8- 2.
	10	.4-.7	Feb.	1	.4-.7
	11	.4-.7		8	.02
	13	.8- 2.		10	.2
	16	.8- 2		12	.02
	17	.4-.7		13	.03
	18	.4-.7		15	.08
	19	.4-.7		16	.03
	20	.4-.7		17	.12
	21	.4-.7		18	.1
	22	.4-.7		23	.3
	27	.4-.7		24	.1
	31	.8- 2.		27	.02
Jan. 1973	1	.4-.7	Mar.	2	.2
	2	.4-.7		5	.2
	4	.4-.7			
	5	.8- 2.			
	6	.4-.7			
	10	.4-.7			
	11	.4-.7			

* No data for Oct.-Dec. 1971

Total Salt applied in Birch Cove:

Jan. 1, 1972-May 13, 1972	24 Tons/mi	=	144 tons
Nov. 15, 1972-Mar. 5, 1973	22 Tons/mi	=	132 tons

Total Sand-Salt mix applied:

Water Year 1971-1972	14,400 Tons
Water Year 1972-1973	13,200 Tons

APPENDIX 3 CARBONATE EQUILIBRIA AND pCO_2 CALCULATIONS

The five basic equilibria for carbonate-water systems at 25°C are (Garrels et al, 1965):

$$(1)\quad K_{CaCO_3} = \frac{a_{Ca^{++}}\, a_{CO_3^{=}}}{a_{CaCO_3}} = 10^{-8.3}$$

$$CaCO_3 \rightleftharpoons Ca^{++} + CO_3^{=}$$

$$(2)\quad K_{H_2CO_3} = \frac{a_{H^+}\, a_{HCO_3^-}}{a_{H_2CO_3}} = 10^{-6.4}$$

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

$$(3)\quad K_{HCO_3} = \frac{a_{H^+}\, a_{CO_3^{=}}}{a_{HCO_3^-}} = 10^{-10.3}$$

$$HCO_3^- \rightleftharpoons H^+ + CO_3^{=}$$

$$(4)\quad K_{H_2O} = \frac{a_{H^+}\, a_{OH^-}}{a_{H_2O}} = 10^{-14}$$

$$H_2O \rightleftharpoons H^+ + OH^-$$

$$(5)\quad K_{CO_2} = \frac{a_{H_2CO_3}}{a_{CO_2}\, a_{H_2O}} = 10^{-1.47}$$

$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$

where K = equilibrium constant and a = activity = γ m (γ is the activity coeffi-

cient and m is the concentration in moles per liter). In dilute solutions, γ can be calculated from the Debye-Hückel equation (Garrels et al, 1965).

From samples with pH and HCO_3 determinations, pCO_2 can be calculated by combining equations (2) and (5) to give (6) (Garrels et al, 1967):

$$(6)\quad pCO_2 = a_{CO_2} = \frac{a_{HCO_3}\, a_{H^+}}{K_{CO_2}} \qquad (\text{where } K_{CO_2} = 10^{-7.82})$$

The following table lists the calculated pCO_2 values. It is notable that all are greater than the atmospheric value of $10^{-3.5}$.

Also, checks for $CaCO_3$ saturation were made by calculating $a_{CO_3^{=}}$ from equation (3) and substituting into equation (1). The saturated wells are shown in fig. 6.19 in the text.

Well No.	x, where $pCO_2 = 10^{-x}$ atm.	Well No.	x
Birch Cove, Monitored Wells		S34*	1.43
R1*	1.15	S35	1.20
R3*	0.92	S36*	1.40
R5*	0.98	S37	2.08
R6*	0.96	S38*	1.60
R10*	0.92	S39	1.54
R14*	0.79	S40	1.38
R21*	1.40	S41*	1.15
R22*	1.18	S42*	1.36
R31*	1.05	S43	1.10
R44*	1.38	S44*	1.06
R46*	1.44	S45	2.20
R53*	1.16	S46	2.30
R58*	1.16	S47*	1.89
R59*	1.04	S48*	1.30
R60*	1.19	S49	1.10
R61*	1.23	S50	0.73
R62*	0.90	S51	1.10
R63*	0.88	S52*	1.18
R64*	1.35	S53*	1.97
R65*	1.26	S54*	2.17
R67	1.57	S55	1.73
Sackville Monitored Wells		S56	2.04
S1*	1.35	S57*	2.00
S5*	1.43	S58*	1.72
S10	1.37	S59*	2.00
S14	1.08	S60*	2.60
S19	1.26	S61	2.17
S20*	1.31	S62*	2.27
S21*	1.39	S63	2.27
Sackville Spot Samples		S64	2.30
S30*	0.94	S114	1.78
S31*	1.53	S115	1.98
S32	1.88	S116*	2.17
S33*	1.43	S117	2.08
		S118	1.56
		S119	1.73
		S120*	2.08
		S121	1.65
		S122	1.52
		S123	2.04

Well No.	x
S124	1.28
S125*	1.60
S126	1.80
S127	1.73
S128	1.18
S129*	1.73
S130*	2.04
S131	1.54
S132*	1.45
S133	2.20
S134	1.78
S135	1.88
S136*	2.03
S137	1.68
S138	1.78
S139*	1.70
S140	1.48
S141*	1.80
S142	1.60
S143*	1.68
S144*	1.03
S145*	1.67
S147	1.88
S151*	2.08
S152*	1.90
S153*	1.60

Well No.	x
Birch Cove Spot Samples	
R70*	1.89
R71	1.78
R72*	1.43
R73	1.88
R74*	1.39
R75*	2.00
R76	1.98
R77*	2.07
R78	2.18
R79	1.58
R80*	2.20
R81	1.93
R82	1.78
R83*	2.10
R84*	2.44
R85*	1.36
R86*	2.03
R87*	1.60
R88*	1.70
R89*	2.43
R90*	1.53
R91	1.48
R92	1.28
R93*	1.27
R68*	0.78
R69*	0.78
R69a*	2.04

* refers to drilled wells

APPENDIX 4

MEAN AND STANDARD DEVIATION VALUES OF CHEMICAL PARAMETERS IN THE MONITORED WELLS, BIRCH COVE AND SACKVILLE

Well No.	Cond.	Na	K	Ca	Mg	Fe	Mn	HCO_3	SO_4	Cl	NO_3-N
BIRCH COVE *											
R1	269	11.9	1.5	28.1	7.1	0.04	0.01	58	5	48	0.5
	22	1.1	0.2	3.1	0.7	0.04	0.01	7	1	5	0.2
R3	292	14.6	1.3	38.3	4.5	0.21	1.01	93	13	30	0.2
	10	1.4	0.1	2.2	0.4	0.19	0.66	7	3	3	0.2
R5	671	55.6	2.1	64.8	10.5	0.02	0.05	82	42	142	1.2
	76	7.1	0.2	6.9	1.4	0.02	0.03	13	6	22	0.3
R6	687	75.6	2.5	43.1	13.4	0.25	2.64	92	14	158	0.4
	107	17.1	0.4	3.9	1.6	0.24	0.49	7	3	34	0.1
R10	1597	187.0	4.2	94.1	19.5	0.17	0.40	45	46	455	3.4
	383	52.6	1.1	29.1	5.6	0.13	0.11	14	6	130	0.6
R14	2561	325.5	4.4	191.7	13.8	0.25	0.21	82	208	702	2.2
	501	83.5	1.0	35.7	2.9	0.19	0.06	12	29	166	0.5
R21	275	10.9	1.0	34.5	5.9	0.02	0.34	82	11	31	0.1
	22	3.3	0.1	2.8	0.6	0.02	0.06	7	3	5	0.2
R22	518	23.3	1.1	72.2	6.5	0.02	0.02	81	71	75	1.7
	35	2.4	0.1	4.4	0.8	0.01	0.01	4	11	11	0.2
R31	650	33.7	2.2	57.5	16.5	0.15	0.10	71	25	149	0.8
	130	4.9	1.3	10.9	3.7	0.15	0.03	8	5	37	0.4
R44	408	19.5	1.3	48.1	7.3	0.01	0.01	57	15	85	0.9
	111	5.4	0.2	14.3	2.1	0.02	0.00	8	4	33	0.2

Well No.	Cond.	Na	K	Ca	Mg	Fe	Mn	HCO_3	SO_4	Cl	NO_3-N
R46	168	8.7	1.1	16.9	5.3	0.06	0.04	52	16	15	1.1
	18	0.7	0.1	2.5	0.8	0.04	0.03	11	3	2	0.3
R53	663	101.3	1.9	18.7	5.7	0.11	0.21	15	29	180	0.3
	168	25.1	0.4	6.8	1.9	0.05	0.08	4	7	54	0.3
R58	736	81.9	3.5	39.3	15.1	0.07	0.16	20	46	178	6.1
	233	26.3	0.5	10.1	5.7	0.07	0.07	7	5	69	1.6
R59	518	34.2	2.6	44.2	13.9	0.01	0.05	62	18	112	2.4
	51	2.9	0.3	4.2	1.5	0.01	0.03	7	2	17	0.5
R60	205	11.5	1.1	18.3	5.2	0.05	0.26	42	15	33	0.6
	36	1.0	0.1	5.3	1.0	0.04	0.10	9	2	8	0.1
R61	443	30.2	1.7	35.7	11.7	0.03	0.02	38	15	105	1.9
	42	6.0	0.5	3.1	0.9	0.02	0.02	9	3	11	0.3
R62	1295	34.5	2.2	144.8	43.2	0.06	0.02	66	18	368	3.0
	98	2.7	0.2	16.9	4.6	0.04	0.09	10	2	37	0.5
R63	590	32.4	1.8	75.7	8.4	0.04	0.34	145	21	78	5.0
	36	2.0	0.2	5.2	0.7	0.03	0.06	9	3	13	1.1
R64	447	40.6	2.0	25.1	11.5	0.05	0.12	23	36	97	2.5
	103	12.2	0.3	6.2	2.3	0.04	0.02	5	6	33	0.4
R65	609	33.3	2.2	47.3	19.2	2.50	3.04	32	19	167	0.1
	101	8.0	0.3	7.9	3.3	1.15	0.39	5	5	35	0.2
R67	260	38.9	1.1	7.6	2.0	0.03	0.08	14	22	62	0.2
	125	24.0	0.4	2.9	1.9	0.05	0.05	5	17	39	0.5

* The top row of figures for each well represents the mean values of the parameters, the second row the standard deviations.

Well No.	Cond.	Na	K	Ca	Mg	Fe	Mn	HCO_3	SO_4	Cl	NO_3-N
SACKVILLE *											
S1	179	15.4	1.5	19.5	2.6	0.06	0.01	84	8	5.1	0.17
	6	1.2	0.1	1.2	0.3	0.05	0.01	6	2	0.4	0.05
S5	169	30.5	0.9	7.8	0.7	0.10	0.01	76	10	5.5	0.02
	4	1.8	0.1	0.9	0.3	0.00	0.00	6	2	1	0.02
S10	158	6.0	4.0	21.0	2.7	0.06	0.01	66	7	8.3	0.61
	29	0.6	0.9	5.2	0.7	0.11	0.00	14	3	3	0.37
S14	388	29.0	4.5	37.2	6.1	0.03	0.71	50	69	54.3	0.56
	157	28.9	2.6	11.5	2.2	0.05	0.48	24	28	47	0.33
S19	249	10.1	1.3	32.0	6.1	0.06	0.01	76	8	30.4	0.52
	51	1.6	0.2	8.8	1.6	0.06	0.01	22	4	6	0.11
S20	153	6.5	0.7	20.4	1.4	0.03	0.01	45	6	19.4	0.42
	13	1.1	0.1	1.9	0.1	0.06	0.00	6	2	5	0.16
S21	192	23.7	1.2	16.9	1.5	0.06	0.04	87	10	6.7	0.02
	4	1.5	0.1	1.3	0.1	0.15	0.01	5	2	2	0.02

* The top row of figures for each well represents the mean values of the parameters, the second row the standard deviations.

APPENDIX 5

SEMILOG PLOTS OF THE COMPOSITION OF MONITORED WELLS AND SPOT SAMPLES, BIRCH COVE AND SACKVILLE

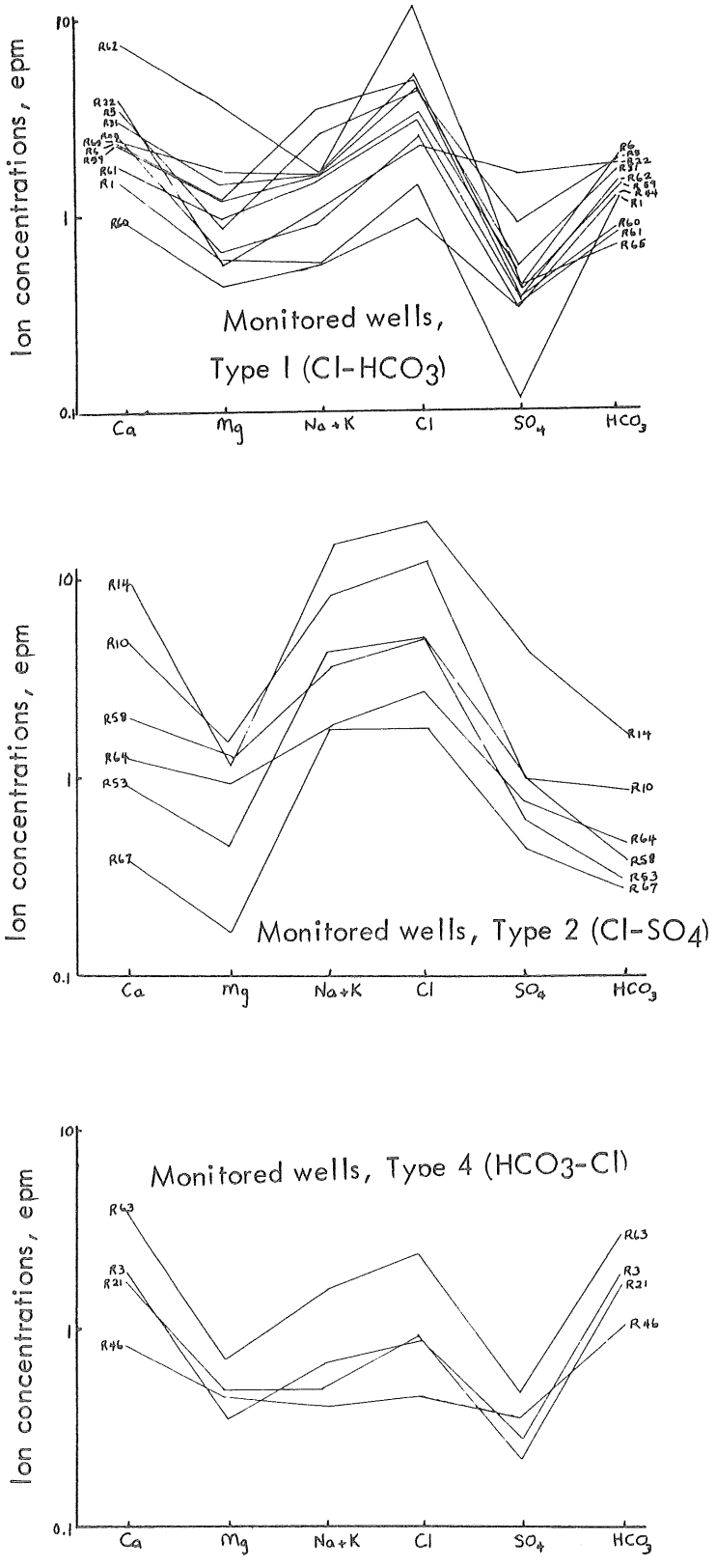


Figure 1. Semilog plots of the composition of monitored wells, Birch Cove.

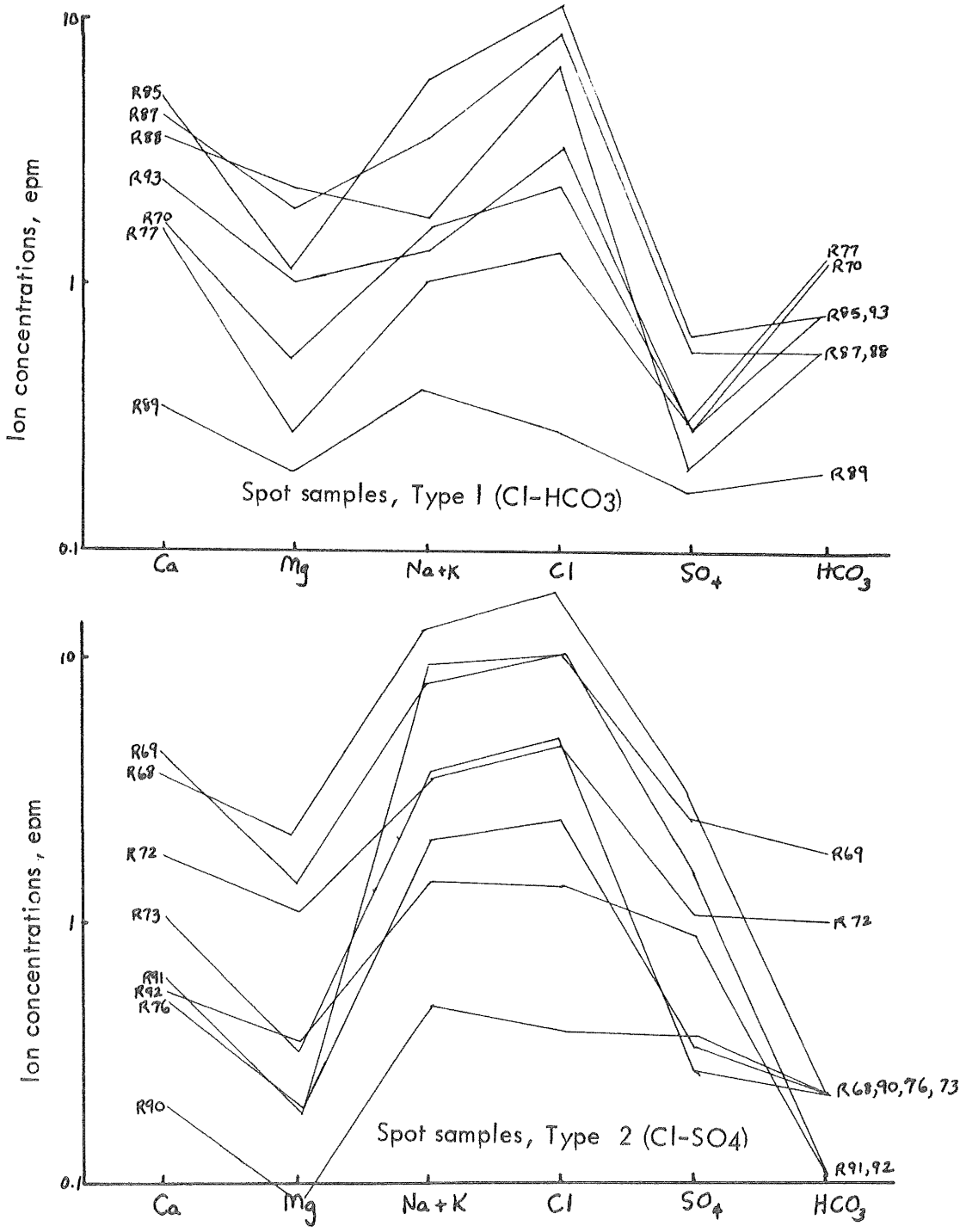


Figure 2. Semilog plots of the composition of spot samples, Birch Cove.

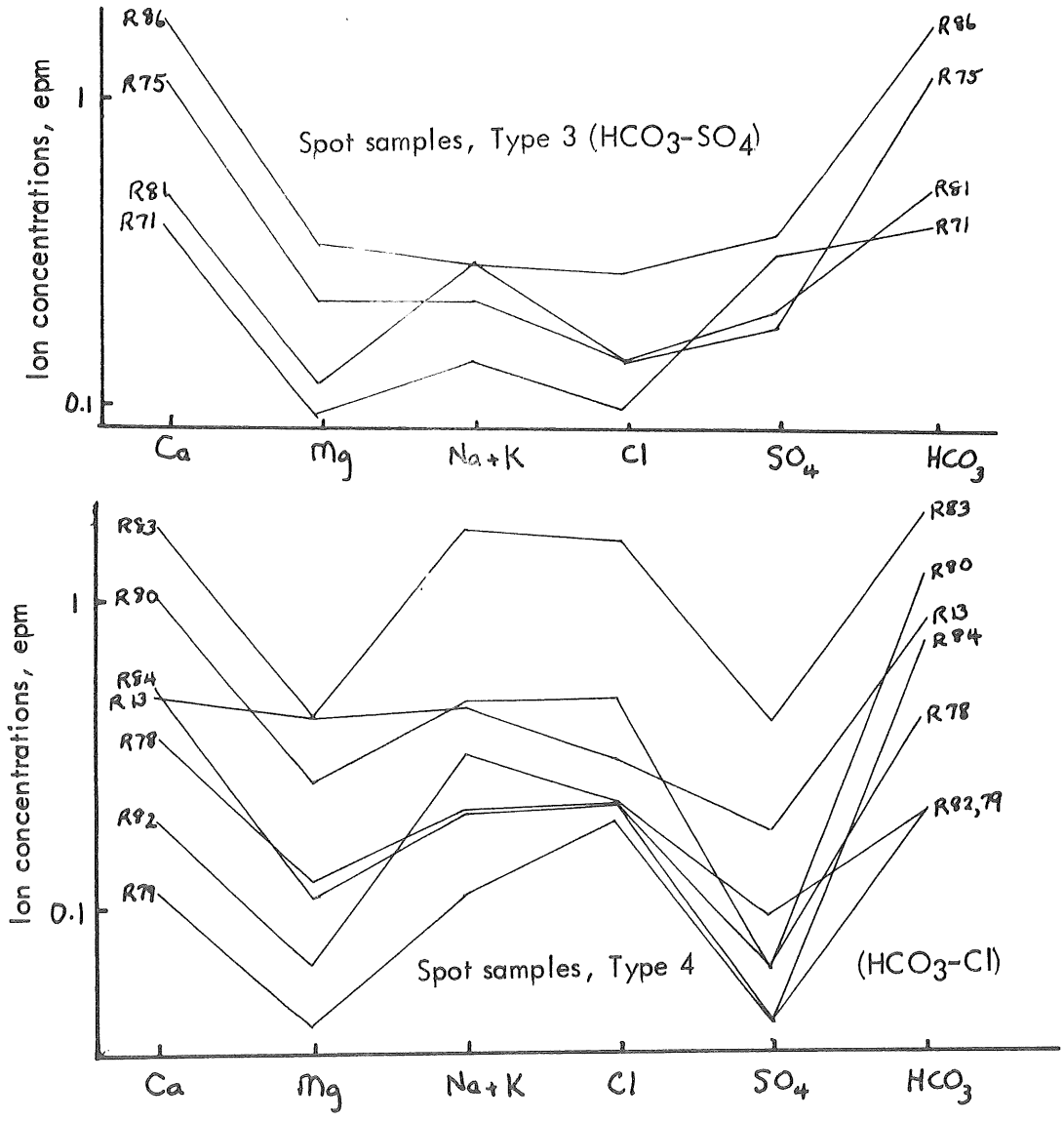


Figure 2 (cont'd). Semilog plots of the composition of spot samples, Birch Cove.

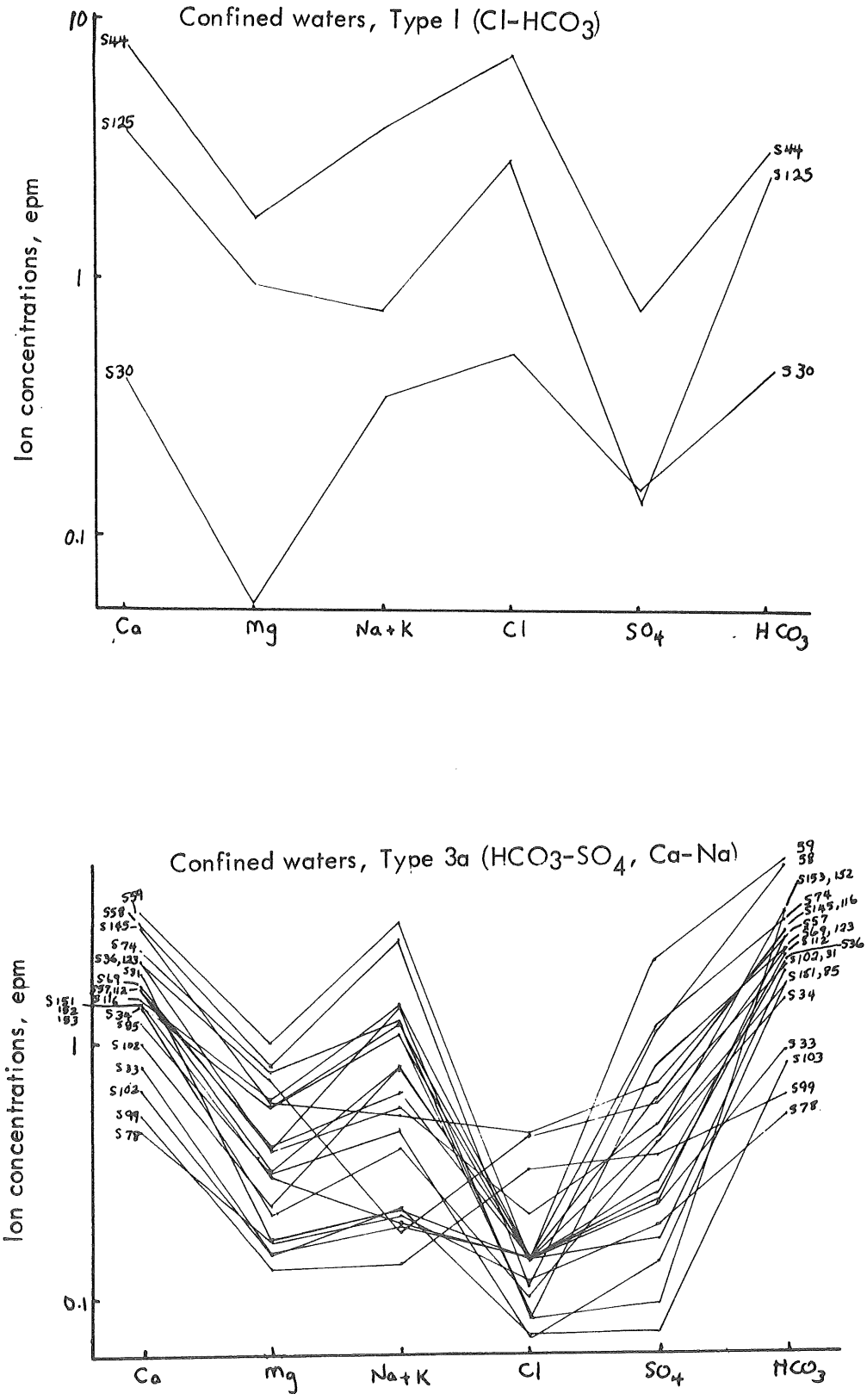


Figure 3. Semilog plots of the composition of confined waters, Sackville.

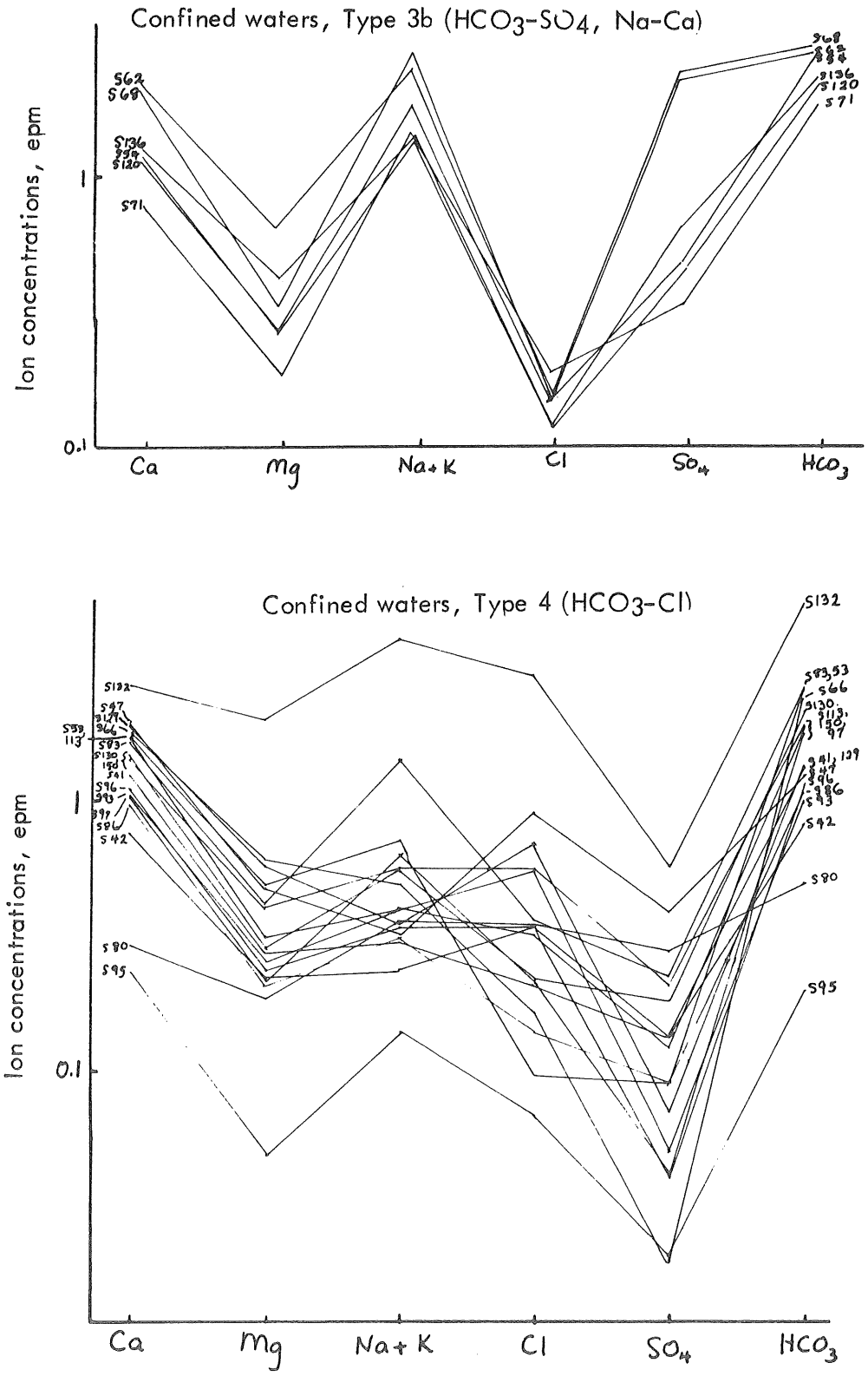


Figure 3 (cont'd). Semilog plots of the composition of confined waters, Sackville.

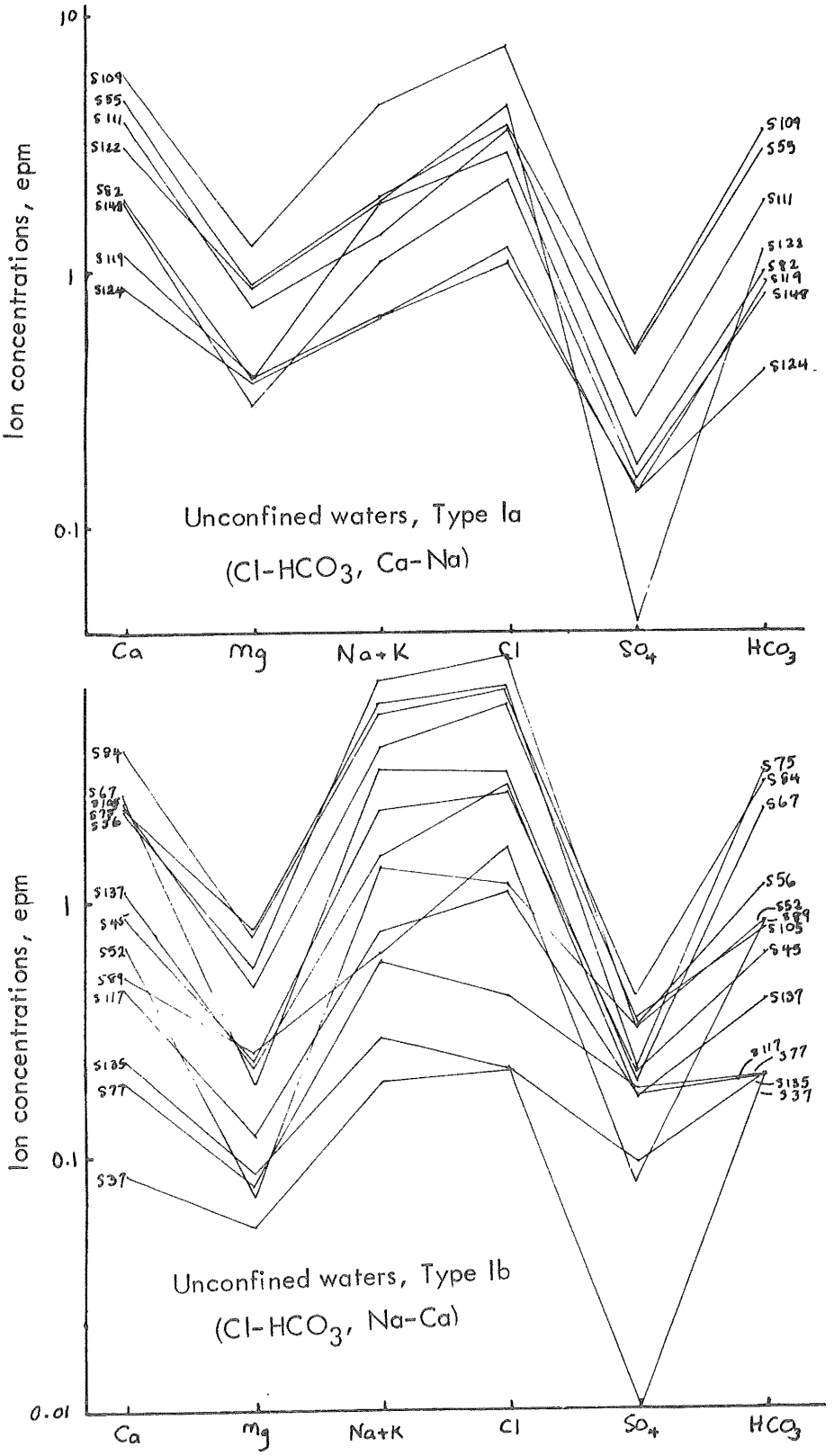


Figure 4. Semilog plots of the composition of unconfined waters, Sackville.

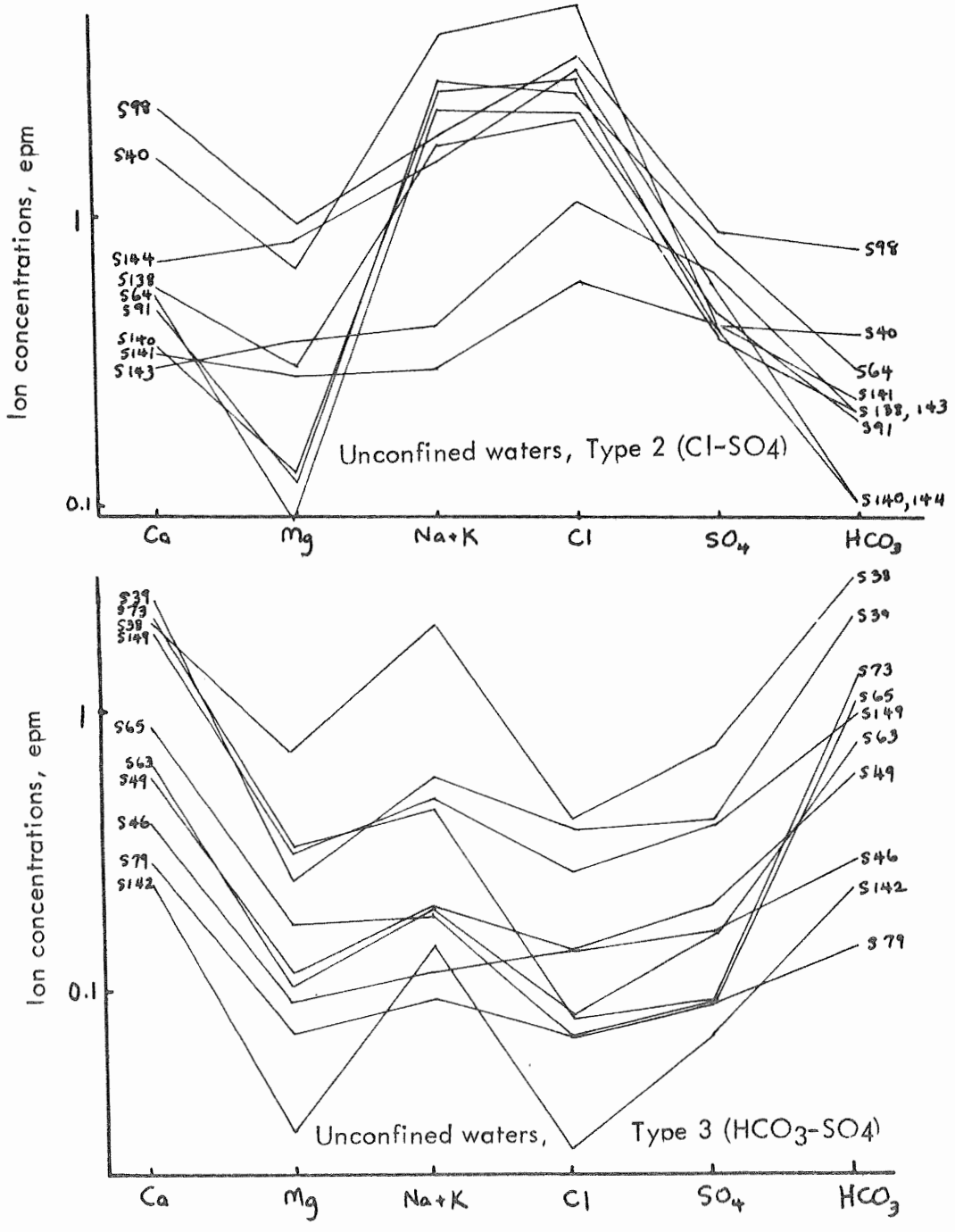


Figure 4 (cont'd). Semilog plots of the composition of unconfined waters, Sackville.

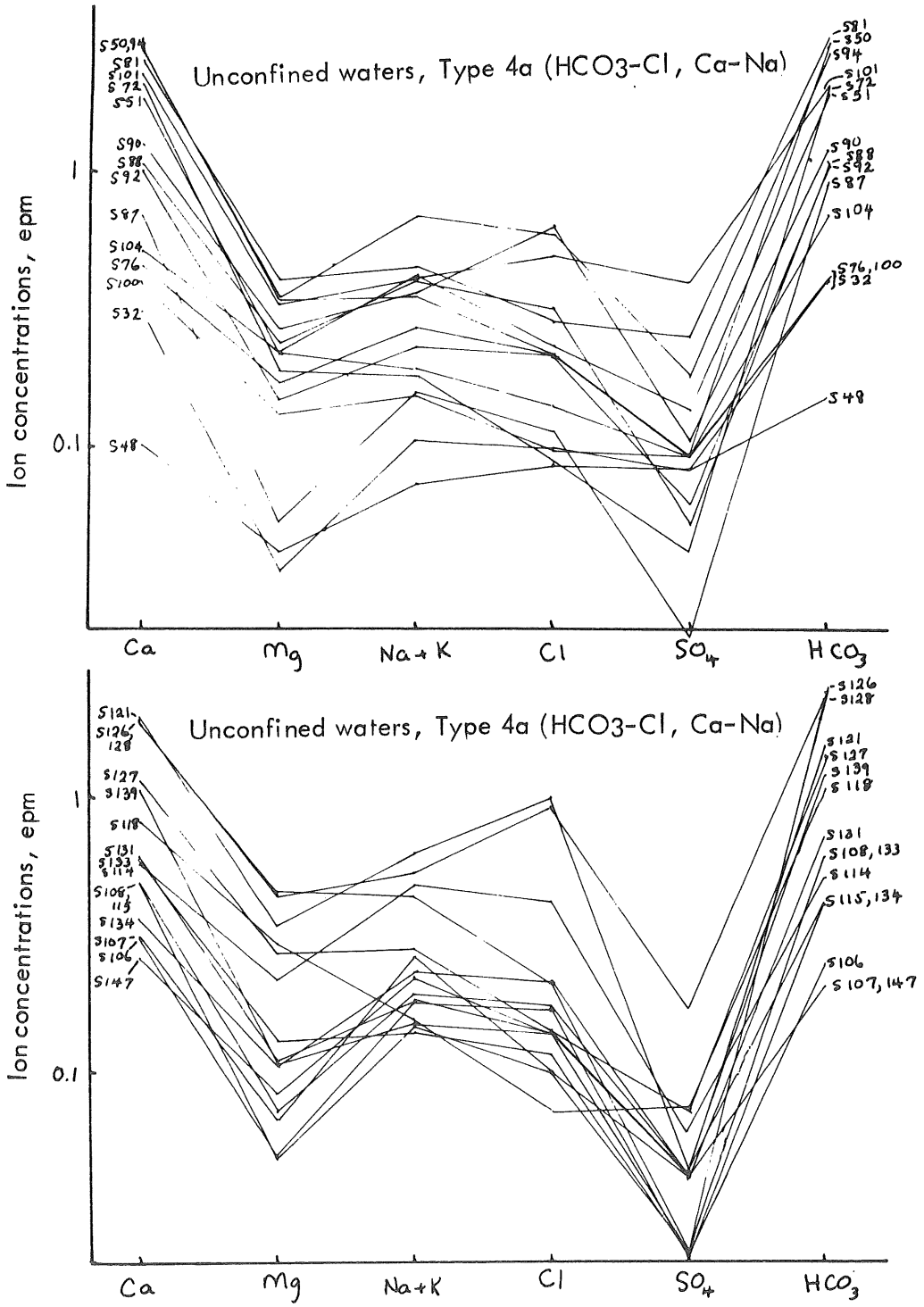


Figure 4 (cont'd). Semilog plots of the composition of unconfined waters, Sackville.

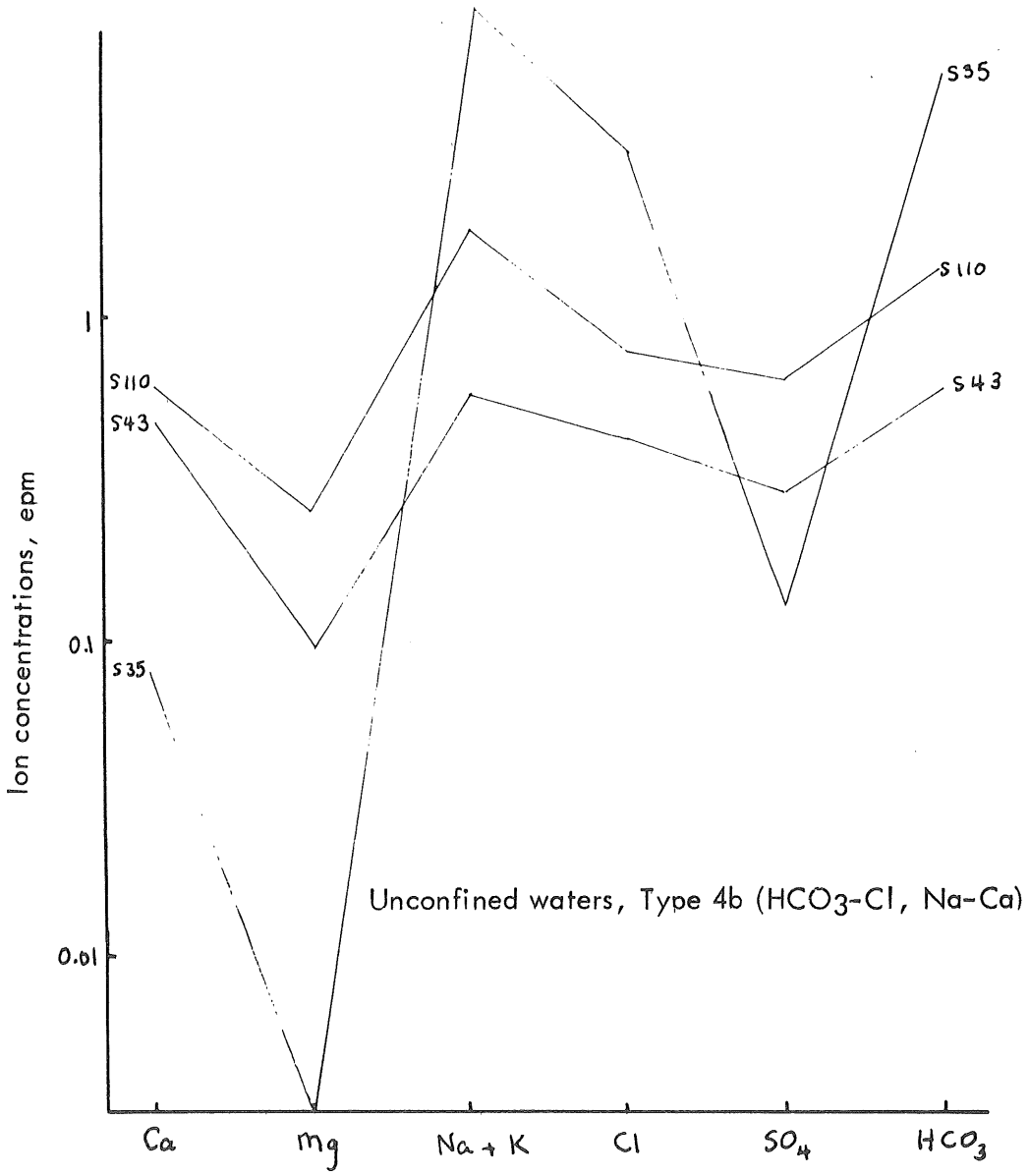


Figure 4 (cont'd). Semilog plots of the composition of unconfined waters, Sackville.

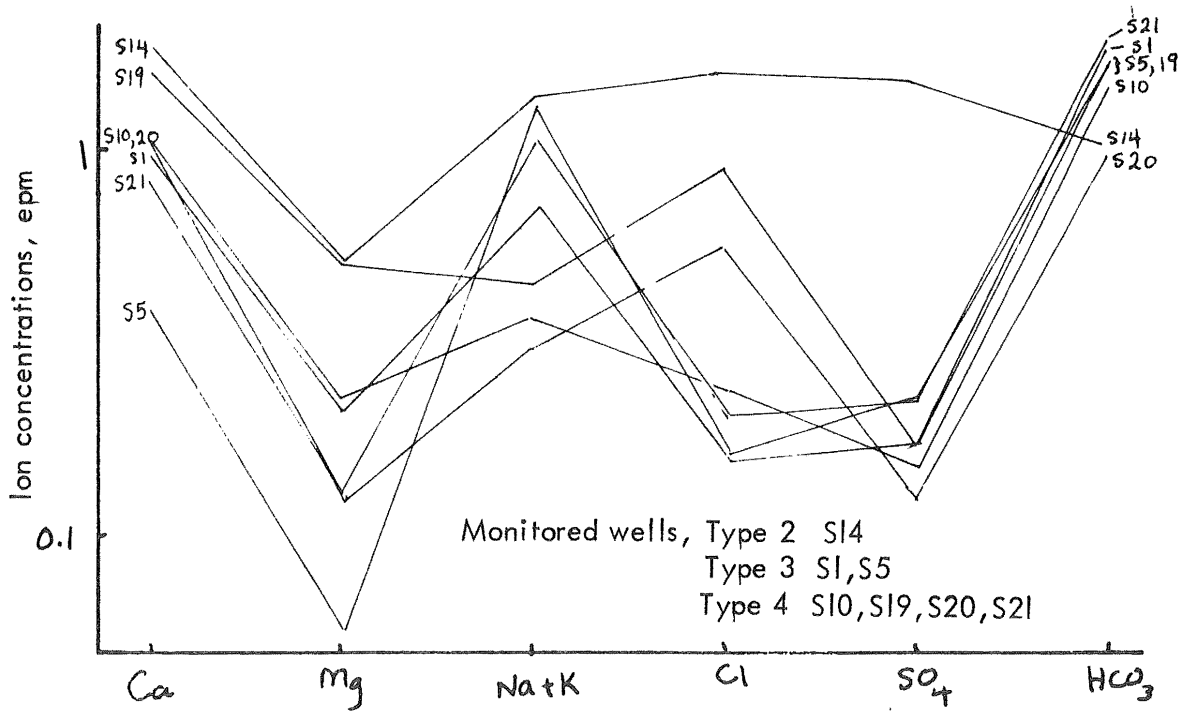


Figure 5. Semilog plot of the composition of monitored wells, Maxwell Subdivision, Upper Sackville.

GEOLOGY

BIRCH COVE

FIGURE 2.1

True North

BEDFORD SYNCLINE

Kearney Lake

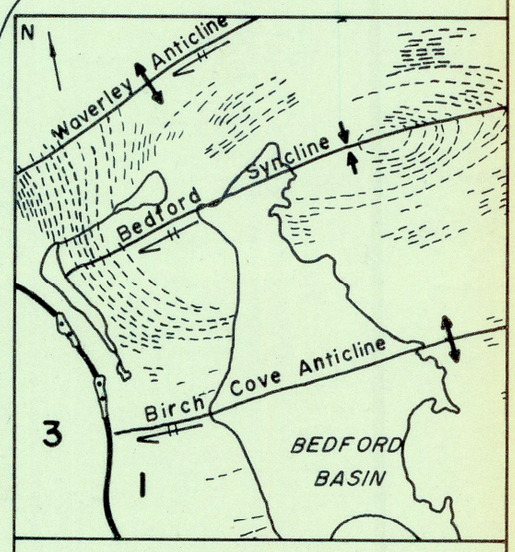
Charlie Lake

Washmill Lake

BIRCH COVE ANTICLINE

1000 0 1000

feet



LEGEND

- x5 Well Yield, gpm
- Geologic Contact
- Lineation (possible shear zone)
- Fold Axis, assumed
- Anticline
- Syncline
- Plunge of Fold
- Outcrop
- 50 Bedding, inclined
- Pond, Swamp
- Pit or Quarry
- Road

TABLE OF FORMATIONS

DEVONIAN

3 Granite

LOWER ORDOVICIAN

1 Goldenville Quartzite

SACKVILLE AREA

GEOLOGY

FIGURE 2.2

2000 0 2000 4000

Feet

SHUBENACADIE LAKE ANTICLINE

DOME ANTICLINE

WAVERLEY ANTICLINE

Beaverbank Road

Square Lake

Hamilton Lake

Tucker Lake

Fenerty Lake

Horse Shoe Lake

Beaverbank Lake

True North

Lake Fletcher

Kinsac Lake

Springfield Lake

Wilson Lake

Barrett Lake

Duck Pond

Feely Lake

Webber Lake

McCabe Lake

Second Lake

First Lake

Third Lake

Rocky Lake

Sackville River

LEGEND

- Monitored Wells
- Drilled Well Samples
- Dug Well Samples
- Spring Samples
- Control Wells
- Major Roads
- 10 Well Yield, gpm
- G Gravel Layer (in drillers log)
- Geologic Contact
- Anticline
- Syncline
- Lineation (from air photos)
- Bedding (inclined, vertical)
- Plunge of Fold

TABLE OF FORMATIONS

DEVONIAN

3 Granite

LOWER ORDOVICIAN

MEGUMA GROUP

2 Halifax Formation (slate)

1 Goldenville Formation (quartzite)

SACKVILLE AREA

SIMPLIFIED BEDROCK SURFACE

FIGURE 2.8

2000 0 2000 4000

Feet

True North

LEGEND

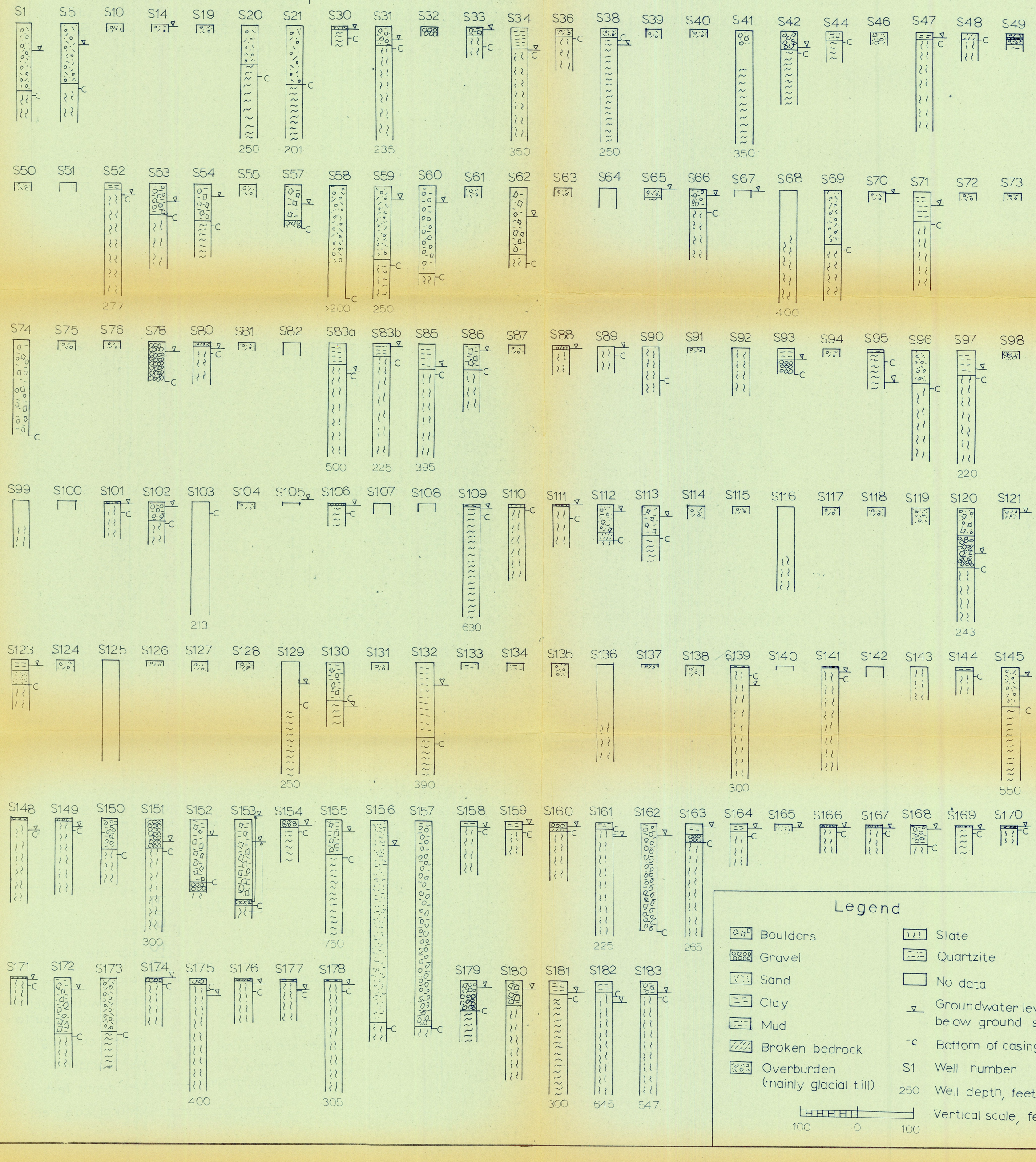
- ▲ Monitored Wells
- ○ Drilled Well Samples
- ○ Dug Well Samples
- ○~ Spring Samples
- ● Control Wells
- —— Major Roads
- —100— Bedrock Surface Elevation, Feet Above Sea Level
- ◎ Well Logs Indicating Gravel

Beaverbank Lake
Square Lake
Hamilton Lake
Tucker Lake
Lake Fletcher
Horse Shoe Lake
Fenerty Lake
Beaverbank Road
Kinsac Lake
Springfield Lake
Barrett Lake
Wilson Lake
Duck Pond
Feely Lake
Third Lake
Second Lake
First Lake
Webber Lake
McCabe Lake
Rocky Lake
Sackville River

WELL LOG DATA, SACKVILLE AREA

FIGURE 2.9

Monitored Wells



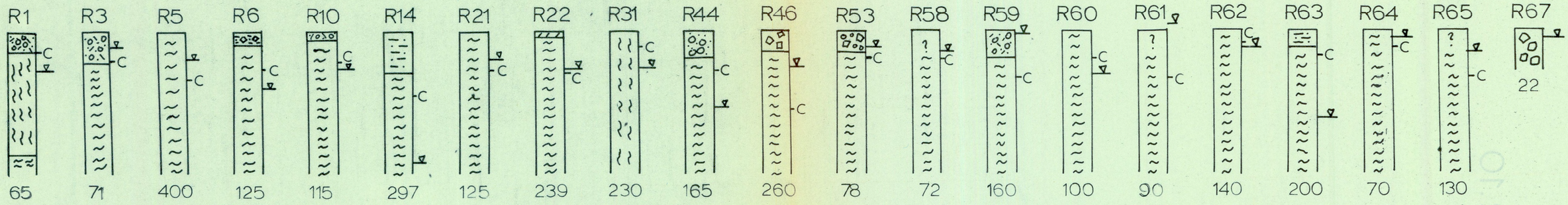
Legend

- Boulders
- Gravel
- Sand
- Clay
- Mud
- Broken bedrock
- Overburden (mainly glacial till)
- Slate
- Quartzite
- No data
- Groundwater level, feet below ground surface
- C — Bottom of casing
- S1 — Well number
- 250 — Well depth, feet
- Vertical scale, feet (100 0 100)

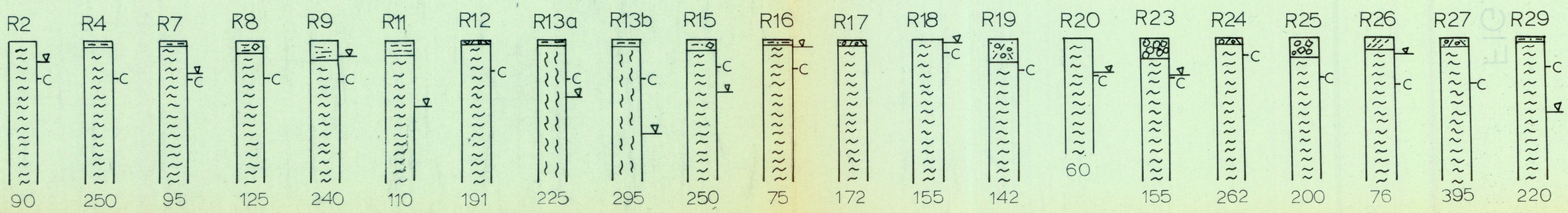
WELL LOG DATA, BIRCH COVE

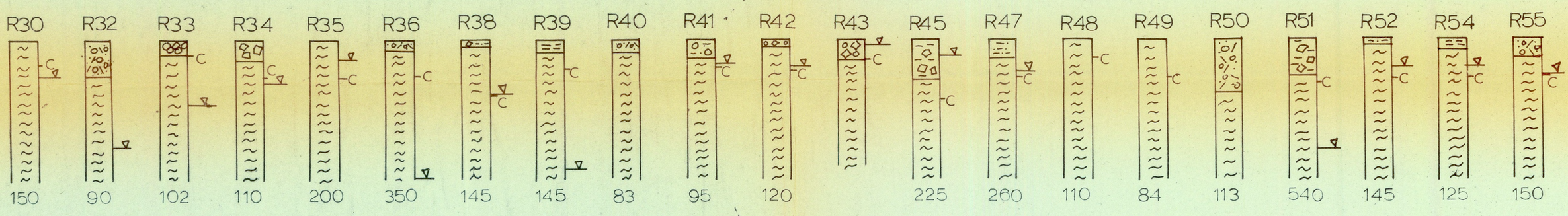
FIGURE 2.10

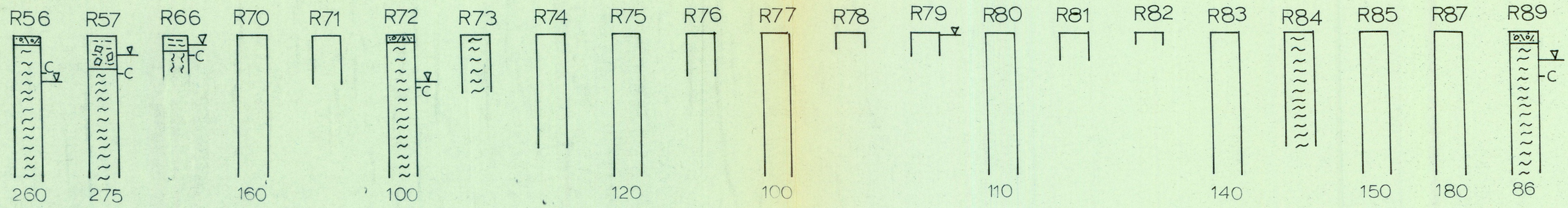
Monitored Wells

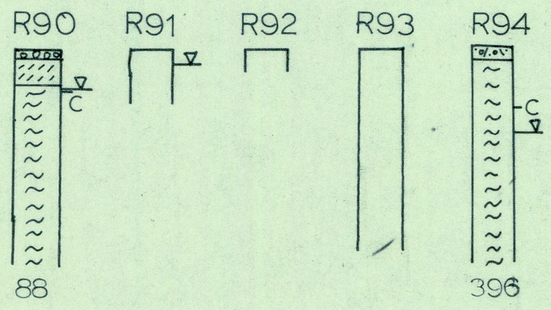


Other Wells









Legend

- Boulders
- Gravel
- Sand
- Clay
- Mud
- Broken bedrock
- Overburden (mainly glacial till)
- Granite
- Slate
- Quartzite
- No data
- Groundwater level, feet below ground surface
- -c Bottom of casing
- R1 Well number
- 70 Well depth, feet
- Vertical scale, feet: 50 0 50

TOPOGRAPHY AND SAMPLE LOCATIONS, BIRCH COVE

FIGURE 5.1

T. N.

KEARNEY L.

WASH-MILL L.

BIRCH COVE

BIRCH COVE HIGH

Gravel Pit

Gravel Pit

Gravel Pit

1A

2A

4A

LEGEND

- Monitored Wells
- Spot Samples
- Pump Test Locations
- Control Wells
- 1A Areas referred to in text
- —100— Topographic elevation, feet above sea level
- Stream
- Road
- Rain Stations

400 0 400 feet

Water Table Elevation and Profiles, Birch Cove

FIGURE 5.2

T. N.

Kearney Lake

BIRCH COVE

BIRCH COVE HIGH

anticline axis

LEGEND

- MONITORED WELLS
- × OTHER CONTROL WELLS
- o THEORETICAL SPRING LOCATIONS
- 100 WATER TABLE ELEVATION, FT. ABOVE SEA LEVEL
- → FLOW PATHS (examples)
- A—B PROFILE LINES

400 0 400 feet

Topographic Profile, Bearing 074°
Horizontal Scale 1:25000 (vert. exagg. ×4)

Blue Mountain Hills — Birch Cove High — Regional Flow — Sea level

LEGEND FOR PROFILES A-B to I-J

- --casing, --open hole } WELL
- R1, etc. WELL NO.
- S.L. SEA LEVEL
- -▽- WATER TABLE
- × ROAD
- \X/ "AVERAGE" JOINT

Horizontal Scale
400 0 400 feet

Vertical Scale
200 0 200 feet

SACKVILLE AREA

TOPOGRAPHY AND SAMPLE LOCATIONS

FIGURE 6.1

2000 0 2000 4000

Feet

LEGEND

- ▲ Monitored Wells
- ○ Drilled Well Samples
- ○ Dug Well Samples
- ○~ Spring Samples
- ● Control Wells
- — Major Roads
- S30, etc. Well No.
- PT Pump Test Site
- —100— Topographic Elevation, Feet Above Sea Level
- Swamp
- Gravel Pit
- △ Rain Station

Beaverbank Lake
Square Lake
Hamilton Lake
Tucker Lake
Fenerty Lake
Horse Shoe Lake
Springfield Lake
Wilson Lake
Barrett Lake
Beaverbank Road
Kinsac Lake
True North
Lake Fletcher
Duck Pond
Feely Lake
Third Lake
Second Lake
First Lake
Rocky Lake
McCabe Lake
Webber Lake
Sackville River

SACKVILLE AREA
PIEZOMETRIC SURFACE

FIGURE 6.3

2000 0 2000 4000
Feet

True North

Beaverbank Lake
Square Lake
Hamilton Lake
Tucker Lake
Horse Shoe Lake
Fenerty Lake
Lake Fletcher
Kinsac Lake
Springfield Lake
Wilson Lake
Barrett Lake
Beaverbank Road
Duck Pond
Feely Lake
Third Lake
Second Lake
First Lake
Webber Lake
McCabe Lake
Rocky Lake
Sackville River

LEGEND

- Monitored Wells
- Drilled Well Samples
- Dug Well Samples
- Spring Samples
- Control Wells
- Major Roads
- —100— Piezometric Elevation, Feet Above Sea Level
- Groundwater Flow
- Surface Water Divide
- Swamp