Geological Survey of Canada

CURRENT RESEARCH
2002-D8

Groundwater resources assessment in the Carboniferous Maritimes Basin: preliminary results of the hydrogeological characterization, New Brunswick, Nova Scotia, and Prince Edward Island

M. Stapinsky, Y. Michaud, R.H. Morin, K E. Butler, C. Deblonde, G. Chi, T. Thériault, S. Castonguay, V. Boisvert, H.P. Julien, D. Conohan, B. Hulsman, C. Carrier, J. Marion, and É. Boisvert

2002

Natural Resources Canada
Ressources naturelles Canada

Canada

Catalogue No. M44-2002/D8E-IN
ISBN 0-662-31678-9

Available in Canada from the
Geological Survey of Canada Bookstore website at:
http://www.nrcan.gc.ca/gsc/bookstore (Toll-free: 1-888-252-4301)

A copy of this publication is also available for reference by depository libraries across Canada through access to the Depository Services Program's website at http://dsp-psd.pwgsc.gc.ca

Price subject to change without notice

Authors' addresses

Y. Michaud *(ymichaud@nrcan.gc.ca)*
C. Deblonde *(chdeblon@nrcan.gc.ca)*
G. Chi *(guchi@nrcan.gc.ca)*
S. Castonguay *(scastong@nrcan.gc.ca)*
H.P. Julien *(hjulien@nrcan.gc.ca)*
J. Marion *(jmarion@nrcan.gc.ca)*
É. Boisvert *(eboisver@nrcan.gc.ca)*
Quebec Geoscience Centre
880, chemin Sainte-Foy
C.P. 7500
Sainte-Foy (Québec) G1V 4C7

M. Stapinsky *(martin.stapinsky@dessausoprin.com)*
Dessau-Soprin Inc.
1441, boul. René-Lévesque Ouest
bureau 500
Montréal, Quebec H3G 1T7

R.H. Morin *(rhmorin@usgs.gov)*
United States Geological Survey
Mail Stop 403
Federal Centre
Denver, Colorado 80225 U.S.A.

K.E. Butler *(kbutler@unb.ca)*
D. Conohan *(f10f@unb.ca)*
B. Hulsman *(m087a@unb.ca)*
University of New Brunswick
PO Box 4400
Fredericton, New Brunswick E3B 5A3

T. Thériault *(ttheriau@nrcan.gc.ca)*
C. Carrier *(cycarrier@nrcan.gc.ca)*
Laval University
Cité Universitaire
Sainte-Foy, Quebec G1K 7P4

V. Boisvert *(vboisver@nrcan.gc.ca)*
INRS-Géoressources, Québec
Quebec Geoscience Centre
880, chemin Sainte-Foy
C.P. 7500, Sainte-Foy (Québec) G1V 4C7

Groundwater resources assessment in the Carboniferous Maritimes Basin: preliminary results of the hydrogeological characterization, New Brunswick, Nova Scotia, and Prince Edward Island[1]

M. Stapinsky, Y. Michaud, R.H. Morin, K E. Butler, C. Deblonde, G. Chi, T. Thériault, S. Castonguay, V. Boisvert, H.P. Julien, D. Conohan, B. Hulsman, C. Carrier, J. Marion, and É. Boisvert

GSC Quebec, Quebec

Stapinsky, M., Michaud, Y., Morin, R.H., Butler, K.E., Deblonde, C., Chi, G., Thériault, T., Castonguay, S., Boisvert, V. , Julien, H.P., Conohan, D., Hulsman, B., Carrier, C., Marion, J., and Boisvert, É., 2002: Groundwater resources assessment in the Carboniferous Maritimes Basin: preliminary results of the hydrogeological characterization, New Brunswick, Nova Scotia, and Prince Edward Island; Geological Survey of Canada, Current Research 2002-D8, 12 p.

Abstract: The study area is located in the Carboniferous Maritimes Basin, which consists of sedimentary rock sequences covering parts of New Brunswick, Nova Scotia, and Prince Edward Island. Extensive fieldwork was carried out during the summer of 2001 to initiate the characterization of the main aquifers in the basin, including: a regional water-level survey; hydraulic testing; drift, rock, and groundwater sampling; installation of shallow monitoring wells; and surface and borehole geophysical surveys. A preliminary assessment of the groundwater resources in the basin is underway based upon existing information and new fieldwork results. More specifically, a piezometric map displaying regional groundwater flowlines has been prepared along with a series of assessments regarding the geological context and the hydraulic properties of distinct rock units and surficial deposits.

Résumé : Le secteur d'étude est situé dans le Bassin des Maritimes du Carbonifère, lequel est constitué de formations sédimentaires variées et comporte à une partie du Nouveau-Brunswick, de la Nouvelle-Écosse et de l'Île-du-Prince-Édouard. Les travaux sur le terrain réalisés à l'été 2001 comprennent un levé piézométrique régional, des essais hydrauliques, l'échantillonnage des formations superficielles, des unités rocheuses et de l'eau souterraine, l'installation de puits d'observation, ainsi que des levés géophysiques en surface et en forage. Une évaluation préliminaire des ressources en eau souterraine est en cours d'élaboration et s'appuie sur les données déjà disponibles et sur les résultats de nouveaux travaux sur le terrain. Plus spécifiquement, une carte des directions d'écoulement de l'eau souterraine a pu être préparée et on a procédé à une évaluation du contexte géologique et des propriétés hydrauliques de différentes formations rocheuses et superficielles.

[1] Contribution to the Maritimes Groundwater Initiative

INTRODUCTION

Groundwater is a source of water supply for more than 60% of the population in New Brunswick, 50% in Nova Scotia, 29% in Newfoundland, and the entire population of Prince Edward Island. The bulk of this groundwater comes from aquifers within sedimentary rocks of the Carboniferous Maritimes Basin and its surficial sediment cover. This aquifer system thus represents one of the main hydrogeological regions of Canada. The Maritimes Groundwater Initiative is a multidisciplinary and multi-agency research project initiated by the Geological Survey of Canada and designed to improve our general understanding of groundwater flow dynamics within the major aquifers in the Carboniferous Maritimes Basin. This project will provide the baseline information necessary for a detailed assessment of regional groundwater resources in the Maritimes, thereby allowing groundwater management and protection to be efficiently integrated into the land-use planning process. The goals of the project include building a conceptual hydrogeological model of the Carboniferous Maritimes Basin based on detailed mapping in the study area and providing a series of assessments on groundwater quantity, quality, and vulnerability both to contamination and to climate change. This information will serve as a valuable basis for regional groundwater management.

STUDY AREA AND CLIMATE

The Carboniferous basin is located in what is referred to as the Maritimes Basin, which contains Middle Devonian to Early Permian consolidated sediments. It covers the eastern part of New Brunswick, the entirety of Prince Edward Island, the northeastern part of Nova Scotia, and small parts of Newfoundland and Quebec. The region specifically under study (Fig. 1) centres mostly on the Moncton sub-basin, and covers an area of about 27 000 km^2, of which 15 000 km^2 consist of Carboniferous rocks.

The climate of the Maritimes is described as humid-continental with long and cold winters and warm summers (Brown, 1967). Daily average air temperature varies in the summer between 17°C and 24°C; and during the winter between –12°C to –4°C. Average precipitation is in the range of 1000–1600 mm/year. Figure 2 presents, as an example, yearly average rainfall and air temperature recorded at the Moncton meteorological station (Environment Canada, unpub. data, 2001).

WORK PERFORMED

A detailed review of all available data was completed during the first stage of the project. Data were first compiled then integrated into a unique database through a geoscientific information management system (GIMS) and a geographic information system. Data were gleaned primarily from governmental reports, provincial water well and water chemistry databases, consultants' reports, and scientific papers. The project also included the implementation of a website and the publication of a descriptive flyer.

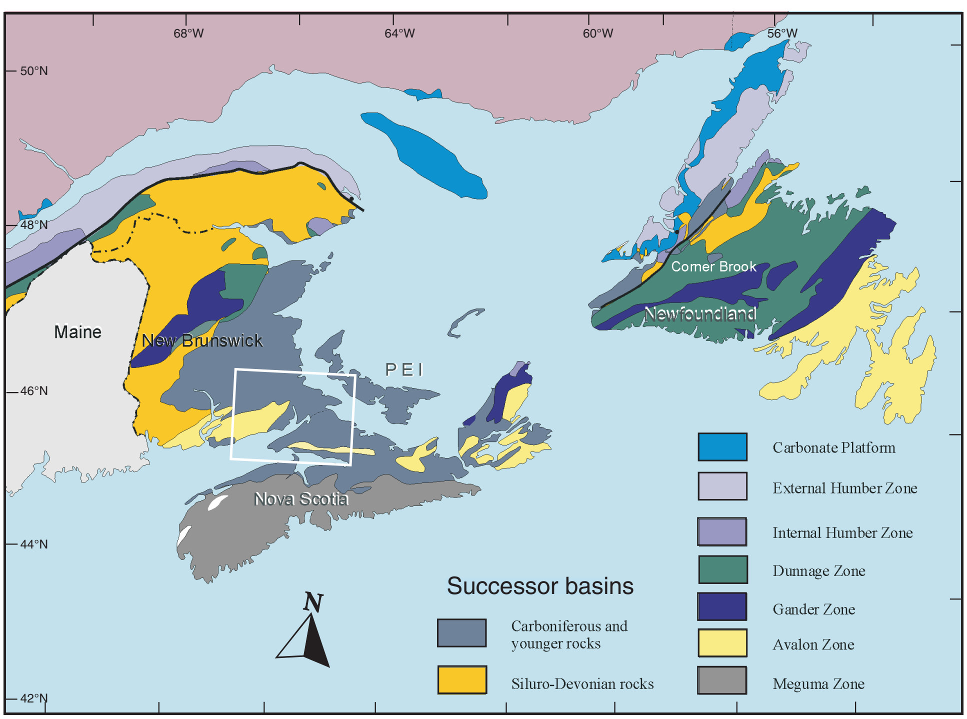

Figure 1. *Location of the study area.*

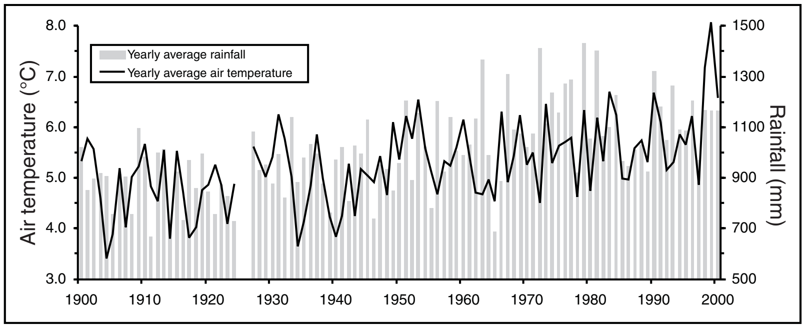

Figure 2.

Yearly average rainfall and air temperature, Moncton Meteorological Station (1900–2000).

An intensive field program was carried out during the summer of 2001 to gather additional hydrogeological information. Topics covered consisted of geological investigations of both sedimentary rocks and surficial deposits; water-level measurements in over 200 wells; short-duration pumping tests in four wells; packer tests in six wells; borehole geophysical logging in five wells; surface geophysical surveys; groundwater sampling of 20 wells for chemical analysis; and a thorough investigation of the hydrogeology of a peatland.

This paper summarizes the results obtained from the hydrogeological characterization of the main aquifers in the Carboniferous Maritimes Basin. Results on the definition of the geological setting, the first assessment of the hydraulic properties of the aquifer formations, and a preliminary piezometric map are presented in this paper.

GEOLOGICAL AND HYDROGEOLOGICAL SETTINGS

Geology

The Maritimes Basin is a composite successor basin, postdating the Acadian Orogeny, consisting of a series of sedimentary sub-basins, which unconformably overlies a complex collage of Appalachian tectonostratigraphic terranes (*see* van de Pool et al. (1995), for a synthesis). The sub-basins are oriented in a general northeast to east trend and are separated by basement uplifts along large regional faults. The central part of the basin, often termed as the 'Maritimes Rift', features a thick sequence (locally up to 12 000 m deep) of Late Paleozoic sedimentary rocks that were periodically deformed and reworked, resulting in a complex temporal and spatial pattern of erosion and deposition. These rocks are overlain by a relatively thin cover of unconsolidated Quaternary glacial deposits (Rampton et al., 1984). The study area covers the Moncton, Sackville, and Cumberland sub-basins, and a part of Prince Edward Island (Fig. 3).

A typical stratigraphic cross-section is composed of the following main geological units (from base to top; Fig. 3): the Horton, Windsor, Canso-Riversdale (Mabou in Nova Scotia), Cumberland, Pictou, and Prince Edward Island groups. Internal stratigraphy of these units is complex and often laterally discontinuous, as the result of different sedimentation rates, synsedimentary faulting, and sedimentary reworking.

Hydrostratigraphy

A preliminary hydrostratigraphic classification of the geological units has been proposed by Brown (1967). The rocks in the Maritimes Basin are first divided into three groups according to their hydrogeological properties: the basement complex, which consists of low-permeability rocks ranging from Precambrian to Devonian; the Carboniferous and Triassic rock formations, in which groundwater flows predominantly through fractures and to a lesser extent through the porous matrix; and surficial deposits consisting of sand and gravel, which also provide a large quantity of groundwater, but are restricted to narrow zones near major streams and to glaciofluvial complexes.

The hydrogeological properties corresponding to these hydrostratigraphic units are quite variable. This results from the large lithological variability (conglomerate, sandstone, siltstone, mudstone) within the different geological formations. Therefore, some geological units can act as aquifers, whereas others behave more like aquitards. Lateral extents and thickness of aquifer and aquitard units within the geological formations are not well known and this will be addressed later in the project with a detailed analysis of the hydraulic properties associated with the main geological formations.

Groundwater quality

Groundwater is generally of good quality. Two natural causes that may alter the water quality are: 1) high iron, manganese, and sulphate content derived from pyrite in certain rocks, primarily observed in the northern part of the study area; and 2) high calcium sulphate and sodium chloride content derived from evaporitic rocks in the southwest part of the area (Brown, 1967). D.R. Boyle (poster presentation, New Brunswick Department of Natural Resources Annual Review, November 4–5, 1991) reported that groundwater in various parts of the basin often contains very high concentrations of F, U, Rn, Na, SO_4, Ba, Fe, Mn, and As. Some of these elements are of great concern for health safety. In some areas where the water presents concentrations above guidelines for drinking water (iron, manganese, hydrogen sulfide gas), the water remains within effective treatment limits.

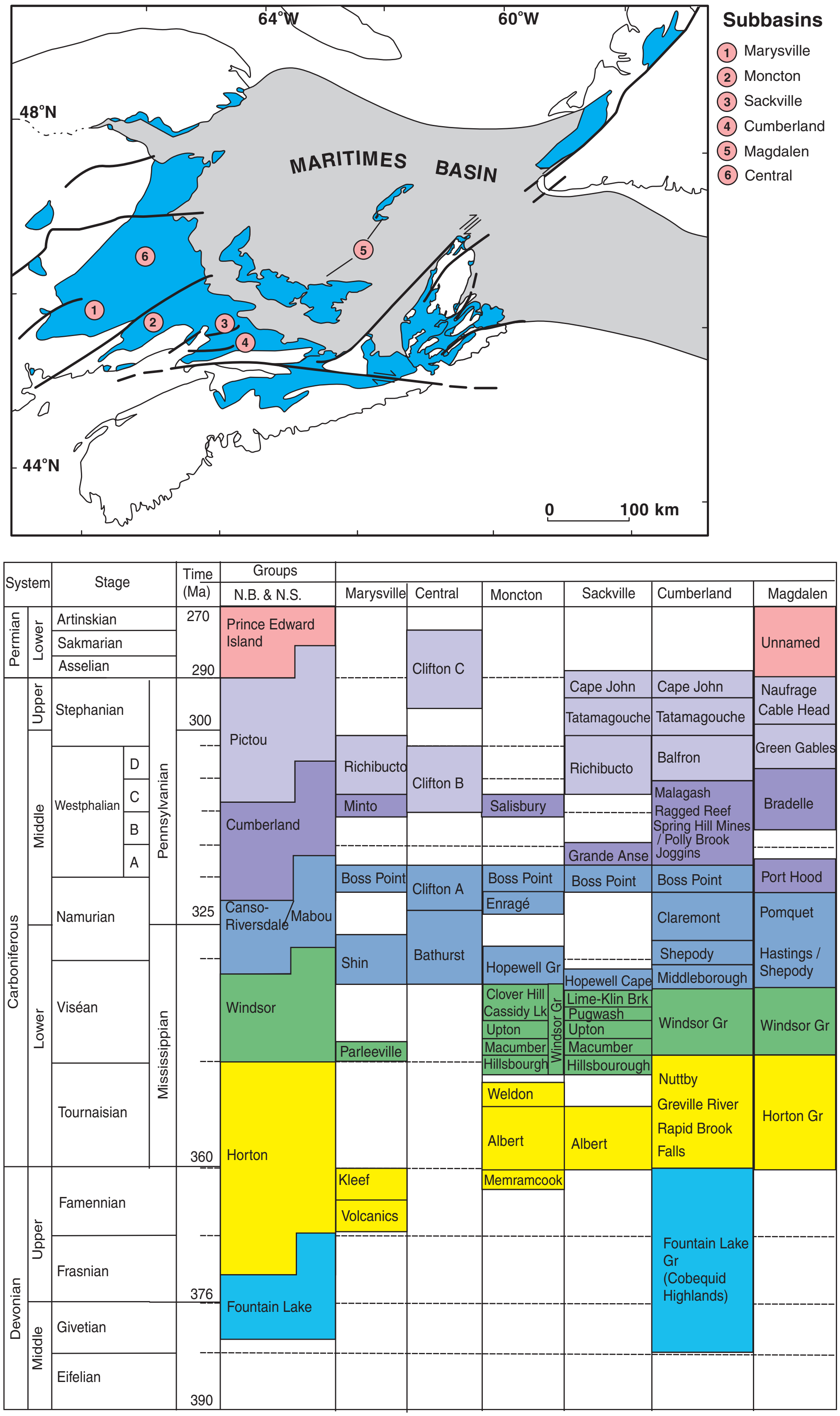

Figure 3. *Location of sub-basins within the study area and their preliminary stratigraphic interpretation.*

Major aquifers

A preliminary review of the data indicates that groundwater in the Carboniferous Maritimes Basin is available for water supply in high abundance from several rock formations in both sedimentary rock units and in unconsolidated sediments. Five geological formations of interest have been deemed major aquifers in the Carboniferous Maritimes Basin. These hydrostratigraphic units are located in southeastern New Brunswick, northeastern Nova Scotia, and in Prince Edward Island and are described hereafter.

Surficial deposits

Sandy and gravelly unconsolidated sediments are known to be excellent granular aquifers with hydraulic conductivities in the order of 1 x 10^{-4} m/s. These deposits can often be found in relatively thick bodies of glaciofluvial sediments, marine deltas and beaches, and alluvial plains. In areas where sediments were deposited near streams, high well yields result from induced infiltration from streambeds.

The cases of Sussex, Sussex Corner, and Fredericton (New Brunswick) exemplify the large aquifer potential of glaciofluvial sediments. Individual wells can yield as much as 4600 m^3/day (1 million Imperial gallons per day (Igpd)).

Naufrage Formation

The Naufrage Formation is one of the (redbed) sandstones included in the Pictou Group that are widespread in eastern Prince Edward Island. These rocks are composed of variable proportions of sandstone, siltstone, breccia, and conglomerate. Near the surface, the Naufrage Formation sandstone features vertical joints and subhorizontal bedding planes typically associated with fractured-rock aquifers; however, some intergranular permeability has also been noted in these rocks.

The two well fields supplying the city of Charlottetown, Prince Edward Island, are pumping groundwater from the Naufrage Formation: the Union well field has a total withdrawal rate of about 6400 m^3/day (1.4 million Igpd) and the Brackley well field about 12 300 m^3/day (2.7 million Igpd). These well fields are located slightly to the east of the study area, but intercept similar geological formations.

Richibucto Formation

The Richibucto Formation covers a large portion of the study area located to the north and east of Moncton, New Brunswick. It is comprised of grey to maroon-grey, medium- to very coarse-grained sandstone with narrow (<100 cm) lenticular interbeds, and thick, red-brown channel lag conglomerate. The rocks are not well consolidated. It is thought that bedding heterogeneity and sandstone porosity are responsible for the high water-bearing capacity of the beds. Secondary joints and fractures may also contribute to the high permeability of the sandstone aquifers. The quality of the water is generally good, except for high content of manganese in some areas. Also, some high-capacity wells located near the coast show evidence of seawater intrusion.

The Richibucto Formation is highly exploited for water-supply in the Moncton region. Six of the most productive wells in this aquifer have a combined pumping capacity greater than 9000 m^3/day (2 million Igpd) (C. St. Peter, unpub. report, 2000). The municipal wells of the town of Shediac, New Brunswick, have an average capacity of 1160 m^3/day (0.25 million Igpd). Other towns (Port Elgin and Sackville, New Brunswick; Amherst and Oxford, Nova Scotia) in the area have also high-yield wells tapping the Richibucto Formation.

Boss Point Formation

The Boss Point Formation is an important aquifer within the Moncton Basin. It is comprised of conglomerate units exhibiting fairly high porosity and permeability. The beds have widely spaced, steeply dipping joints that in all likelihood contribute to the formation permeability.

Groundwater in a well located in Hillsborough, New Brunswick, is derived from interbedded grey and brown conglomerate and sandstone units of the Upper Carboniferous Boss Point Formation. The well is pumping about 1310 m^3/day (0.29 million Igpd). The average pumping rates for wells in the Boss Point Formation in Nova Scotia is about 498 m^3/day (0.1 million Igpd).

Hillsborough Formation

Exposure of the Hillsborough Formation is restricted to small areas located to the south of Moncton and near Sussex Corner. The formation is comprised mostly of red-brown polymictic granule to cobble conglomerate in beds more than 1 m thick. The conglomerate is poorly sorted and clast supported and has a slightly muddy sand to granular matrix. This matrix appears to be quite ‘tight’, suggesting that fractures rather than primary matrix porosity are controlling the flow of water through these beds.

The towns of Sussex Corner and Hillsborough are supplied by groundwater from this unit. Pumping rates on the order of 655 m^3/day (0.14 million Igpd) are common for some of the wells penetrating this aquifer (Maritime Groundwater Inc., unpub. report, 1989).

Hydraulic properties of the rock formations

Existing data

A thorough review of available relevant reports and studies was performed in order to develop a preliminary understanding of the hydrogeological setting and obtain first estimates of hydraulic properties of the geological formations. These data consisted primarily of thematic maps; meteorological and hydrological data; water-well and water-chemistry databases (three databases with more than 15 000 entries each); pumping test results reported in consultant and government reports and studies; and scientific papers. The results of more than 30 pumping tests were also re-examined as well as the water-well databases in order to locate areas of specific interest for more detailed studies and to provide expected yield ranges for wells in each formation. The major sources were found in the provincial New Brunswick, Prince Edward Island, Nova Scotia, and the federal Geological Survey of Canada files and archives. First, data were subject to a strict screening and quality control. This information was used to assist in the planning and execution of the fieldwork in order to fill the gaps in the existing knowledge.

Fieldwork

Short-duration pumping tests, packer tests, and downhole geophysical logs were performed during the field campaign. Geophysical logging operations consisted of obtaining caliper, natural gamma ray, temperature, electrical resistivity, acoustic televiewer, and flowmeter logs under ambient as well as pumping conditions. Logging results proved to be indispensable for the successful implementation of packer tests by providing information regarding borehole geometry and fracture frequency and permeability. Surface seismic surveys were also carried out with an objective, i.e. in this first field season, to identify sites where seismic reflection profiling of stratigraphy in the upper 100 m could contribute to the understanding of Quaternary and bedrock geology and hydrogeology. All these tests were performed in several geological formations representative of the major aquifers in the study area.

Pumping tests

Hydraulic properties of geological formations are estimated through the completion of hydraulic tests. In particular, transmissivity is a critical parameter in hydrogeological investigations because it provides a quantitative estimate of groundwater availability. Transmissivity is best calculated from observed water-level drawdown and/or recovery during the pumping test. These tests are fairly expensive and relatively few have been reported for the study area.

Short-term (8 hour) pumping tests were performed in this study in order to estimate the transmissivity. The interpretation of the tests was done using the Cooper-Jacob approximation for drawdown and recovery for water levels recorded in the pumping well. Figure 4 shows an example of pumping test interpretation for a well located in Harcourt, New Brunswick.

Borehole geophysical logging

When applying geophysical logging to the characterization of aquifer properties, the general approach consists in obtaining three primary categories of logs: 1) logs that yield information on grain size, mineralogy, and depositional processes, such as natural gamma-ray and electrical resistivity logs, allowing us to determine rock type and construct lithological columns; 2) logs that yield information regarding the properties of the borehole fluid, such as temperature, specific conductance, and velocity, allowing us to identify the zones of particular importance in controlling groundwater flow patterns; and 3) logs that provide magnetically oriented images

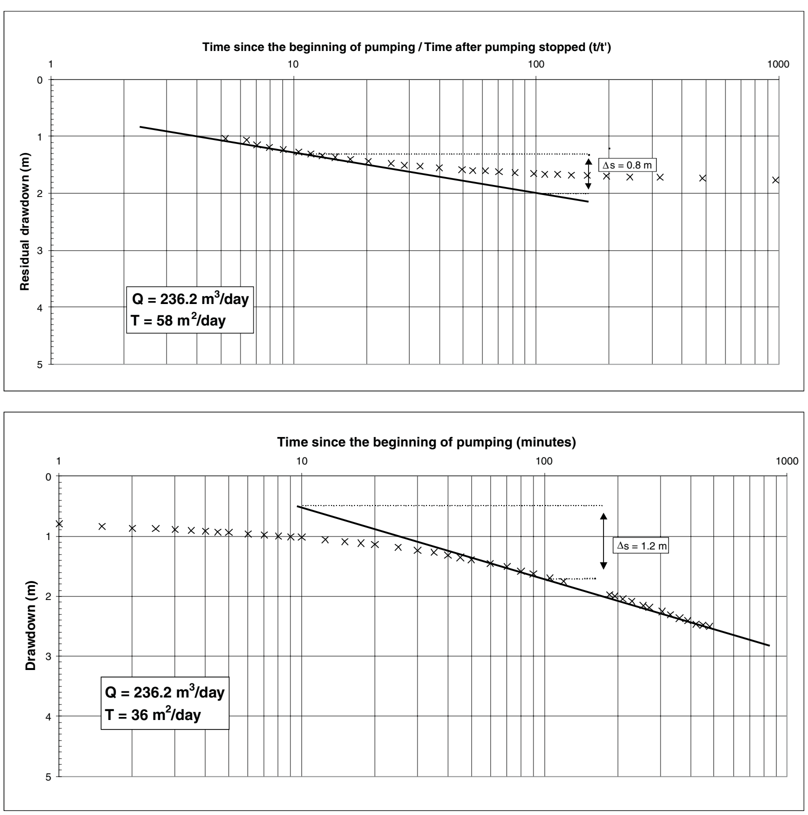

Figure 4.

Example of pumping test interpretation in a well near Harcourt, New Brunswick.

of the borehole wall from which structural features such as fractures and bedding planes can be identified. By systematically combining all of these data into a broad interpretative scheme, the structural features that control flow can be distinguished from the general population of features intersected by the well. From trends in the orientation, distribution, and frequency of these features, a conceptual understanding of the groundwater system can be developed. Figure 5A presents several geophysical logs obtained in a well in Harcourt indicating water-bearing fractures.

The zones of interest for detailed packer test analysis were selected according to geophysical profiles obtained from borehole and flow logging done by the United States Geological Survey. These profiles accurately identified the distinct lithologies and water-bearing zones in the wells that could be isolated with the packers.

Packer tests

An efficient method to determine the vertical distribution of the transmissivity is the constant-head injection test using straddled packers. The method consists in injecting water at a constant flow rate (constant pressure) in an interval of rock isolated with two packers. The equipment can be used in various well diameters and allows measurements of permeability over several orders of magnitude, which is essential to calculate matrix or fracture hydraulic properties at various scales. The transmissivity of the tested zone can be obtained by using a simple equation (Thiem Equation) assuming steady-state flow conditions.

Six wells in the study area were selected to evaluate the hydraulic properties of distinct lithologies of the major aquifers within the Carboniferous Maritimes Basin. A total of 40 intervals in the wells were examined by constant-head injection tests. Three of these wells (Port Elgin and Shediac, New Brunswick; Fort Lawrence, Nova Scotia) intercept the Richibucto Formation, which primarily consists of sequences of shale, conglomerate, and sandstone. Another well tested intersects the Salisbury Formation (Petitcodiac, New Brunswick). The well tested in Harcourt is located in undifferentiated rocks of the Pictou unit. The well tested in Borden, Prince Edward Island is located in the Kildare Capes Formation. The length of the interval was 2–3 m and the number of sections per well

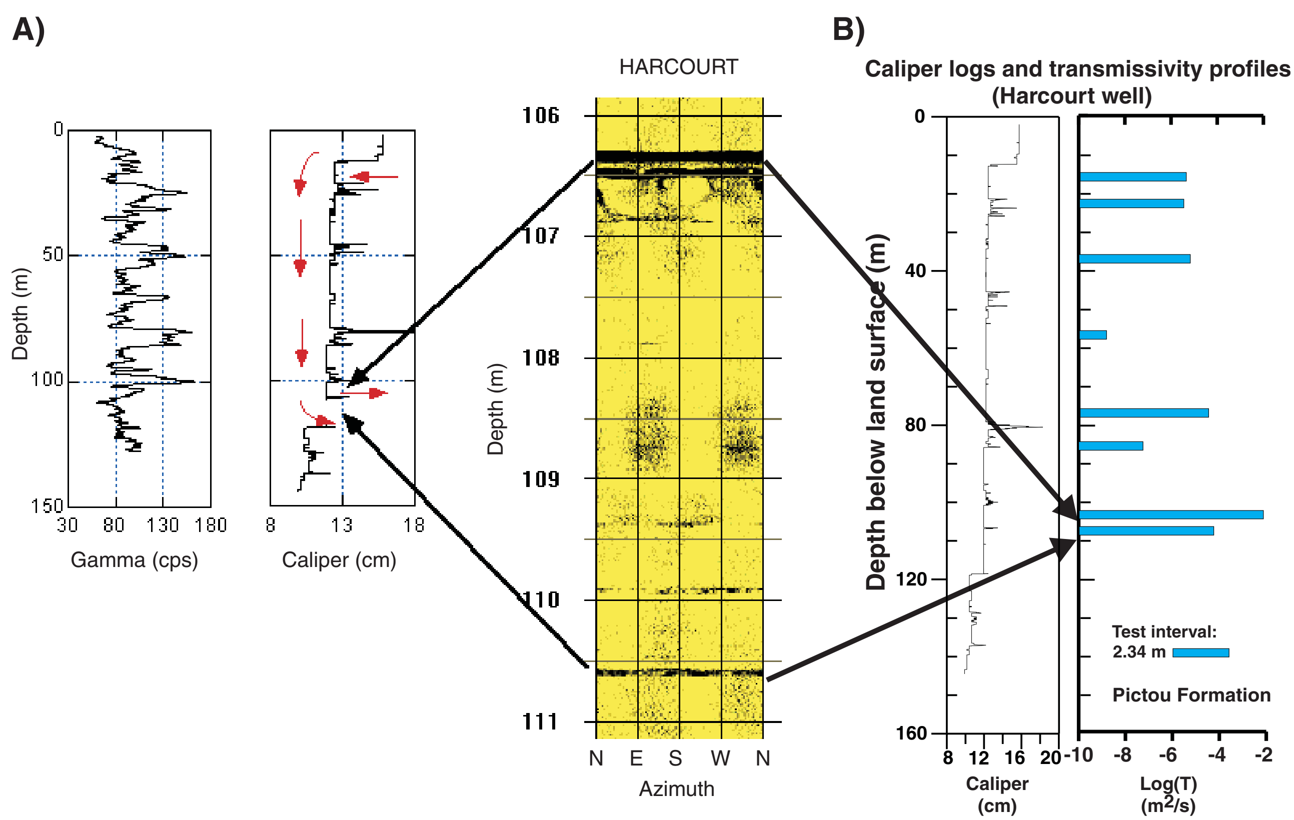

__Figure 5.__ Combined geophysical logs and packer tests results in a well near Harcourt, New Brunswick. __A)__ Example of borehole geophysical logging (gamma ray, caliper, and televiewer). Notice the groundwater flow arrows superimposed on the caliper log (courtesy of United States Geological Survey). __B)__ Comparison between a caliper log and the results of packer testing in a well near Harcourt, New Brunswick. The major water-bearing structures identified in the geophysical logs have also exhibited a high transmissivity.

depended on the total depth of the well. Thus, each distinct rock type in a well had at least one section isolated and tested to obtain a representative value of transmissivity.

The zones of higher transmissivity (>1 m^2/d) represent rocks dominated by fracture flow, whereas the zones of low transmissivity (<1 x 10^{-2} m^2/d) indicate the presence of few fractures. For instance, a zone of high transmissivity (approximate depth 107 m) identified from the results of geophysical logging in the well in Harcourt (Fig. 5A), was also presenting a high transmissivity from the results of the packer tests (Fig. 5B).

Seismic surveys

Surface seismic surveys were carried out under the direction of geophysicists from the University of New Brunswick. Walkaway noise tests and refraction profiles were completed at four sites prioritized for investigation and a 18-fold common mid-point shallow seismic profile, approximately 1 km in length, was acquired in the Riverview area (New Brunswick). This line, extending through the marshlands across a portion of the Petitcodiac River valley directly opposite downtown Moncton, was acquired in order to support the study of the glacial and/or Quaternary history in the area. The seismic source was a 'buffalo gun' firing 12-gauge blank shotgun shells in 2" (5 cm) diameter holes drilled to a depth of 1 m using a portable power auger.

Processing of the Riverview seismic reflection data is still underway, but analyses of the walkaway noise tests and refraction profiles is nearing completion. A brief summary of those results, including estimates of the depth to bedrock at four of the sites is presented in Table 1. Figure 6 shows an example of the seismic refraction interpretation obtained for the Anagance, New Brunswick, site located in the upper reaches of the Petitcodiac River valley approximately half way between Moncton and Sussex. The interpreted depth to bedrock, where seismic P-wave velocity increases sharply from 1800 m/s to 3700 m/s, varies from about 10 m to 15 m at this site. Though not shown here, the walkaway tests carried out in Anagance indicate that it would be a relatively good site for a seismic reflection survey; a number of shallow, coherent reflection times are evident in the shot records above 150 ms two-way traveltime.

Results

Typical values for the hydraulic properties of the geological formation of the Carboniferous Maritimes Basin were compiled from existing data and our own test results. Table 2 summarizes the hydraulic properties estimated for some of the major geological formations.

As expected, there are large variations in the hydraulic properties of the individual rock units within each geological group. These variations may be associated with the variability in lithology observed within each geological formation. Geological units dominated by sandstone and conglomerate present larger aquifer potential. In general, the hydraulic property values seem to increase slightly towards the north and east of the area.

Geological formations from the Pictou Group exhibit the largest transmissivity values. Transmissivity values are typical for a high-capacity formations. Rocks in the southern part

Table 1. Brief summary of results from the walkaway tests and refraction profiles carried out at four sites in the Maritimes Groundwater Initiative study area in August 2001.

Site	Bedrock depth estimate	Suitability for seismic reflection profiling
College Bridge (45.98°N, 64.56°W) – in ditch on south side of Highway 925, immediately west of the Memramcook River	Could not be determined (poor data quality at long offsets)	Poor; very low-frequency seismic data, lack of coherent reflectors
Riverview – line crossing the marshlands directly opposite downtown Moncton	Ranges from 10 m at outer edge of Petitcodiac valley to ~ 35 m near middle of the valley	Fair; coherent reflectors are visible over large portions of line, especially following FK filtering; however, dominant frequencies are very low and signal-to-noise ratio is poor at higher frequencies (> about 150 Hz). Source-generated noise is also very strong in some areas. The limited bandwidth, and some statics problems, may be due in part to shallow biogenic gas in the marshlands. (CMP reflection data from this line are currently being processed.)
River Glade (46.00°N, 65.095°W) – alongside road leading to covered bridge, 5.25 km northeast of River Glade	2–3 m	Fair; relatively low-frequency data, and significant source-generated noise
Anagance (45.87°N, 65.255°W) – line crossing part of upper Petitcodiac River valley	10–15 m	Good; shallow coherent reflections clearly visible at reflection times less than 150 ms.

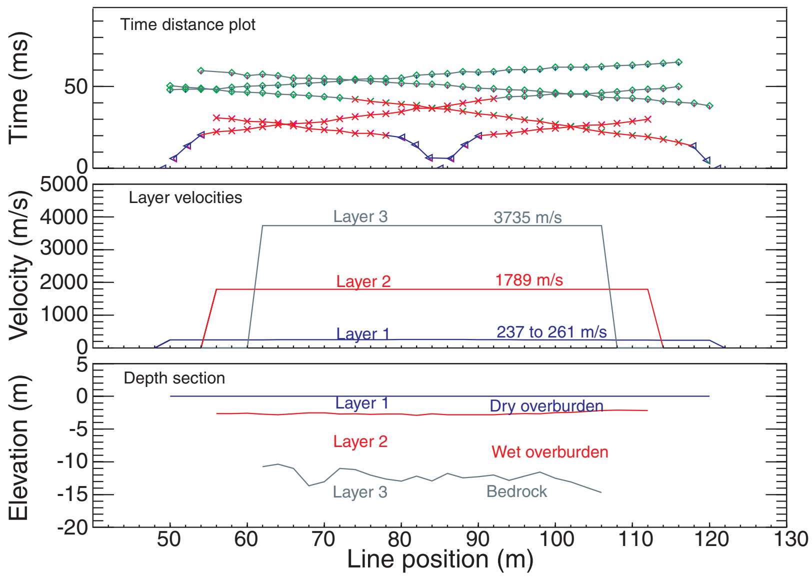

Figure 6.

Example of a seismic refraction interpretation from a line, 70 m in length, crossing part of the upper Petitcodiac River valley in the village of Anagance. Partially saturated sediments overlie saturated sediments at a depth of 2–3 m. The estimated depth to bedrock, determined by application of the generalized reciprocal method (GRM), varies from 10 m to 15 m along the length of the line.

Table 2. Overview of the hydraulic properties of some typical formations in the Carboniferous Maritimes Basin.

Geological unit	Number of wells or tests	Transmissivity (m^2/day)		Horizontal hydraulic conductivity (m/s)		Storage Coefficient		Reference or source
		Average	Range	Average	Range	Average	Range	
Prince Edward Island Group								
Naufrage Fm (Orby Head)	3	170			10^{-7} to 10^{-4}	0.014		Mutch et al., 1992; Francis, 1989
Hillsborough River Fm	1	203	-	-	-	0.00091	-	Jacques, Whitford, and Associates Limited, 1990
Kildare Capes Fm	2	228	90–77	-	-	0.0028	1.2×10^{-3} to 6.4×10^{-3}	Jacques, Whitford, and Associates, 1990
Pictou Group								
Undivided	14	157	29–1407	-	-	0.0014	2.0×10^{-4} to 1.0×10^{-2}	Aqua Terra Investigation Inc., unpub. report, 2000; this study
Cape John Fm	1	1.8	-	-	-	-	-	Vaughan and Somers, 1980
Richibucto Fm	15	52	5.2–1166	3.7×10^{-5}	9.5×10^{-6} to 3.0×10^{-5}	-	4.0×10^{-4} to 2.2×10^{-3}	Brown, 1967; Washburn and Gillis Associates Ltd., unpub. report, 1996; this study
Salisbury Fm	2	3.2	-	1.9×10^{-6}	1.2×10^{-6} to 6.4×10^{-4}	-	4.0×10^{-4} to 2.2×10^{-3}	Brown, 1967; this study
Cumberland Group								
Undivided	1	15	-	-	-	-	-	Vaughan and Somers, 1980
Ragged Reef Fm	1	18	-	-	-	0.001	-	Vaughan and Somers, 1980
Springhill Mines Fm	3	19	5.2–49			0.00048	1.6×10^{-4} to 1.5×10^{-3}	Vaughan and Somers, 1980
Polly Brook Fm	2	16	12–21	-	-	-	-	Vaughan and Somers, 1980
Boss Point Fm	8	10	3–18	-	-	-	-	Vaughan and Somers, 1980; ADI Limited, unpub. report, 2000
Mabou Group								
Undivided	1	51	-	-	-	0	-	Vaughan and Somers, 1980
Windsor Group								
Hillsborough Fm	2	23	19–26	-	-	-	-	ADI Limited, unpub. report, 2000

of the region have lower transmissivities, except for the Hillsborough Formation; however, the transmissivity still represents values acceptable for water supply of small communities.

The observed storativity values are consistent with semiconfined to confined aquifer conditions. An extensive groundwater exploration project in the St-Antoine, New Brunswick, area showed that some wells were tapping both a surface and a deeper bedrock aquifer (Aqua Terra Investigation Inc., 2000). This may explain the large variations observed in the storativity coefficient.

Groundwater flow system

Water-depth and water-level fluctuations

Information on the depth of the water table across the study area was obtained from several water-level surveys performed in the past in New Brunswick, Nova Scotia, and Prince Edward Island (Environment Canada, 1991; New Brunswick Department of the Environment, 1992). A groundwater-level monitoring network is still active in Prince Edward Island and a network in New Brunswick was active from 1977 to 1991. Also, the depth to the water table is usually reported by the drillers in provincial water-well databases. The data were validated with data from a regional water-level survey carried out in the course of the project.

According to the water-well databases, the water level measured in wells located in the study area varies from artesian flowing conditions to depths that can reach more than 50 m. The water-level depth in the New Brunswick part of the study area has an average of 9.3 m; the depth of the water level in wells on Prince Edward Island has an average of 8.9 m. Only a few water-level data are currently available for Nova Scotia and they present similar depths. The regional water-level survey confirmed these values with depth ranging from above the surface to 46 m deep and a slightly lower regional average of 7.6 m.

A preliminary analysis of the water-level data indicate deeper water levels in highland areas located near large rivers (Petitcodiac River). Some free-flowing artesian wells are found near the coast, although they are not restricted to that area: some wells in topographic low or near break in slope (Magnetic Hill, New Brunswick) are also free-flowing artesian; other deep wells located in the Amherst area near the seashore in Nova Scotia presents similar free-flow conditions.

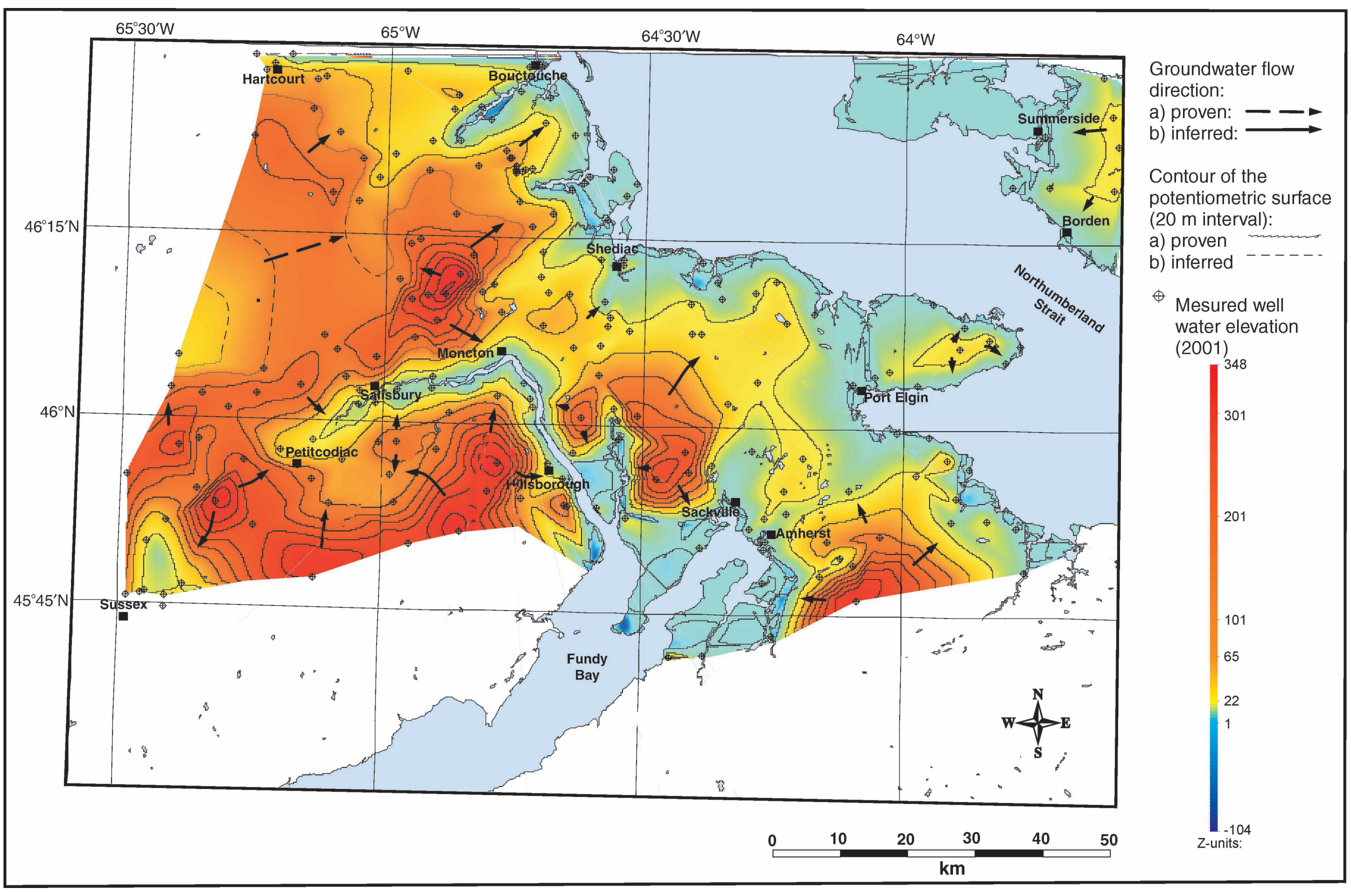

Figure 7. Preliminary piezometric map of the bedrock aquifer of the Moncton sub-basin.

Water-level records in the monitoring wells provide data necessary to describe natural fluctuations in water level in the bedrock aquifer. The hydrographs usually show the typical response of water levels to seasonal patterns: a major spring recharge event, followed by a decline of the water table during the summer; a smaller recharge event during the fall; and finally a decline during the winter. Annual water-level fluctuations recorded by the New Brunswick monitoring network (1991) were in the range of 0.4–4.0 m, depending on the geographical location. Data loggers have been installed in wells located at strategic locations in the Carboniferous Maritimes Basin (Harcourt, Shediac, Petitcodiac, New Brunswick; Beechman Road, Nova Scotia) to allow a better study of natural water-level fluctuations.

Piezometric map of the bedrock aquifer

The groundwater dynamics within the Carboniferous Maritimes Basin is not well understood. There are many case studies indicating that this aquifer system can produce high groundwater yields of variable groundwater quality, but very little work has been done to delineate and characterize the aquifers on a regional scale. Groundwater-level data analysis is the first step towards the spatial and vertical delineation of distinct aquifers, the evaluation of the sustainable yield, and the assessment of groundwater vulnerability to contamination.

The water-level survey carried out during the summer of 2001 allowed a preliminary evaluation of the direction and gradients of the groundwater flow in the bedrock aquifers. The depth to the water table was measured in more than 200 private wells. The elevation of the piezometric surface was calculated using the land elevation, from a digital elevation model (DEM) at 1:250 000 scale, at the well location and then subtracting the water-level depth measured during the survey. Measurements were validated with water-level data from municipal wells and the water-level databases. Figure 7 presents the preliminary piezometric map of the study area.

Preliminary observations indicate the general patterns in the groundwater flow regime. Regional recharge probably occurs to the west of the study area as mountain-front recharge from the uplands of New Brunswick, with groundwater flow towards the sea. Local recharge probably occurs in highland areas to the south of the Petitcodiac River, on the Kingston uplift to the northwest of Moncton, and in the highlands surrounding the Memramcook Valley. Steep hydraulic gradients seem to dominate the central part of the area due to hilly conditions. The lowlands, from Shediac to Port Elgin and Cape Tormentine (New Brunswick), suggest a more gentle horizontal hydraulic gradient. Since the topography varies greatly in the study area and because of the small number of surveyed sites, these conditions result in many uncertainties in local groundwater flow direction. It can be assumed that several local and regional flow systems exist in the area. Because it can reasonably be assumed that the configuration of the piezometric surface usually follows the land topography, efforts will be made to integrate surface elevation from grid operations and river levels and increase the data points to refine the piezometric map. Despite its limitations, the preliminary piezometric map provides valuable information for the conceptual model of the groundwater flow system in the Carboniferous Maritimes Basin.

SUMMARY AND CONCLUSIONS

Data analyses and fieldwork performed in the course of this project demonstrated the complexity of the hydrogeological system of the Carboniferous Maritimes Basin. The preliminary hydrogeological synthesis has allowed a general representation of the groundwater flow system, description of the main hydrostratigraphic units with estimates of their hydrogeological properties, and a first evaluation of groundwater resource development in the area. The following year of the project will aim at completing the existing knowledge and produce a detailed hydrogeological conceptual model of the groundwater flow system of the region under study.

ACKNOWLEDGMENTS

This contribution is part of the Maritimes Groundwater Initiative that is funded through the Geological Survey of Canada Project Approval System (PAS). Major contributors to the project are New Brunswick Department of Environmental and Labour (D.A. Pupek and R. Brinsmead), Prince Edward Island Department of Fisheries, Aquaculture and Environmental (G. Somers and J. Mutch), Nova Scotia Department of Environment and Labour (D. Briggins), Environment Canada, United States Geological Survey, University of New Brunswick, Laval University, and INRS-Géoressources. The authors wish to thank Édith Bourque, Miroslav Nastev, and Michel Parent for the manuscript review and constructive comments.

REFERENCES

Brown, I.C.
1967: Groundwater in Canada; Economic Geology, no. 24, 227 p.

Environment Canada
1991: Evaluation and Planning of Water Related Monitoring Networks on Prince Edward Island; Environment Canada and PEI Department of the Environment, 69 p.

Francis, R.M.
1989: Hydrogeology of the Winter River Basin, Prince Edward Island, Department of the Environment Prince Edward Island, 118 p.

Jacques, Whitford and Associates Limited
1990: Water and Wastewater Treatment for Industrial Development – Borden Area, Prince Edward Island, Report to Prince Edward Island Department of Industry, Atlantic Canada Opportunity Agency, Public Works Canada, Project no. 5423, 69 p.

Mutch, J.P., Jackson, R.E., Priddle, M.W., and Bray, D.I.
1992: The Fate and Simulation of Aldicard in the Soil and Groundwater of Prince Edward Island; Environment Canada, Scientific Series no. 194, 96 p.

New Brunswick Department of the Environment
1992: Summary of 1991 groundwater levels from observation wells of the groundwater level monitoring network in New Brunswick; Water Resource Monitoring Section, Environmental Planning & Sciences Branch, 48 p.

Rampton, V.N., Gauthier, R.C., Thibault, J., and Seaman, A.A.
1984: Quaternary geology of New Brunswick, Geological Survey of Canada, Memoir 416, 77 p.

van de Poll, H.W., Gibling, M.R., and Hyde, R.S.
1995: Introduction: Upper Paleozoic rocks; in Chapter 5 of Geology of the Appalachian-Caledonian Orogen in Canada and Greenland (ed.) H. Williams; Geological Survey of Canada, Geology of Canada, no. 6, 449–566 (*also* Geological Society of America, The Geology of North America, v. F-1).

Vaughan, J.G. and Somers, G.H.
1980: Regional Water Resources, Cumberland County, Nova Scotia; Nova Scotia Department of the Environment, 81 p.

Geological Survey of Canada Project PS-1009