Hydrogeology Program in Nova Scotia

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Introduction

In 2008, the Nova Scotia Department of Natural Resources (DNR) Hydrogeology Program continued to focus its efforts on the organization, compilation and mapping of existing provincial groundwater data. A two year intern position, starting in September 2008, was created to assist with mapping and spatial analysis of groundwater data. The program also supported provincial groundwater research and groundwater management initiatives, such as the Nova Scotia observation well network.

Program Highlights

Observation Well Network

The Nova Scotia observation well network, operated by Nova Scotia Environment (NSE), is a key source of information on background groundwater chemistry and groundwater levels in the province. The number of observation wells in the network has varied since the network's inception in 1965. Following a period of decline in the 1980s and 1990s, when the total number of observation wells was reduced from 40 to 14, the observation well network has been expanded in recent years, and updated with new monitoring equipment.

In consultation with DNR, NSE identified several potential sites for the installation of new observation wells. For example, Halifax County had only two active observation wells. Priority sites were identified, and DNR assisted NSE with drilling supervision, well testing and data interpretation at three sites (Table 1). With the addition of the three observation wells, there are presently a total of 30 active observation wells in the province.

In addition, the potential for converting existing abandoned drilled wells at various provincial parks to dedicated observation wells was assessed at 12 park sites. A list of priority sites was developed based on various criteria, including the condition of the drilled well and whether the watershed currently hosts an active observation well. Existing wells at the following sites were recommended for incorporation into the observation well network:

1. Tatamagouche Provincial Park, Colchester County,
2. Jerry Lawrence (Lewis Lake) Provincial Park, Halifax County,
3. Coldbrook Provincial Park, Kings County,
4. Arisaig Provincial Park, Antigonish County, and
5. Long Lake Provincial Park, Halifax County.

DNR conducted short-term pumping tests and water quality sampling of the three new observation wells, and, where accessible, the abandoned park wells proposed for incorporation into the network. The pumping test results are presented in Table 2.

Groundwater Database Development

Advancements have been made toward the development of a central spatial database for groundwater management, including the addition of information layers such as government test holes, water well logs, pumping tests and inorganic groundwater chemistry.

Government Test Holes

The drill logs of over 500 test holes constructed between 1964 and 1978, under the supervision of

[1]Nova Scotia Department of Environment

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Table 1. Observation wells added in 2008.

Station Name	Station Number	Watershed	Geological Unit
Fall River, Halifax County	76	Shubenacadie/Stewiacke	Halifax Group
West Northfield, Lunenburg County	77	LaHave	Halifax Group
Musquodoboit Harbour, Halifax County	78	Musquodoboit	Halifax Group

the former Nova Scotia Department of Mines or Nova Scotia Department of the Environment, were scanned from microfiche, and the information was entered into a Microsoft Access™ database using standard lithological descriptions.

Well Logs Database

The 2008 version of the Nova Scotia well logs database (Nova Scotia Environment, 2008a), which includes 107 205 records of wells constructed between 1940 and February 2008, was plotted on the map of Nova Scotia using various methods to locate the wells. The accuracy of the assigned UTM (Universal Transverse Mercator Projection, Zone 20, Central Meridian 63°00' West, North American Datum (NAD) 1983 Canadian Spatial Reference System (CSRS) 98) coordinates varies greatly, depending on the original information available for the well. Figure 1 shows the distribution of water wells in the province, generated from assigned coordinates. Table 3 provides a summary of the methods used to locate the wells and to estimate the potential error inherent in the assigned coordinates.

The georeferenced water well database will have broad applications for geoscience research and groundwater assessment in Nova Scotia. Patterns of well characteristics, such as well yield, can be plotted across the province and the well logs database can be more effectively applied to develop geological cross-sections and three-dimensional geological models by database users, recognizing the limitations of the accuracy of the well locations. Georeferencing is defined here as the assignment of UTM coordinates to give the best approximate locations of water wells.

Pumping Tests

The version of the Nova Scotia pumping test database (Nova Scotia Environment, 2008b), most recently compiled and analyzed using statistics by McDonald (2008), was updated with 41 new pumping tests (total of 941 records). The pumping test database was cross-checked against other groundwater databases (e.g. well logs) to improve the accuracy of the well locations, and well location information was digitized when available. This work permitted groundwater regions to be assigned to each pumping test with a greater level of confidence. Hydraulic characteristics of wells grouped by groundwater regions were recalculated and are presented in Table 4. Pumping tests of less than three hours duration, and pumping wells that intercept multiple groundwater regions, were excluded from the statistical analysis.

The Nova Scotia pumping test database (Nova Scotia Environment, 2008b) contains an inventory of pumping tests submitted to the province, typically in support of a water withdrawal approval application, or as a regulatory requirement for nondomestic use of the well under the previous Well Construction Regulations. The records contained in the database, therefore, are more representative of high capacity groundwater supplies than typical domestic well water supplies.

Inorganic Groundwater Chemistry

The Nova Scotia inorganic groundwater chemistry database, most recently compiled and analyzed using statistics by Keddie (2006), was revised with new sources of groundwater chemistry data. Location coordinates were assigned to each unique

site or well in the database by cross-checking them against existing groundwater databases (e.g. well logs, pumping tests). Based on the location of the groundwater source, groundwater regions were assigned to each site or well. Statistics were then recalculated for 16 water chemistry parameters based on the grouping by groundwater regions (Tables 5 and 6).

Samples below the detection limits were considered in the statistical analysis by assigning a level equal to half of the detection limit (United States Environmental Protection Agency, 1998). For a given site or well, only the most recent groundwater sample result was used.

Groundwater Data Availability

Groundwater Regions of Nova Scotia Map

Based on mapping previously published by the Nova Scotia Department of the Environment and Environment Canada (1985), a revised 1:500 000 scale map of the groundwater regions of Nova Scotia was released in 2008 (Kennedy and Drage, 2008). The groundwater regions map is available as a hard copy and GIS download, and is also available on an interactive groundwater mapping web page (see below).

The following six major groundwater regions were identified: (1) Quaternary, (2) Sedimentary, (3) Carbonate/Evaporite, (4) Volcanic, (5) Plutonic, and (6) Metamorphic. Boundaries of the various bedrock groundwater regions were outlined based on the dominant rock type interpreted from the 1:500 000 scale bedrock geology map of the Province of Nova Scotia (Keppie, 2000). Boundaries of the Quaternary groundwater region were outlined based on the 1:500 000 scale surficial geology map of glaciofluvial and alluvial deposits in Nova Scotia after Stea *et al.* (1992). These deposits represent the more permeable aquifer materials.

Primary watershed boundaries and active observation wells maintained by NSE (Nova Scotia Environment, 2008c) are also shown on the Kennedy and Drage (2008) map.

Online Interactive Groundwater Map

An online interactive groundwater map service and portal for government groundwater information

Table 2. Summary of short-term pumping test results, 2008.

Location	Test Type	Duration (mins)	Average Pumping Rate (m^3/d)	Static Water Level (m)	Well Transmissivity (m^2/d)	Hydraulic Conductivity (m/d)	Specific Capacity (m^2/d)	Long-Term Yield (Q_{20})[1] (m^3/d)
TatamagoucheProvincial Park, Colchester County	Constant rate	155	3.9	1.49	0.46	4.30×10^{-2}	1.07	4.57
Jerry Lawrence (Lewis Lake) Provincial Park, Halifax County	Step test	190	12.5-21.4	2.71	1.53	2.70×10^{-2}	-	57.31
Fall River Observation Well, Halifax County	Constant rate	240	4.4	3.89	0.07	1.21×10^{-3}	0.43	2.13
West Northfield Observation Well, Lunenburg County	Step test	305	6.6-15.7	1.13	0.44	1.44×10^{-2}	-	10.53
Musquodoboit Harbour Observation Well, Halifax County	Constant rate	95	2.5	2.20	1.68	4.63×10^{-2}	0.26	49.39

[1]The Q_{20} refers to the potential long-term (20 year) safe yield. Due to the short duration and low pumping rate of tests, the Q_{20} estimates provided in the table are not considered reliable.

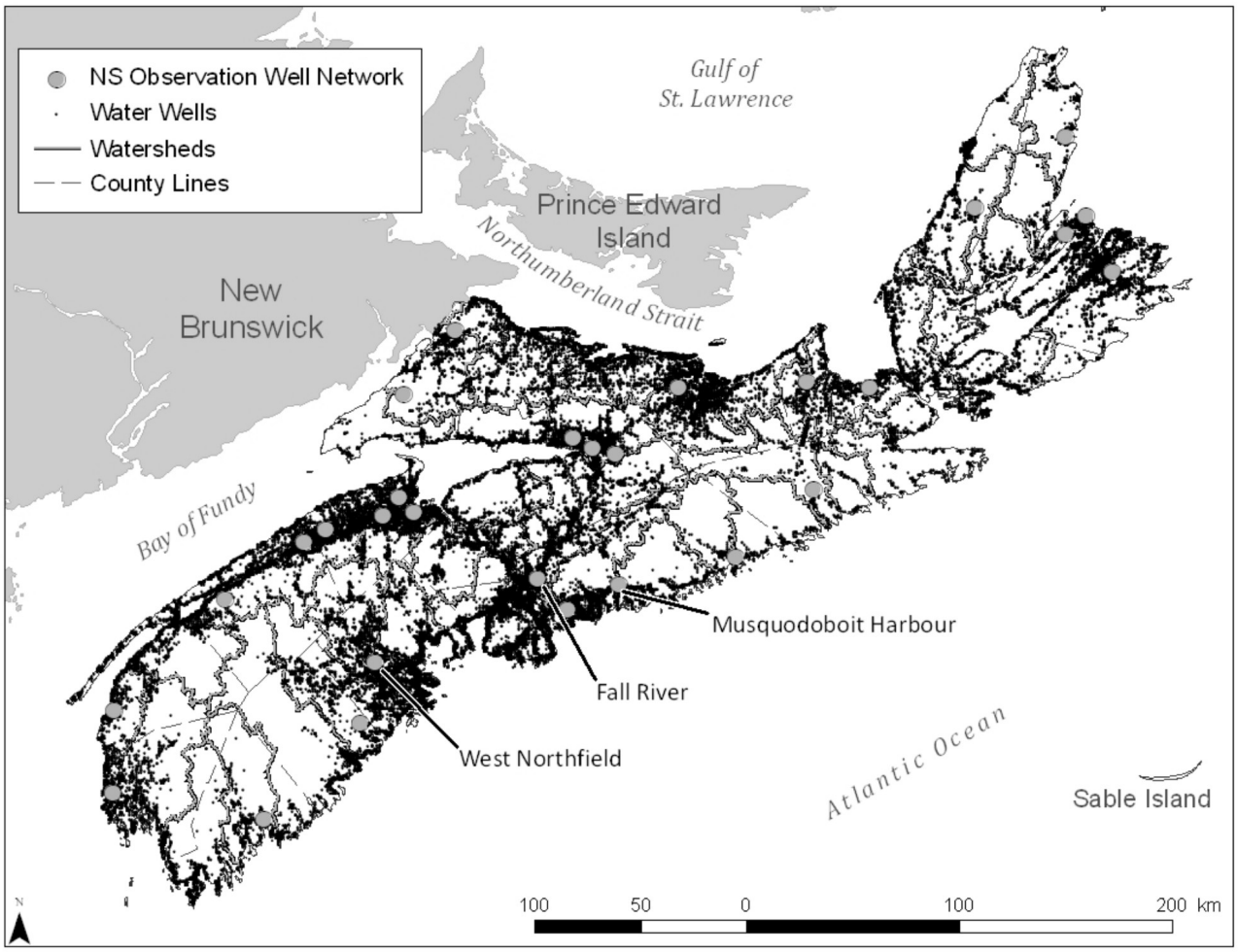

Figure 1. Distribution of water wells and observation wells in Nova Scotia generated from assigned coordinates. See Table 3 for accuracy of assigned coordinates.

was originally launched in August 2008 and a major update to the service was completed in December 2008. The update included plotting water wells and pumping tests (Kennedy and Drage, 2008) (gis4.natr.gov.ns.ca/website/nsgroundwater).

Water well information, such as location, well depth, groundwater level, depth to bedrock, yield, and the type of well construction, is shown on the interactive map. The interactive map also includes pumping test information, such as pumping well location, the aquifer being pumped, and the potential long-term yield (Q_{20}). Summaries for selected aquifer yield and inorganic groundwater chemistry (Tables 4-6) for each groundwater region can also be viewed on the interactive map.

Well owners can use the interactive map to help locate information about their well. Groundwater managers and researchers can use the map to characterize groundwater resources and identify well users in an area of interest, and water professionals, developers and contractors can use the map to help plan the development of appropriate groundwater supply.

National Water Well Mapping and Analysis Project

DNR collaborated with NSE and federal partners on the development of a national water well mapping and analysis system in 2008. The initiative is being led by Natural Resources Canada (NRCAN) and will result in the publication of a national scale interactive water well map (sst.rncan.gc.ca/gm-ces/proj2/a2_e.php). DNR's role involved organization of the Nova Scotia well

Table 3. Summary of sources of water well locations and the estimated accuracy of assigned coordinates used to plot the wells on the map of Nova Scotia.

Georeference Method Code[1]	Information Provided for Well Location	Estimated Accuracy of Assigned UTM Coordinates	Number of Wells
A1	Nova Scotia Mapbook (grid reference centroid)	±707 m	74 439
A2	Nova Scotia Atlas (grid reference centroid)	±641 m	869
B1	Nova Scotia Claim Reference Map (claim centroid))	±1130 m	1 862
B2	Nova Scotia Claim Reference Map (mining tract centroid)	±282 m	16 064
C	Community gazeteer location from Nova Scotia Mapbook	±7829 m	3 619
D1	Property centroid from Nova Scotia Property Registration Database	~10 - 2000 m	1 149
D2	Property location using Nova Scotia Property Registration Database	~10 - 2000 m	595
G	GPS coordinates	±15 m	7 812
M	Estimate from site map	50 - 100 m	367
U	Could not locate UTM	-	429
		TOTAL	107 205

[1]The code used in the database attached to each water well to identify the possible errors inherent in the coordinates assigned. The 2008 version of the Nova Scotia well logs database (Nova Scotia Environment, 2008a), which includes 107 205 records of wells constructed between 1940 and February 2008, was plotted using various methods according to the best available location information.

The method used by well contractors to identify well locations has changed over time. Initially, well contractors used the Nova Scotia Mapbook by page number to reference the location of a well (code A1, Table 3). Later, the Nova Scotia Atlas replaced the Mapbook and was used by well contractors to reference well locations using the two letter grid reference for the grid cell that contained the well (code A2, Table 3). Drillers also identified the locations of wells using the grid system of the Nova Scotia Claim Reference Maps noting a claim (code B1) or mining tract (code B2, Table 3). In some cases the only reliable location information was the community name, and therefore the community centroid (C) was assigned to the well location. Where civic address information was available on the well log, and a corresponding property identification number could be located (from Nova Scotia property on line), the well location was determined using the centroid of the property (code D1), or the approximate building location on the property (code D2). More recently, well drillers have used GPS equipment (code G) to collect well coordinate information (note that most well diggers use the Nova Scotia Atlas system). Code M was assigned to a well location when it was estimated from an existing map or site plan showing the location of the water well.

The estimated accuracy of the UTM coordinates assigned to each well record in the database was approximated based on the method used to locate the wells. Users of the database should be aware of how the coordinates were determined, and their corresponding accuracy to understand the limitations on the use of these data. In the database the georeference method codes are attached to each assigned well location to avoid misinterpretation of the actual locations of the water wells. Additional explanation is available online at http://gis4.natr.gov.ns.ca/website/nsgroundwater/viewer.htm.

Table 4. Hydraulic characteristics of groundwater regions in Nova Scotia (median of selected parameters given).

Groundwater Region	Apparent Well Transmissivity (m^2/day)	Potential Long-Term Yield-Q_{20} (L/min)	Well Specific Capacity (m^3/d/m)
Quaternary	122.34 (118)	181.80 (121)	121.35 (121)
Sedimentary	15.58 (394)	181.80 (390)	20.40 (393)
Carbonate/ Evaporite	5.15 (28)	55.95 (28)	7.38 (29)
Volcanic	4.59 (18)	46.35 (18)	6.92 (18)
Plutonic	1.15 (91)	22.70 (93)	2.52 (90)
Metamorphic	1.30 (189)	20.50 (190)	2.12 (182)
Number of samples shown in brackets Initial analyses adapted from McDonald, 2008			

logs database according to a national standard, and creation of web feature services for use by NRCAN. The project is still under way, with an expected 2009 release date.

Provincial Groundwater Availability and Use

A key objective of the Hydrogeology Program is to generate preliminary estimates of groundwater availability and groundwater use throughout the province. A preliminary GIS model was developed to estimate potential groundwater recharge to bedrock aquifers based on the distribution of precipitation throughout the province, and typical recharge ratios (precipitation/groundwater recharge) for the major groundwater regions in Nova Scotia. A more comprehensive model, which considers water balance components such as evaporation, runoff and changes in water storage to estimate groundwater recharge, and hence groundwater availability in each of the province's 44 primary watersheds, is currently under development.

To advance one of the program's objectives to quantify groundwater use on a watershed scale throughout the province, a private consultant was contracted under a provincial-federal partnership to conduct a comprehensive groundwater use survey in the Annapolis Valley. The survey involved site interviews, a mailout/online questionnaire of nondomestic groundwater users, and development of a spatial database (indexed by location) of groundwater use in the region. The spatial database was developed in collaboration with DNR, using available groundwater databases to identify existing groundwater users. The survey results are expected to be released in 2009.

Research Directions

The DNR Hydrogeology Program will continue its efforts to organize provincial groundwater information into a central spatial database. When possible, groundwater information will be published on the online interactive groundwater map. Updates to the interactive map, with additional layers of groundwater information, such as government test hole and historical observation well data, are planned for 2009.

Map products proposed for 2009 include the publication of groundwater quality and quantity data. Selected parameters from the inorganic groundwater chemistry database will be published as a groundwater chemistry atlas (series of 1:500 000 scale maps) of Nova Scotia. Distribution maps for selected parameters from pumping tests (e.g. transmissivity, potential long-term yield, specific capacity) will be published as a series of open file maps (1:500 000 scale).

The Geological Services Division has recently developed partnerships with land-use planners to ensure that geological information is easily accessible to planners and incorporated into planning decisions and policy development. As part of this project, the compilation and development of groundwater map layers for use by planners, including the construction of three-dimensional geological models and aquifer vulnerability has been proposed for central Antigonish County.

Table 5. Inorganic chemical analysis of groundwater samples grouped by groundwater regions in Nova Scotia (median of selected parameters given).

Groundwater Regions	Alkalinity Total as $CaCO_3$	Hardness $CaCO_3$	Total Dissolved Solids	Calcium	Magnesium	Potassium	Sodium	pH	Chloride	Fluoride	Nitrate+ Nitrite	Sulphate
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L		mg/L	mg/L	mg/L	mg/L
Quaternary	30.0	68.7	131.8	20.0	3.1	1.5	13.8	7.0	22.8	0.05	0.32	11.0
Sedimentary	100.0 (407)	113.0 (436)	200.5 (408)	34.7 (442)	4.3 (438)	1.6 (409)	20.0 (440)	7.8 (438)	25.7 (438)	0.10 (324)	0.17 (374)	13.0 (441)
Carbonate/ Evaporite	142.5 (62)	219.5 (64)	433.0 (60)	64.3 (67)	11.0 (67)	2.2 (65)	37.5 (67)	7.9 (65)	33.9 (65)	0.25 (47)	0.03 (61)	75.0 (65)
Volcanic	45.0 (19)	39.3 (19)	147.0 (19)	13.0 (19)	2.9 (19)	0.3 (19)	22.7 (19)	7.7 (19)	35.0 (19)	0.08 (12)	0.55 (16)	8.0 (19)
Plutonic	56.0 (88)	55.2 (89)	135.0 (90)	17.0 (91)	2.6 (91)	1.3 (90)	17.2 (92)	7.1 (90)	25.0 (89)	0.22 (70)	0.08 (90)	7.0 (88)
Metamorphic	56.0 (211)	63.7 (204)	146.0 (202)	19.8 (205)	3.1 (203)	1.3 (202)	21.3 (209)	7.3 (212)	21.0 (211)	0.16 (145)	0.03 (196)	11.0 (210)
Number of samples shown in brackets Analyses adapted from Keddie (2006)												

Preliminary estimates of potential groundwater availability and use will be developed for each primary watershed throughout the province. The GIS model for potential groundwater recharge will be refined to estimate groundwater availability. The approach developed during the Annapolis Valley groundwater use survey will be used to help generate preliminary province-wide estimates of groundwater use. The results of this work will be used to identify a high priority watershed/aquifer for a more detailed regional groundwater resource assessment.

The DNR Hydrogeology Program will work toward refining the hydrogeological characterization of the province's groundwater regions, characterizing and defining its component hydrostratigraphic units where adequate information is available.

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Table 6. Selected metals analysis of groundwater samples grouped by groundwater regions (median and geomean of selected parameters given).

Groundwater Regions	Arsenic		Iron		Manganese		Uranium	
	Median	Geomean	Median	Geomean	Median	Geomean	Median	Geomean
	µg/L		µg/L		µg/L		µg/L	
Quaternary	1.0 (115)	1.2 (115)	50.0 (129)	88.2 (129)	15.0 (130)	18.0 (130)	0.1 (105)	0.2 (105)
Sedimentary	1.0 (393)	1.6 (393)	30.0 (443)	57.5 (443)	7.0 (443)	13.2 (443)	0.6 (360)	0.6 (360)
Carbonate/ Evaporite	1.0 (61)	1.6 (61)	70.0 (67)	123.9 (67)	29.0 (67)	24.9 (67)	0.5 (58)	0.5 (58)
Volcanic	1.2 (17)	1.3 (17)	50.0 (19)	50.8 (19)	5.0 (19)	4.3 (19)	0.1 (9)	0.2 (9)
Plutonic	2.0 (87)	2.4 (87)	50.0 (93)	114.4 (93)	50.0 (93)	30.5 (93)	3.5 (82)	2.9 (82)
Metamorphic	1.0 (188)	1.9 (188)	91.0 (206)	143.2 (206)	43.0 (203)	37.4 (203)	0.2 (185)	0.3 (185)
Number of sample shown in brackets Analyses adapted from Keddie (2006)								

Environment Canada, Map E-2, scale 1:1 000 000.

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