An Overview of Hydrogeology Program Activities for April 2020 to March 2021

G. W. Kennedy and J. Drage

Introduction

A major theme of the Geological Survey Division's (GSD) Hydrogeology Program activities over the past year was the safety of private (domestic) well drinking water, especially manganese in private well water. About 40% of Nova Scotians use private wells for their domestic water supply (Kennedy and Polegato, 2017) and it is the well owner's responsibility to ensure that their well water is safe to drink. Improving our understanding and communicating risk about naturally occurring contaminants in well water, such as manganese, is a critical part of motivating health protective behaviours amongst private well users, such as routine water testing and treatment.

The GSD continued to develop and enhance the shallow aquifer monitoring network, maintained and published various groundwater datasets, and worked closely with partners at Nova Scotia Environment and Climate Change (NSECC) on various drinking water and groundwater management projects. Collaboration and support were also provided to various external organizations, which included data and technical support to Aquahacking, an organization that administers a tech challenge designed to engage young innovators to solve critical freshwater issues, and to university led projects. Geological Survey Division activities related to geohazard research are reported in the Geohazard Program report (Drage, this volume).

Program Highlights

Groundwater Data Management and Access

Over the past year, Hydrogeology Program staff has continued work to advance a project with partners at NSECC to define the functional requirements of, and procure an enterprise solution for, the information management of water resource data in Nova Scotia, including the Hydrogeology Program's groundwater databases.

Updates to Groundwater Databases

Various groundwater databases, such as the Well Logs Database (Nova Scotia Department of Energy and Mines, 2021a) and the Pumping Test Database (Nova Scotia Department of Energy and Mines, 2021b) were updated during 2020-21, and digital product versions of these databases were published in the spring of 2020. The percentage of well logs georeferenced to at least the property level of spatial accuracy (total of methods D1, D2, G, GC, and M in Table 1) is currently 37.0% (46,134 wells) compared to 9.3% (9,923 wells) in 2008. The locations of water wells constructed in 2019 are shown in Figure 1.

Web Services and Client Applications

A new story map was developed to bring together knowledge and resources for private well owners looking for information about drinking water hazards to private wells and how to test and interpret their drinking water quality https://storymaps.arcgis.com/stories/a1cf639fda644d65978648d4ff7833bb.

The Nova Scotia Groundwater Atlas, which can be accessed at https://fletcher.novascotia.ca/DNRViewer/?viewer=Groundwater, was last updated in May 2020. The Potential Impact of Drought to Private Wells application was updated monthly during the summer of 2020, and can be accessed at https://fletcher.novascotia.ca/DNRViewer/?viewer=DroughtIndex.

Groundwater Research and Mapping

Manganese in Well Water

Manganese is a naturally occurring contaminant in Nova Scotia groundwater, and is associated with

Kennedy, G. W. and Drage, J. 2021. in Geoscience and Mines Branch, Report of Activities 2020-2021; Nova Scotia Department of Natural Resources and Renewables, Report ME 2021-002, p. 21-31.

Table 1. Summary of well log georeferencing.

Georeference Method	Description	Estimated Georeference Accuracy	Count 2008	Count 2018	Count 2019
A1	Nova Scotia Mapbook (grid reference centroid)	±707 m	74,439 (69.4%)	57,238 (46.3%)	56,690 (45.4%)
A2	Nova Scotia Atlas (grid reference centroid)	±641 m	869 (0.8%)	962 (0.8%)	849 (0.7%)
B1	NTS – Claim (grid reference centroid)	±1130 m	1,862 (1.7%)	1,833 (1.5%)	1,833 (1.5%)
B2	NTS – Tract (grid reference centroid)	±282 m	16,064 (15.0%)	14,323 (11.6%)	14,300 (11.5%)
C	Community gazeteer location from Nova Scotia Mapbook	±7,829 m	3,619 (3.4%)	2,981 (2.4%)	2,946 (2.4%)
D1	Property centroid from NSPRD	~10 to 2,000 m	1,149 (1.1%)	16,385 (13.2%)	17,359 (13.9%)
D2	Property location using NSPRD/ NSCAF/other	~10 to 2,000 m	595 (0.6%)	1,966 (1.6%)	1,968 (1.6%)
E	Grid reference centroid plots location in ocean so point moved to nearest coast	707 to 1130 m	0 (0%)	1,686 (1.4%)	1,684 (1.3%)
G	GPS	±15 m	7,812 (7.3%)	21,084 (17.0%)	21,849 (17.5%)
GC	Geocode Address	~10 to 2,000 m	0	649 (0.5%)	649 (0.5%)
M	Estimated from site map	50 to 150 m	367 (0.3%)	4,287 (3.5%)	4,309 (3.5%)
U	Could not locate UTM	-	429 (0.4%)	343 (0.3%)	343 (0.3%)
		TOTAL	107,205	123,737	124,779

NSPRD: Nova Scotia Property Registration Database
NSCAF: Nova Scotia Civic Addressing File

neurological effects, especially in infants, at concentrations above the Health Canada (2019) maximum acceptable concentration (MAC). Manganese in well water data were assessed to develop an understanding of the factors controlling the distribution of manganese in groundwater, and to develop a province-wide manganese in well water risk map based on the province's geology. The purpose of the risk map is to communicate the risk of manganese in private well drinking water, and to encourage routine water testing and appropriate treatment, which will lead to improved health outcomes. Many of the areas identified as having high relative risk for manganese in well water are also associated with an elevated risk of arsenic and/or uranium in well water. Overall, it is estimated that 75% of the province's private domestic wells are in a high-risk zone for at least one of these three contaminants. An open file report, titled *A Manganese in Well Water Risk Map for Nova Scotia* was published in the spring of 2021 (Kennedy, 2021) and a web map application and website are planned for later this year.

Private Well Contaminants, Testing, and Mitigation Behaviours in Nova Scotia

An open file report was published in 2020 (Kennedy and Drage, 2020a) that compiles information on various private domestic well contaminants in Nova Scotia and summarizes available information on private well stewardship behaviours in the province. Based on the available evidence, it is estimated that over one third of private wells in Nova Scotia have a health-based exceedance of one or more chemical contaminants in their untreated water, and that about 25 to 40% of private wells may have total coliform in their drinking water. The analysis also demonstrated that there is poor adherence to the province's recommended frequency for water testing, which is every six months for bacteria and every two years

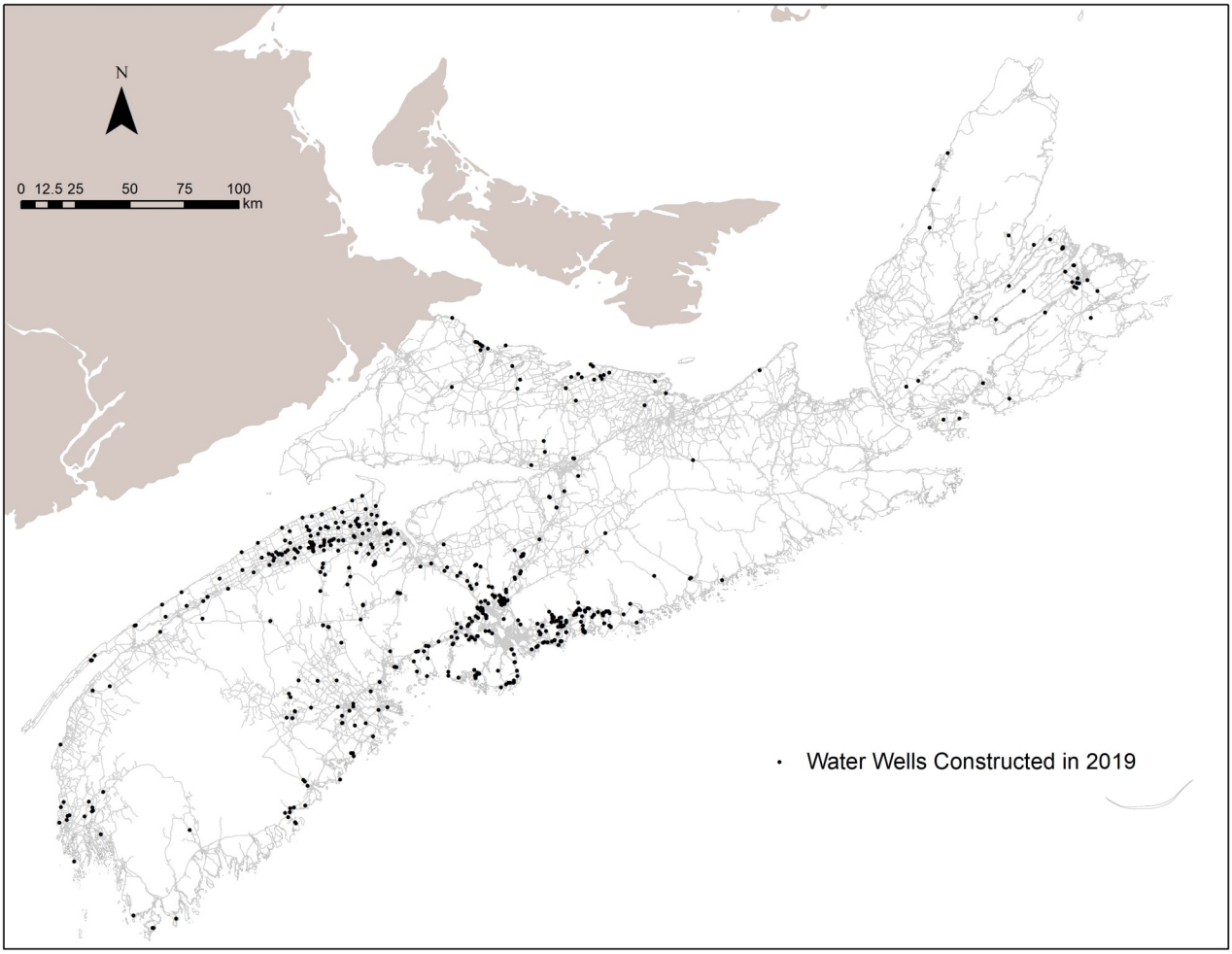

Figure 1. Distribution of water wells constructed in 2019 (as submitted by well drillers and well diggers). Note that additional logs still may be submitted by well drillers and well diggers for the year 2019.

for chemical quality. The evidence suggests that more than 50% of the province's private well owners have never tested, or can't recall testing, the chemical quality of their well water, whereas more than 20% have never tested their well water for bacteriological quality. Multiple important barriers to testing were identified, including procrastination, cost, inconvenience, and a lack of knowledge or awareness.

Profiling Contaminants in Nova Scotia Drinking Water

Well water quality data collected by Atlantic PATH, a longitudinal cohort study of chronic disease in Atlantic Canada (Sweeney et al., 2017; Dummer et al., 2018), was combined with the Nova Scotia Groundwater Chemistry Database to augment the provincial coverage of groundwater chemistry data. The dataset required additional processing in 2020 for use in the manganese in well water project, and for use in other projects with partners at Nova Scotia Health, and Dalhousie University.

These data will be used to better understand the distribution of naturally occurring contaminants, which will enable the province to focus risk mitigation efforts on areas where there is the greatest potential exposure. The combined environmental exposure data will also be used by health researchers to examine the association between the spatial distribution of environmental risk factors and health risk, particularly cancer. For example, a Dalhousie University M.Sc. thesis in the Faculty of Epidemiology is investigating spatial trends of naturally occurring contaminants compared to socio-economic vulnerability to identify areas that should be prioritized for public health intervention.

Real-time Shallow Aquifer Water Level Monitoring Network

The need for a real-time monitoring network for tracking water levels in shallow aquifers was highlighted during a drought in Nova Scotia in 2016. The drought was particularly severe in southwestern Nova Scotia, where it was the driest summer recorded in 137 years. This area of the province relies heavily on shallow dug wells for domestic water supplies and over 1,000 wells went dry over the summer (Kennedy et al., 2017). During the drought, there was a need to track aquifer levels so that emergency management staff could plan appropriate responses and the public could be kept informed about the drought impacts. Although Nova Scotia has a provincial groundwater observation well network, it monitors drilled wells and does not provide real-time reporting. Therefore, a real-time monitoring network for dug wells was developed by the Geological Survey Division in 2017. The network uses low-cost, custom-built water level meters and relies on community volunteers to install the meters in their dug wells and provide access to their home WiFi network to transmit the water level data via the Internet (Drage and Kennedy, 2020). The network currently includes 11 active wells (Fig. 2), and an interactive map provides access to the water level data (https://fletcher.novascotia.ca/DNRViewer/index.html?viewer=Aquifer_Monitoring.Aquifer_Monitoring).

During 2020-21, the monitoring network continued to be developed and maintained. No new monitoring locations were added during this period, but additional water quality probes (temperature and electrical conductivity) were developed and tested at one existing location (Lockeport), which can be viewed here: https://thingspeak.com/channels/316660.

The addition of these probes allows water temperature, water conductivity, and water level to be monitored simultaneously in real time with a single device, as shown in Figure 3. The monitoring of electrical conductivity is useful for identifying any type of groundwater pollution that has a high salt concentration, such as groundwater impacts associated with road salt or seawater intrusion. Instructions for building the temperature, conductivity, water level meters can be found here: https://www.instructables.com/A-Real-Time-Well-Water-Temperature-Conductivity-Wa/.

Additional work completed in 2020-21 included a research project to assess the accuracy of the custom-made, real-time water level meters for monitoring groundwater levels in drilled wells. Although the accuracy of the meters has been previously tested in dug wells, their accuracy had not yet been tested in drilled wells. The project was carried out by students in the Environmental Engineering Technology Program at the Nova

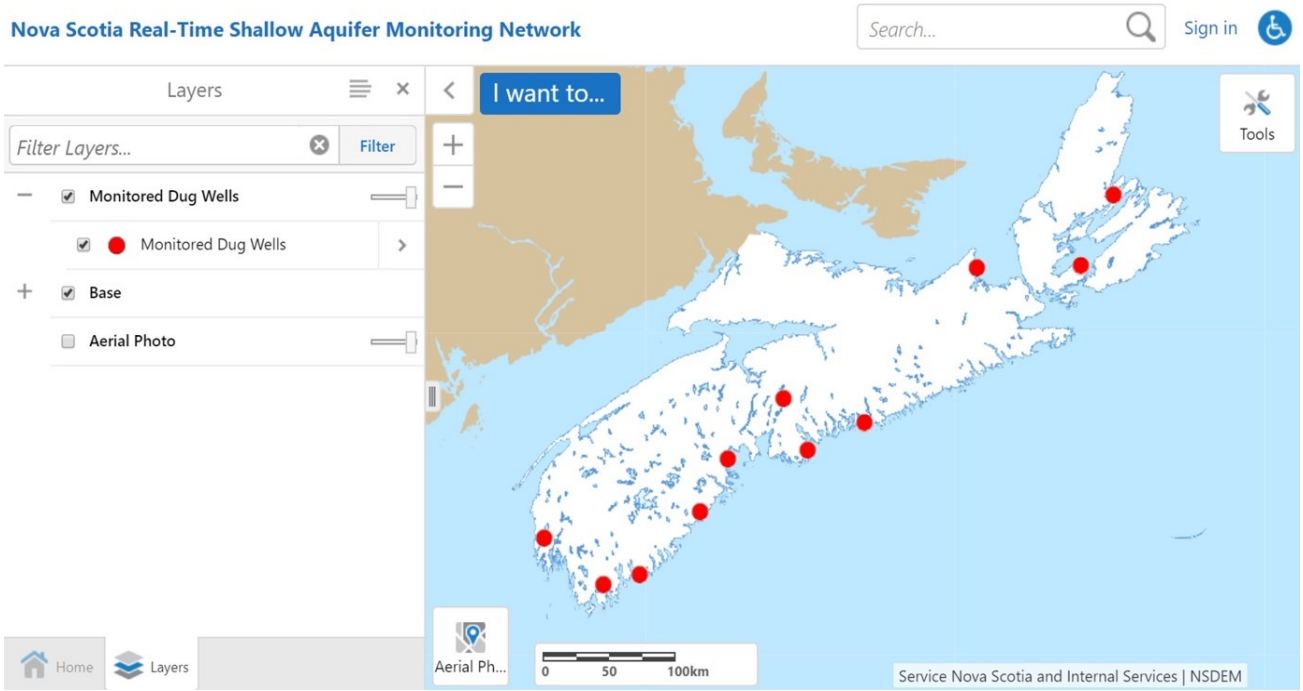

Figure 2. Map of the Nova Scotia real-time shallow aquifer monitoring network.

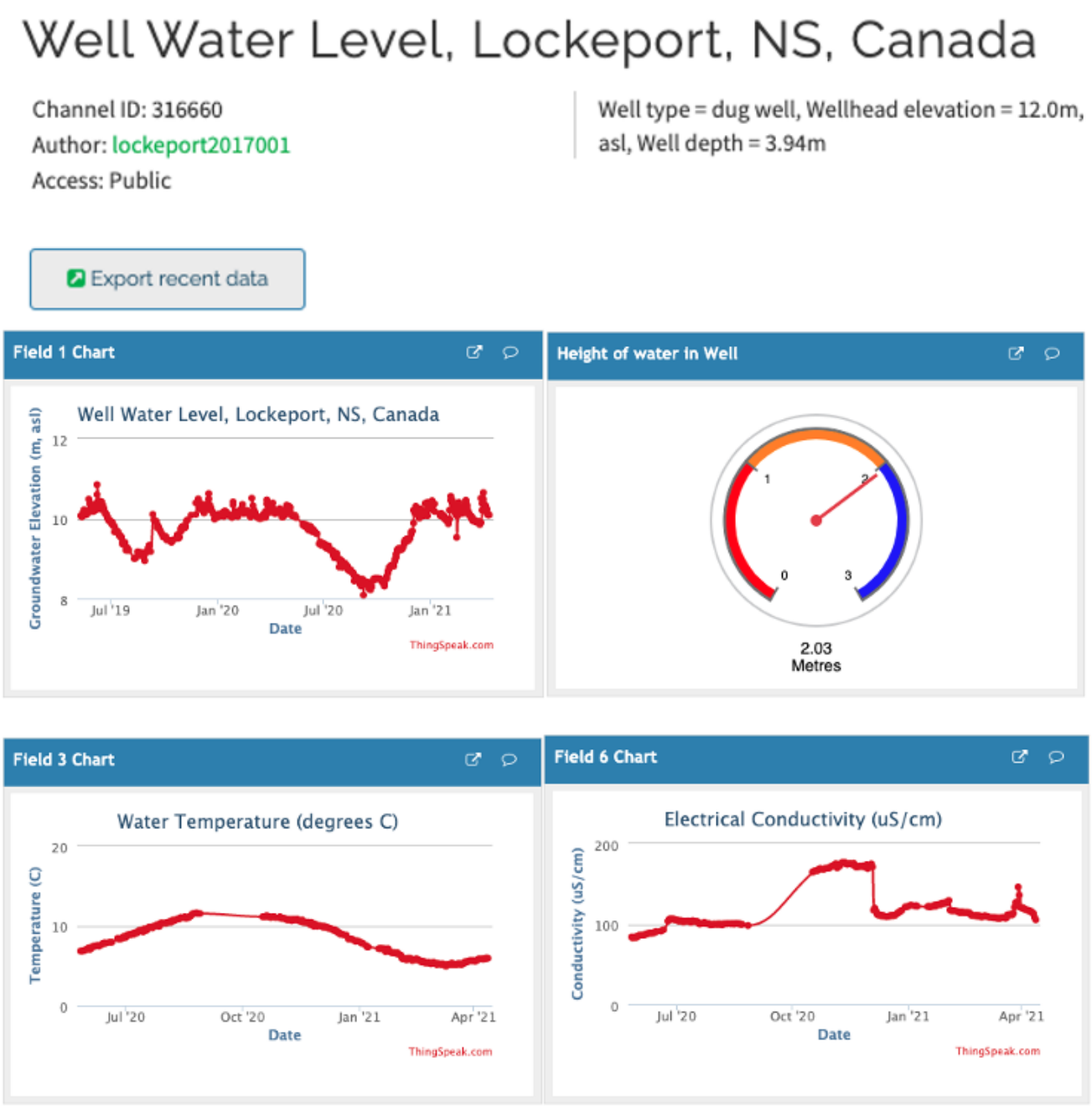

Figure 3. Pilot test results for a dug well in Lockeport, in which real-time temperature and electrical conductivity probes were installed in 2020.

Scotia Community College (NSCC) and involved the installation of a real-time water level meter and a pressure transducer in a drilled well at the NSCC campus on Leeds Street, Halifax (Fig. 4). A report on the results of the project is in preparation.

Further information about the monitoring network, including access to the water level data, instructions for building the real-time water level meters, and a journal article published in 2020 can be found here: https://novascotia.ca/natr/meb/water-resources/aquifer-network.asp.

Preliminary Geothermal Resource Evaluation in Nova Scotia

In support of the province's energy policy objectives related to climate change, inclusive economic development and the sustainable development of Nova Scotia's energy resources, a

Figure 4. NSCC researchers installing a real-time water level meter in a drilled well at the NSCC Leeds Street Campus, Halifax. From right to left: Dr. Lordwin Jeyakumar, Joseph Edosa, and Nuzhat Anjum.

project was commissioned by the province in 2020 as a partnership between the Institute National de Recherche Scientifique and ENKI GeoSolutions Inc. to develop a preliminary understanding of mid to deep geothermal potential resources of onshore Nova Scotia. Project oversight was delivered through a collaboration between the departments of Energy and Mines and Agriculture, and the Offshore Energy Research Association. The Geological Survey Division (GSD) Hydrogeology Program participated on the steering committee and provided data and technical support. In addition, the Hydrogeology Program developed digital products to widely promote and distribute the project deliverables, which will be available later in the year.

The full project results are available here (Comeau et al., 2020) and a summary of the preliminary findings is presented in Figures 5-7. Highlights of the study findings include:

- Areas in Hants and Cumberland counties were identified as having a relatively high geothermal potential for electricity generation.

•Most of the province's sedimentary basins had geothermal potential for direct use of heat.

•New and emerging technologies show promise for expanding the extent of the areas of Nova Scotia that may be considered for direct-use and electricity geothermal development.

The province's legacy of coal mining offers interesting opportunities to use abandoned mines for space heating and cooling.

Groundwater Management

Changes to Health Canada Drinking Water Quality Guidelines

Health Canada periodically reviews the safe limit of water quality parameters according to the latest operational, toxicological, and epidemiological evidence. To assist NSECC with the evaluation of the potential impact of any proposed changes to the Health Canada drinking water guidelines, such as iron, calcium, magnesium, hardness, chloride, sulphate, and TDS, on private and public water supplies in Nova Scotia, Hydrogeology Program staff prepared datasets to inform Health Canada's assessment of the distribution of these well water quality parameters in groundwater.

Private Water Supplies Committee

Hydrogeology Program staff continued to have an active role on the Private Water Supplies Committee, which also includes members from NSECC and the Nova Scotia Department of Health and Wellness. Projects included planning for a pan-Canadian private well workshop and the design of a behavioural insight study with the aim of reducing barriers to testing and treatment of private water supplies.

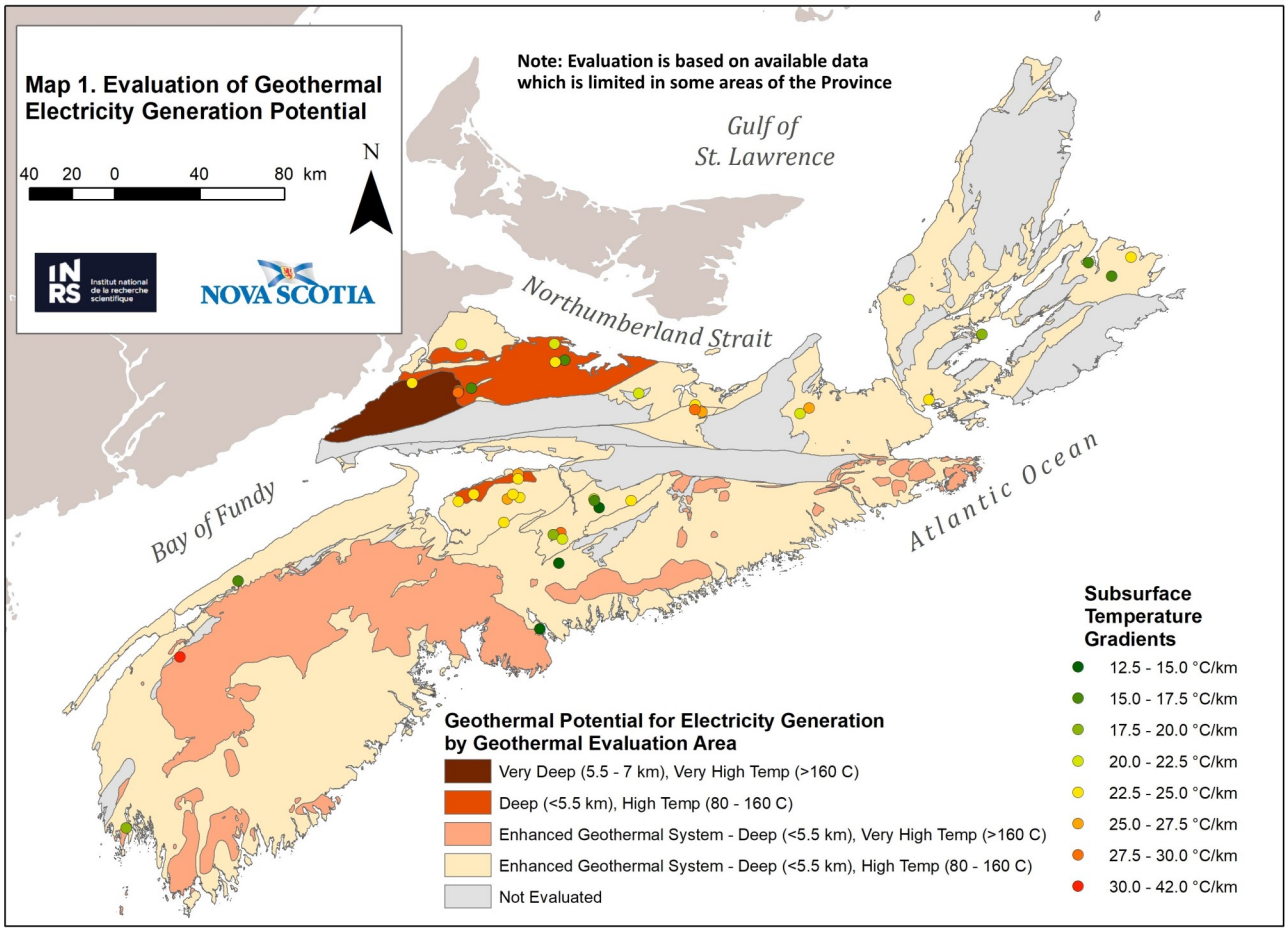

Figure 5. Geothermal potential for electricity generation by geothermal evaluation area, with or without stimulation (enhanced geothermal system), based on similar operational examples around the world (adapted from Comeau et al., 2020).

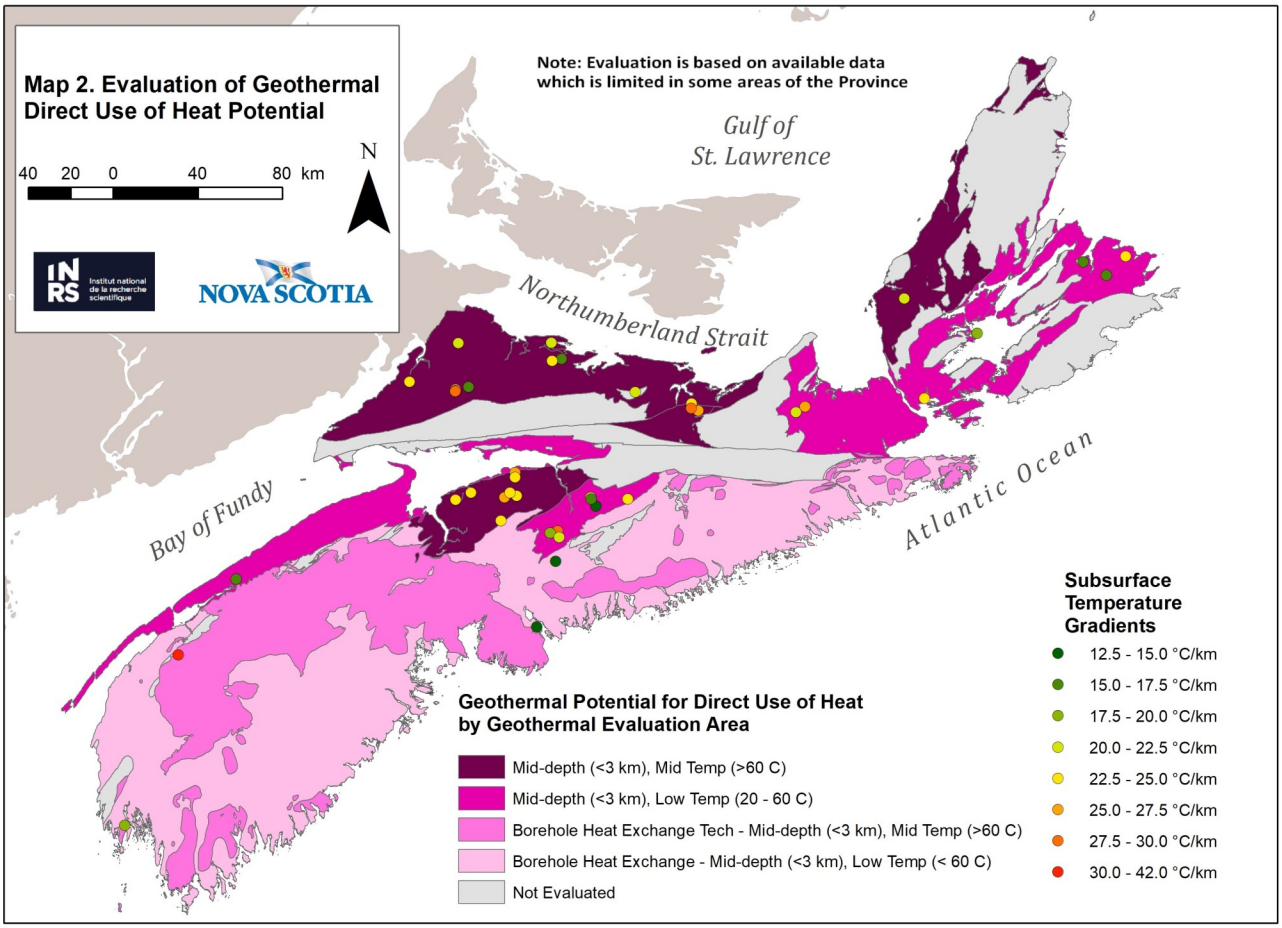

Figure 6. Geothermal potential in Nova Scotia for direct-use of heat, with or without borehole heat exchanger technology (BHE), based on similar operational examples around the world (adapted from Comeau et al., 2020).

Outreach and Support Activities

Support Activities

Geological Survey Division (GSD) staff supported various types of clients in 2020-21, including responding to requests for data and technical advice. Clients included other government departments, universities, municipalities, groundwater consultants, and homeowners. Technical support provided to universities included the provision of data and thesis supervision for various projects at Dalhousie University, including a Ph.D. investigation of groundwater flow dynamics on Sable Island, an M.Sc. investigation of coastal zone groundwater flow in Mabou Harbour, an M.Sc. analysis of spatial trends of naturally occurring contaminants and material, and social deprivation indices as a means of prioritizing public health interventions for private well users, and two M.Sc. wetland hydrology projects. Other research support includes a project examining long-term trends of groundwater temperature in provincial observation wells, an investigation into the accuracy of custom-made water level meters in drilled wells, and the distribution of aluminum in groundwater and associated threats to human health and ecosystems.

GSD staff also contributed to a regional 'hackathon' competition called Aquahacking, where entrepreneurs from across the region were challenged to create innovative solutions to some of Atlantic Canada's leading water issues. The GSD contributed to the competition as an issue leader, along with NSECC, for 'Private Well Water Safety'; one of the five water issues identified for the Atlantic Canada competition. As part of the Hydrogeology Program's efforts to raise awareness about private well safety, staff also contributed an article to the Canadian Institute of Public Health Inspectors – Nova Scotia and Prince Edward Island branch December newsletter.

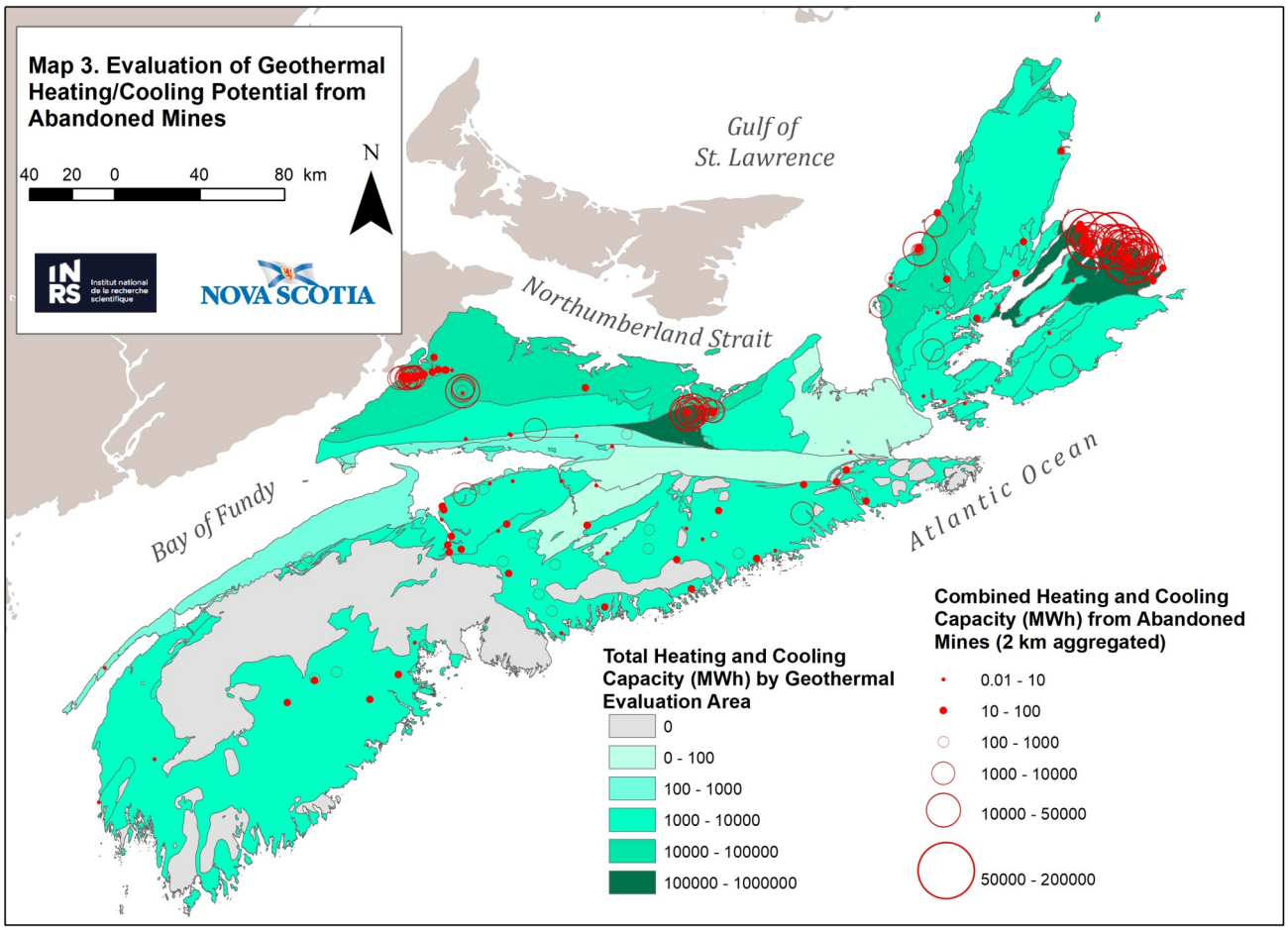

Figure 7. Total geothermal energy production capacity in Nova Scotia from abandoned mines for heating and cooling combined purposes. Mines within a radius of 2 km from each other have been aggregated for clarity (adapted from Comeau et al., 2020).

GSD staff participated as a member of an advisory committee for the Nova Scotia Community Cancer Matrix project. The aim of the project is to use our knowledge about the kinds of cancer found in Nova Scotia communities over the past 15 years to inform prevention efforts. Efforts are also continuing to develop an environmental health index to map potential exposures at various levels of geography.

Finally, GSD staff were involved with preparing submissions to book publications for the Atlantic Geoscience Society's publication the *Last Billion Years* and The Groundwater Project. Hydrogeology Program staff authored preliminary drafts of two submissions for The Groundwater Project over the past year on domestic water wells and well record databases; both of which are currently under review.

Presentations

The Hydrogeology Program delivered the following presentations during 2020-21:

- A lecture on the groundwater resources of Nova Scotia to a first year Dalhousie engineering course.
- A presentation to members of the National Dialogue on Groundwater titled 'Groundwater Management and Research in Nova Scotia – An Overview of Current Activities.'
- A presentation at the Spring into Geomatics conference titled 'Application of GIS to manage public health risks associated with private wells.'

Two lectures about drought impacts on private wells and the development of Nova Scotia's real-time shallow aquifer monitoring network were

given to students in the Dalhousie Department of Earth and Environmental Sciences, and the Dalhousie School for Resource and Environmental Studies.

Publications

The following publications by the Hydrogeology Program were released in 2020-21:

Open File Report: A Review of Private Well Contaminants, Testing, and Mitigation Behaviours in Nova Scotia (Kennedy and Drage, 2020a).

Report of Activities: An overview of Hydrogeology Program activities for April 2019 to March 2020 (Kennedy and Drage, 2020b).

Open File Report: A Manganese in Well Water Risk Map for Nova Scotia (Kennedy, 2021).

Journal Publication: Building a Low-Cost, Internet-of-Things Real-Time Groundwater Level Monitoring Network (Drage and Kennedy, 2020), Groundwater Monitoring and Remediation.

Research Directions

Over the next year, the Hydrogeology Program of the Geological Survey Division will continue to conduct significant research on geogenic groundwater hazards, participate in the contiuing work of the private water supply committee, and develop appropriate risk communication products and platforms to encourage appropriate well water testing and treatment. The Hydrogeology Program will also continue to monitor, test and refine the shallow aquifer monitoring network, and work to enhance the provincial groundwater observation well network by developing tools to improve the visualization and access to provincial groundwater level monitoring information. Other areas of focus will include data management improvements, and deep and mid-depth geothermal energy assessment.

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References

Comeau, F-A., Sejourne, S., and Raymond, J., 2020. Assessment of geothermal resources in onshore Nova Scotia, 214 p.

Drage, J. and Kennedy, G.W., 2020. Building a low-cost, internet-of-things, real-time groundwater level monitoring network; Groundwater Monitoring and Remediation, v. 40, p. 67-73. https://novascotia.ca/natr/meb/data/pubs/cs/cs_me_2020-001.pdf.

Dummer, T.J.B., Awadalla, P., Boileau, C., Craig, C., Fortier, I., Goel, V., Hicks, J.M.T., Jacquemont, S., Knoppers, B.M., Le, N., McDonald, T., McLaughlin, J., Mes-Masson, A-M., Nuyt, A-M., Palmer, L.J., Parker, L., Purdue, M., Robson, P.J., Spinelli, J.J., Thompson, D., Vena, J., Zawati, M., and with the CPTP Regional Cohort Consortium, 2018. The Canadian Partnership for Tomorrow Project: a pan Canadian platform for research on chronic disease prevention; CMAJ, v. 190, p. E710-E717. DOI:10.1503/cmaj.170292.

Health Canada, 2019. Guidelines for Canadian drinking water quality: guideline technical document–manganese; Health Canada, Ottawa, 114 p.

Kennedy, G.W., 2021. A manganese in well water risk map for Nova Scotia; Nova Scotia Department of Energy and Mines, Open File Report ME 2021-002, 35 p; https://novascotia.ca/natr/meb/data/ofr/ofr_me_2021-002.pdf.

Kennedy, G.W., and Drage, J., 2020a. A review of private well contaminants, testing, and mitigation behaviours in Nova Scotia; Nova Scotia Department of Energy and Mines, Open File Report ME 2020-001, 23 p; https://novascotia.ca/natr/meb/data/pubs/20ofr04/ofr_me_2020-004.pdf.

Kennedy, G.W. and Drage, J., 2020b. An overview of hydrogeology program activities for April 2019 to March 2020; in Geoscience and Mines Branch Report of Activities 2019-20; Nova Scotia Department of Energy and Mines, Report ME 2020-002, p. 55-60. <https://novascotia.ca/natr/meb/DATA/pubs/20re02/09ROA_2020_Kennedy&Drage.pdf>.

Kennedy, G.W., Drage, J., and Check, G., 2017. Development of indices to assess the potential impact of drought to private wells in Nova Scotia; GeoOttawa, Ottawa, October 1-4, 2017, 8 p.

Kennedy, G.W., and Polegato, A., 2017. Where does our tap water come from? An analysis of domestic water source and supply demographics in Nova Scotia; Nova Scotia Department of Natural Resources, Open File Report ME 2017-004, 18 p. <http://novascotia.ca/natr/meb/data/pubs/17ofr04/ofr_me_2017-004.pdf>.

Nova Scotia Department of Energy and Mines, 2021a: Nova Scotia groundwater atlas. Water well logs; <https://fletcher.novascotia.ca/DNRViewer/?viewer=Groundwater>.

Nova Scotia Department of Energy and Mines, 2021b: Nova Scotia groundwater atlas. Pumping tests; <https://fletcher.novascotia.ca/DNRViewer/?viewer=Groundwater>.

Sweeney, E., Cui, Y., DeClercq, V., Devichand, P., Forbes, C., Grandy, S., Hicks, J., Keats, M., Parker, L., Thompson, D., Volodarsky, M., Yu, Z.M., and Dummer, T.J.B., 2017. Cohort profile: The Atlantic Partnership for Tomorrow's Health (Atlantic PATH) study; International Journal of Epidemiology, v. 46, p. 1762-1763. doi:10.1093/ije/dyx124.