Identification and Preliminary Mapping of Surficial Aquifers in Nova Scotia

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Introduction

Surficial deposits of sand and gravel with sufficient saturated thickness and extent typically constitute excellent sources of groundwater with respect to both quality and quantity. Over the past 40 years, many of Nova Scotia's surficial aquifers have been mapped and assessed at varying scales in local to regional groundwater exploration/assessment reports (see Nova Scotia Environment, 2013a). Surficial aquifer assessments in the province include the pioneering work conducted in the Musquodoboit Harbour (Pinder and Bredehoeft, 1968) and Rights River (Trescott *et al*., 1970) alluvial aquifer systems by the Nova Scotia Department of Mines (involving the earliest published application of numerical groundwater flow modelling techniques) and the more recent (2003–2005) regional assessment of the Annapolis Valley aquifers by the Geological Survey of Canada and their partners (Rivard *et al*., 2012). In addition, the province's surficial geology has been mapped by Stea (1992) for the mainland and by Grant (1988) for Cape Breton Island, and the province's sand and gravel deposits for aggregate use have been mapped by Fowler (1985). The province-wide distribution of surficial aquifer systems in Nova Scotia, however, has not been systematically evaluated or compiled.

In Nova Scotia, buried sand and gravel deposits with significant thickness typically originated as Cretaceous fluvial materials or as Quaternary ice-contact/outwash materials that were deposited during the last deglaciation episode. The distribution of these deposits is often controlled by bedrock topography, occurring in carbonate rock sinkholes, along bedrock erosional contacts or fault structures, and in bedrock depressions/topographic valleys. Surficial aquifers composed of recent alluvium have also been identified in floodplains adjacent to major stream systems in the province. These aquifers can be an important source of cold water discharge to the stream systems, regulating stream temperatures and providing critical habitat for salmonid populations during the summer months.

Currently there are four provincial monitoring wells (Greenwood, Wilmot, Smiley's, Rainbow Haven) installed in surficial aquifers in the province (Nova Scotia Environment, 2012a) and an additional two observation wells (Beaver Bank, Milford) maintained by the Groundswell network (Ecology Action Centre, 2013). Annual water level fluctuations in these observation wells have been observed to range from approximately 0.5 to 3.5 m. Kennedy and Drage (2009) found that surficial aquifers are associated with greater median well yields and lower concentrations of trace metals, hardness and total dissolved solids compared to Nova Scotia's major bedrock groundwater-regions. Surficial aquifers are therefore often strategically targeted for municipal, industrial or agricultural water uses (large-capacity groundwater supply development). Approximately 28% of municipal groundwater supply systems in the province are at least partly supplied by surficial aquifers.

Surficial aquifers can also provide strategic opportunities for private well-water supplies (Kennedy and Utting, 2011). Households located in areas of the province not serviced with municipal water are typically supplied by individual water wells. In unserviced areas with high-intensity residential development (e.g. suburban Halifax) and underlain by bedrock aquifers with limited groundwater supply capacity (e.g. metamorphic and plutonic groundwater regions), surficial aquifers can help alleviate groundwater quantity issues by providing an alternative water supply

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source. These aquifers, however, are seldom targeted for individual household water supplies largely because their distribution is not well understood and they are associated with higher well-construction costs. A review of water well logs indicates that drillers encountering sand and/or gravel typically extend casing through this layer and complete the well in fractured bedrock (Kennedy and Utting, 2011). In some cases where bedrock aquifers are known to have limited capacity, drillers have completed surficial aquifer wells by extending the well casing into a sand and/or gravel layer and backfilling the casing with pea gravel to reduce siltation and heaving effects. Drillers rarely complete household wells using properly designed screens and gravel packing to optimize well water quality and quantity.

Objectives

The objective of the current work is to build a spatial inventory and preliminary characterization of surficial aquifers across the province through the analysis of existing stratigraphic information and relevant historical reporting. The identification and characterization of surficial aquifers may help alleviate groundwater quantity and quality issues in some areas of the province by providing alternative water supply targets for various types of water users. The aquifer mapping could also foster economic development opportunities by identifying potential water supplies for large-capacity individual or cumulative (e.g. residential development) groundwater uses. Surficial aquifers can be more difficult to manage due to their susceptibility to surface contamination (Rivera, 2014). An inventory of key surficial aquifers should improve the province’s understanding of these water resources and assist groundwater protection and management efforts.

Methods

Historical groundwater assessment reports produced by government agencies were reviewed, and any surficial aquifers delineated in these studies were georeferenced and compiled in an ArcGIS format. Test-hole and pumping-test information associated with surficial aquifers referenced in the historical reporting but missing from provincial groundwater databases (Nova Scotia Department of Natural Resources, 2013a, 2013b) was also digitized.

The general approach previously used by Kennedy and Utting (2011) for mapping surficial aquifers in suburban areas of Halifax was applied to the provincial surficial aquifer mapping project. The focus of the mapping was to identify surficial aquifers that were deeper (potentially buried) than, and may offer some protection from surface contamination compared to, the province’s more regionally extensive shallow, unconfined high-permeability surficial deposits, which are often accessed by dug wells. A minimum depth of 12 m was used for screening purposes because this depth represents approximately two lengths of well casing and is used in the Nova Scotia Groundwater Under Direct Influence of Surface Water (GUDI) Protocol as the minimum length of well casing to pass Step 1 of the GUDI Assessment Process for the well construction criteria (Nova Scotia Environment, 2012b). The following screening criteria were therefore applied to identify wells intercepting surficial aquifers:

- Drilled wells completed in a surficial aquifer for a water supply (typically these wells are at least 12 m deep). Note that the stratigraphic record did not always indicate the presence of sand and/or gravel layers.

- Drilled wells intercepting at least 1 m of sand and/or gravel below 12 m depth (below ground surface).

A number of well records meeting these criteria but with poor location accuracy were identified in the well logs database. The location of these water wells was improved where possible using available civic address information contained in the well record. The subset of water well logs indicating the presence of surficial aquifers was then filtered to exclude any water well locations that were not accurate to at least the property level (e.g. location accuracy to within ~100 m).

A merged table of water wells, test holes and pumping tests—all of which intercept surficial aquifer materials—was created (i.e. surficial aquifer points). This table was imported to ArcGIS (~3000 records). The following steps were then used to process the spatial data in ArcGIS:

1. The 'Generate Near Table' geoprocessing tool was used to select only surficial aquifer points that have at least two other surficial aquifer points located within 500 m of each other.

2. The resulting point shapefile was then buffered by 500 m to create a polygon, and the 'Dissolve' geoprocessing tool was applied to the resulting point-buffer polygon to merge overlapping portions of polygons and create single-part polygon features with unique IDs.

3. A spatial join was then performed between the point shapefile generated in Step 1 and the polygon shapefile generated in Step 2 so that the polygon IDs could be transferred to the surficial aquifer points and each cluster of points could be associated with a unique polygon ID.

4. Using the 'Minimum Bounding Geometry' geoprocessing tool, the clusters of surficial aquifer points (grouped by surficial aquifer ID) were outlined (convex hull option), and unique surficial aquifer polygons enclosing these points were generated. The surficial aquifer polygons were then smoothed using the 'Smooth Polygon' geoprocessing tool (Bezier option), and the resulting polygons were buffered by 50 m for improved visualization.

5. The resulting surficial aquifer polygons were reviewed. Aquifers were added or merged, or boundaries refined, based on available surficial geology mapping (e.g. Stea *et al*., 1992) and a more detailed review of well log stratigraphic information surrounding the polygons. During this review, a maximum separation distance of 1000 m between any two surficial aquifer points was used for the purpose of enclosing a grouping of surficial aquifer points within a given surficial aquifer polygon.

Results

A total of 206 surficial aquifers were identified based on the spatial interpolation of available stratigraphic information. There was no minimum aquifer size established for the interpolated aquifers. In some areas where there was limited subsurface information available and points were located close together, the interpolated surficial aquifer features were very small; however, it is likely that the identified surficial aquifers are indicative of the presence of a larger feature. Hence, aquifer boundaries range from reasonable assessments (where extensive subsurface information is available) to general indications of aquifer presence (scarce information availability). The boundaries generated using the screening criteria (>12 m depth below ground surface) exclude lateral and more shallow extensions of the aquifer systems. It should also be noted that adjacent surficial aquifers may be part of a continuous feature, and as more stratigraphic information becomes available to fill in spatial data gaps, adjacent surficial aquifers may be merged.

Figure 1 shows the distribution of surficial aquifer points used during the interpolation and the distribution of municipal wells that use surficial aquifers. A selection of some of the key potential surficial aquifers is shown in Figure 2, and a preliminary characterization of the aquifers is summarized in Table 1. The aquifers shown in Figure 2 represent some of the larger, greatest permeability and/or most utilized surficial aquifers in the province, including surficial aquifers supplying municipal water supplies. A comprehensive map series is planned to be released in 2014 as Department of Natural Resources open file maps.

The largest surficial aquifer systems identified during the mapping project were generally located in the Annapolis Valley and in the central areas of the province in the Shubenacadie and Musquodoboit Carboniferous basins. Regional assessments of the Annapolis Valley surficial aquifers previously were conducted by Trescott (1968) and Rivard *et al*. (2012), and regional assessments of surficial deposits in the Shubenacadie and Musquodoboit basins were conducted by Stea *et al*. (1996) and Stea and Pullan (2001) during resource exploration work of Cretaceous deposits for industrial clay and silica sand. More detailed stratigraphic information is available in these reports.

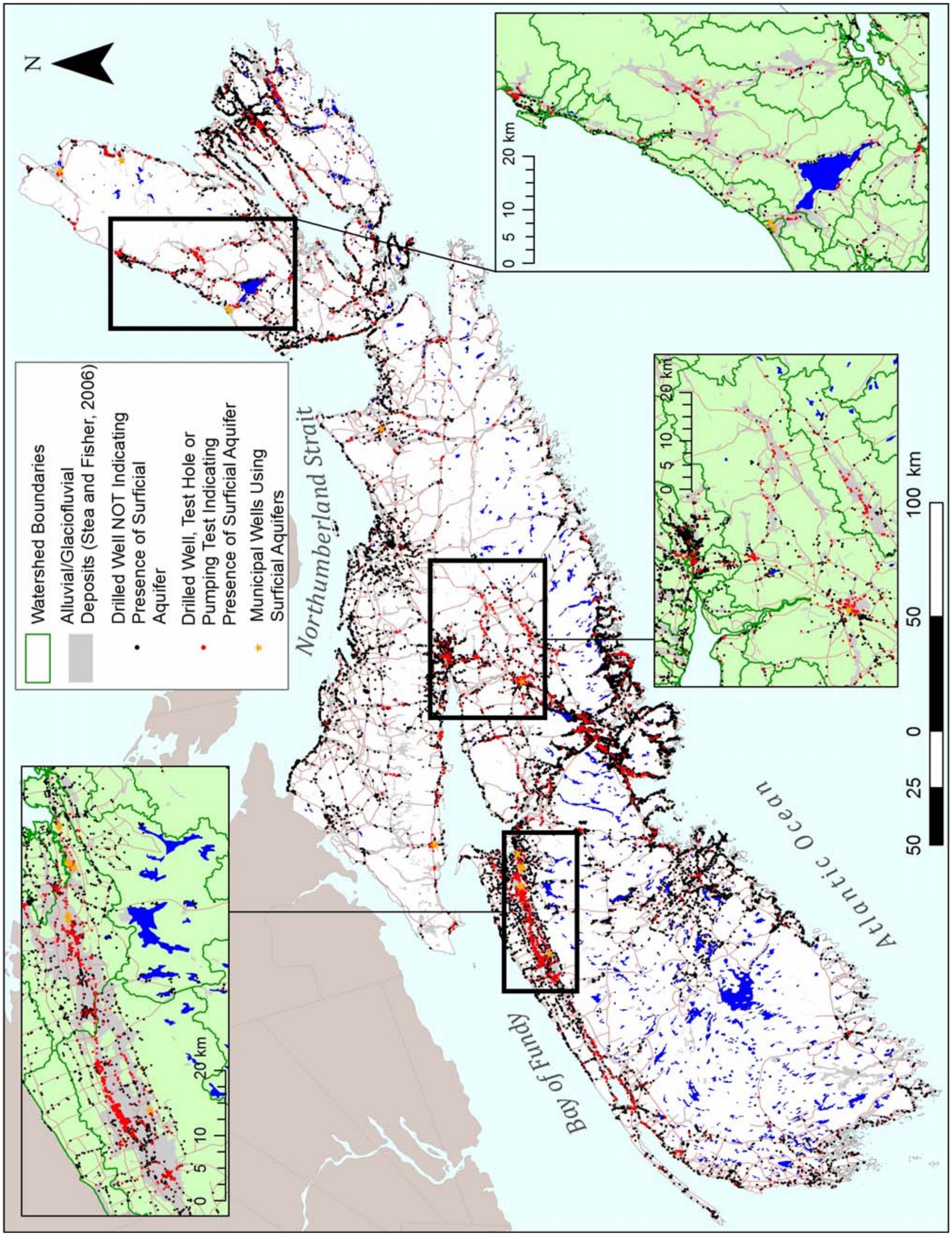

Figure 1. The distribution of surficial aquifer points used during the mapping of surficial aquifer areas, and the distribution of municipal wells using surficial aquifers.

Approximately 16% (33) of the 206 surficial aquifers identified during the map project contain a well that has been subject to a pumping-test yield assessment. The Hardwood Lands surficial aquifer (SA-164), which supplies the Indian Brook First Nation, had the greatest interpreted mean transmissivity (3884 m^2/d) and long-term (20 year) well yield (4850 Lpm) based on pumping test results. The Musquodoboit Harbour (SA-46) and Wolfville (SA-191) surficial aquifers had the next highest transmissivity and long-term yield values in the province. Analysis of well yields reported in the NS Well Logs Database (Nova Scotia Environment, 2013b) indicates that the surficial aquifers with the greatest median well yield (minimum n = 5, values range from 227 to 681 Lpm) include SA-68 and SA-66 in the Cornwallis River watershed and SA-176 in the Salmon/Mira River watershed. Surficial aquifer SA-66 supplies the Town of Kentville with municipal groundwater.

Approximately 17% (35) of the 206 surficial aquifers identified during the map project have available well-chemistry data (Nova Scotia Department of Natural Resources, 2013c). These data show that only three (SA-25, SA-62, SA-65) of the identified surficial aquifers have an exceedance of a Canadian Drinking Water Quality Guideline (CDWQG) (Health Canada, 2012) health-based maximum acceptable concentration. All three of these exceedances were for arsenic. A number of the surficial aquifers, however, overlie Windsor Group rocks, which can impart elevated concentrations of sulphates, hardness and total dissolved solids to groundwater in these aquifers. Elevated concentrations of iron and manganese compared to CDWQG criteria are also common in surficial aquifers throughout the province.

Although detailed estimates of groundwater use are not available for surficial aquifers throughout Nova Scotia (see Kennedy *et al.*, 2010), surficial aquifers supplying municipalities tend to have the greatest groundwater usage, with the highest reported surficial aquifer extraction rates reported for the Kentville (SA-66), New Minas (SA-67), Wolfville (SA-191) and Shubenacadie (SA-65) municipal water systems. The glaciofluvial aquifer SA-61 in the Annapolis River watershed had the greatest number of wells completed in the aquifer. Other aquifers with a large number of individual users based on well log data include three surficial aquifers in the Shubenacadie watershed (SA-3, SA-65 and SA-72) and a surficial aquifer located in the Cheticamp watershed (SA-116). The three deepest surficial aquifers identified during the map work were located in the Sackville River watershed (SA-4), the St. Mary’s River watershed (SA-87) and the Shubenacadie River watershed (SA-3), with sand and/or gravel materials encountered at depths greater than 50 m.

Discussion and Recommendations

The preliminary surficial aquifer map (Figure 2) provides a foundation for additional assessment and classification. The map should be published in various formats tailored to the needs of potential end-users after consultation with them (e.g. municipal planners, water managers, drillers, developers), and it should be updated as new stratigraphic information becomes available. The surficial aquifer map does not exclude areas unsuitable for groundwater supply development due to land-use restrictions (e.g. protected wetlands, quarries) and environmental concerns (e.g. seawater intrusion, contaminant release, flood risk, watercourse baseflow maintenance).

In many cases, the surficial aquifer boundaries do not correspond to surficial geology mapping of aquifer materials (alluvial, glaciofluvial) since surficial geology mapping is based largely on surface expression, whereas the interpreted surficial aquifer boundaries integrate subsurface information through interpolation of stratigraphic data. The surficial aquifer mapping can be used to supplement the surficial geology mapping and provide a more refined drill target or higher probability of encountering buried surficial aquifer materials. It should also be noted that the mapping does not consider multi-layered aquifer systems.

In strategic areas, especially where available subsurface information is limited, field activities should be conducted to better characterize the aquifers. These activities may include test drilling, geophysical surveys, grain-size analyses and groundwater-chemistry testing. Other sources of

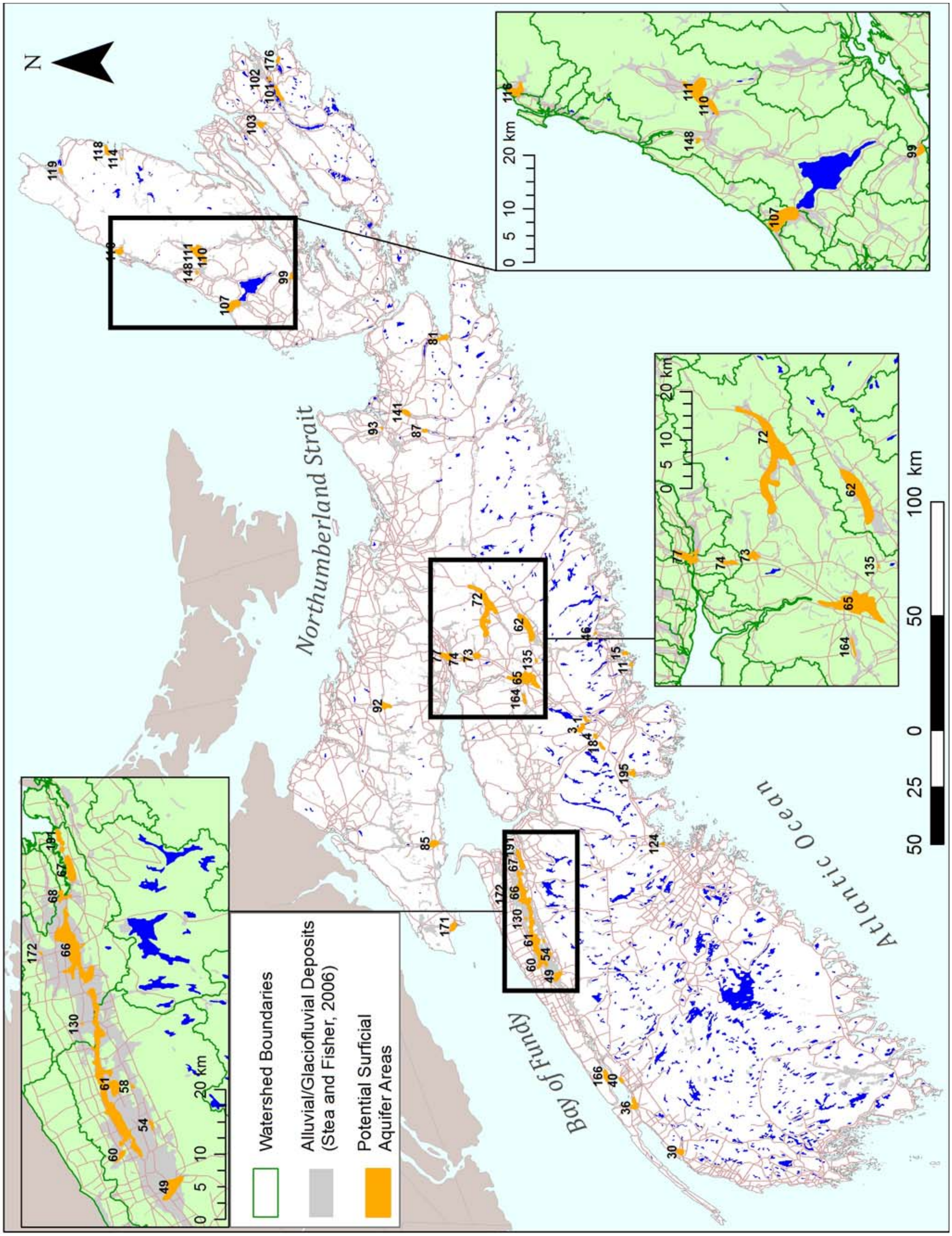

Figure 2. The distribution of key potential surficial aquifer areas in Nova Scotia.

stratigraphic information could also be incorporated to support the mapping approach presented here, including diamond-drill holes from mineral assessment activities in the province and Nova Scotia Department of Transportation and Infrastructure Renewal geotechnical logs.

Where detailed stratigraphic information is available, 3D mapping showing the depth, stratigraphy and subsurface extension of surficial deposits should be developed. Also, estimates of groundwater baseflows to surface water and estimates of aquifer sustainable yield should be generated. These aquifers could also be evaluated using groundwater vulnerability assessment techniques (e.g. DRASTIC, Aller *et al.*, 1987). It is recommended that a classification system be developed and applied to the surficial aquifers of Nova Scotia based on quality, quantity, utilization (e.g. type and abstraction rate) and vulnerability characteristics to increase public knowledge of the resource and to assist water resource protection and management.

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Table 1. Summary information of key surficial aquifers in Nova Scotia. SA: Surficial Aquifer, GW: Groundwater,

Aquifer ID	SA Area (m^2)	Primary or Secondary Watershed	Municipal GW System Using SA	Number of Pumping Tests in SA	GW Chemistry Available for SA?
SA-72	42634325.1	Shubenacadie R.			n
SA-65	30733578.4	Shubenacadie R.	Shubenacadie	6	y
SA-61	27057064.4	Annapolis R.		3	y
SA-62	22765724.4	Musquodoboit R.		5	y
SA-66	17970112.7	Cornwallis R.	Kentville	11	y
SA-107	12989748.2	Margaree	Inverness	4	y
SA-111	9976870.2	Margaree R.		1	y
SA-85	5570767.3	Parrsboro R.	Parrsboro	5	y
SA-77	5468297.9	Farnham Brk.		4	y
SA-166	4762473.9	Annapolis			n
SA-49	4548744.6	Annapolis R.		2	y
SA-92	4416020.4	Wallace R.			y
SA-81	4282335.4	Clam Harbour/St. Francis		1	n
SA-101	4205609.2	Mira R.			y
SA-171	4149766.4	Parrsboro			n
SA-36	3891910.2	Sissiboo/Bear			y
SA-3	3741698.7	Shubenacadie R.		2	y
SA-67	3675773.8	Cornwallis R.	New Minas	11	y
SA-116	3647752.1	Cheticamp R.		1	y
SA-141	3645572.5	South R.			n
SA-30	3334904.3	Sissiboo/Bear			y
SA-110	2732871.2	Margaree R.			n
SA-118	2589086.0	Wreck Cove			n
SA-73	2506510.8	Shubenacadie R.		4	y
SA-195	2328529.4	Sackville			n
SA-103	1865451.9	Sydney R.			n
SA-74	1567897.9	McClures Brook			n
SA-191	1519398.7	Cornwallis R.	Wolfville	12	y
SA-99	1384303.6	Skye R.		2	n
SA-40	1142041.5	Moose R.		1	n
SA-68	1121654.7	Cornwallis R.			n
SA-18	943159.5	Sackville R.			n
SA-87	862654.0	St. Mary's R.			n
SA-176	839626.5	Salmon/Mira			n
SA-15	818335.9	Musquodoboit			n
SA-60	773022.5	Annapolis R.			n
SA-164	685968.4	Shubenacadie R.		3	y
SA-1	633289.7	Shubenacadie R.			n
SA-4	536076.0	Sackville R.			n
SA-102	496383.3	Mira R.			n
SA-119	492499.7	Middle, South Aspy R.	Dingwall	1	y
SA-54	359929.6	Annapolis R.	Greenwood	4	y
SA-11	298791.4	Porters Lake			y
SA-124	282667.3	Gold		1	y

WL: Water Level, mbg: metres below ground, Lpm: litres per minute, Q_{20}: sustainable well yield.

Number of Govt. Test Holes Intercepting SA	Number of Bedrock Wells (Well Logs) Intercepting SA	Number of Wells (Well Logs) Completed in SA	Median SA Well Depth (mbg)	Median SA Well Static WL (mbg)	Median SA Well Yield (Lpm)	Mean SA Q_{20}[1] (Lpm)	Study ID
	2	41	15.8	5.5	45.4		
8	20	63	35.9	12.2	90.8	474.2	f
8	189	294	19.8	7.3	68.1	170.5	a
10	2	38	29.5	12.2	68.1	318.0	c
12	132	22	26.8	5.8	454.0	1443.6	a
11	1	6	25.6	7.6	90.8	1678.1	g
	1	37	17.7	11.6	31.8	81.8	
	2	7	30.5	13.9	90.8	562.7	
7	14	16	13.1	4.6	40.9	1022.7	b
	3	5	21.3	7.6	68.1		
2	34	8	11.9	4.3	49.9	131.8	a
	3	11	35.9	2.6	90.8		
	4	11	47.2	4.6	90.8	104.5	
	5	25	15.8	6.1	68.1		
	9	3	21.9	2.4	1362.0		
	13	8	37.0	21.3	79.5		d
	31	43	54.8	18.3	54.5	29.9	
1	14	11	23.1	10.1	45.4	390.9	a
	2	40	14.6	9.1	31.8	2523.6	
2		4	16.1	7.8	13.6		
	5	7	22.8	3.0	136.2		
	2	15	12.8	3.0	90.8		
		35	16.8	6.1	31.8		
2	2	37	11.6	2.1	68.1	862.3	b
	11	9	43.4	7.2	45.4		
	19	12	25.1	4.6	56.8		
	6	5	16.4	2.1	136.2		
2	8	9	31.2	7.6	204.3	2192.9	a
	1	10	18.7	3.4	38.6	238.6	
	6	4	20.6	7.9	136.2	45.5	
1	7	6	35.0	6.1	681.0		a
	7	38	30.5	2.1	45.4		
		5	54.8	3.0	136.2		
	1	5	31.1	7.6	227.0		
	5	8	35.0	9.9	113.5		
	6	23	30.5	9.1	79.5		a
1		2	18.3	4.3	68.1	4854.7	i.
	29	19	36.5	12.2	45.4		
	9	14	57.9	22.1	79.5		
		8	15.1	6.7	68.1		
	1	5	19.3		113.5	181.8	
4	3	1	25.9	7.6	681.0	1116.6	a
	11	5	44.2	21.3	136.2		
	2	2	28.2	12.2	68.1	136.8	

(Table concludes on the following pages)

Table 1. *(Concluded)*

Aquifer ID	SA Area (m^2)	Primary or Secondary Watershed	Municipal GW System Using SA	Number of Pumping Tests in SA	GW Chemistry Available for SA?
SA-148	262131.1	Margaree R.			n
SA-135	169891.2	Shubenacadie R.		1	y
SA-58	168273.7	Annapolis R.			n
SA-172	76915.3	Cornwallis R.			n
SA-130	70445.9	Cornwallis R.			n
SA-93	50426.2	Rights R.	Antigonish II	7	y
SA-46	44061.9	Musquodoboit R.		1	y
SA-114	8243.9	Power Brk.	Ingonish Beach	2	y

[1] Long-term safe pumping rate for a well is calculated using the 20 year safe well yield calculation (Farvolden, 1959).

Study ID:
a. Canadian Groundwater Inventory: Regional Hydrogeological Characterization of the Annapolis Valley Aquifers (Rivard *et al*., 2012)
b. Hydrogeology of the Truro Area, NS (Hennigar, 1972)
c. Hydrogeology of the Musquodoboit River Valley, NS (Lin, 1970)
d. Hydrogeology and Groundwater Flow Systems of the Smiths Cove Area, NS (Lin, 1975)
e. A Resistivity Study of the Rights River Aquifer, Antigonish, Nova Scotia (MacPherson and Peters, 1972)
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Number of Govt. Test Holes Intercepting SA	Number of Bedrock Wells (Well Logs) Intercepting SA	Number of Wells (Well Logs) Completed in SA	Median SA Well Depth (mbg)	Median SA Well Static WL (mbg)	Median SA Well Yield (Lpm)	Mean SA Q_{20}[1] (Lpm)	Study ID
	1	3	16.4		136.2		
		3	19.2	9.7	68.1	58.0	
		4	32.7	4.6	124.9		a
		3	31.1	3.0	181.6		a
	1	5	17.4	2.0	136.2		a
1		2	18.7	2.6	692.4	1681.1	e
3	1						h.
		3	19.2		454.0	626.6	

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