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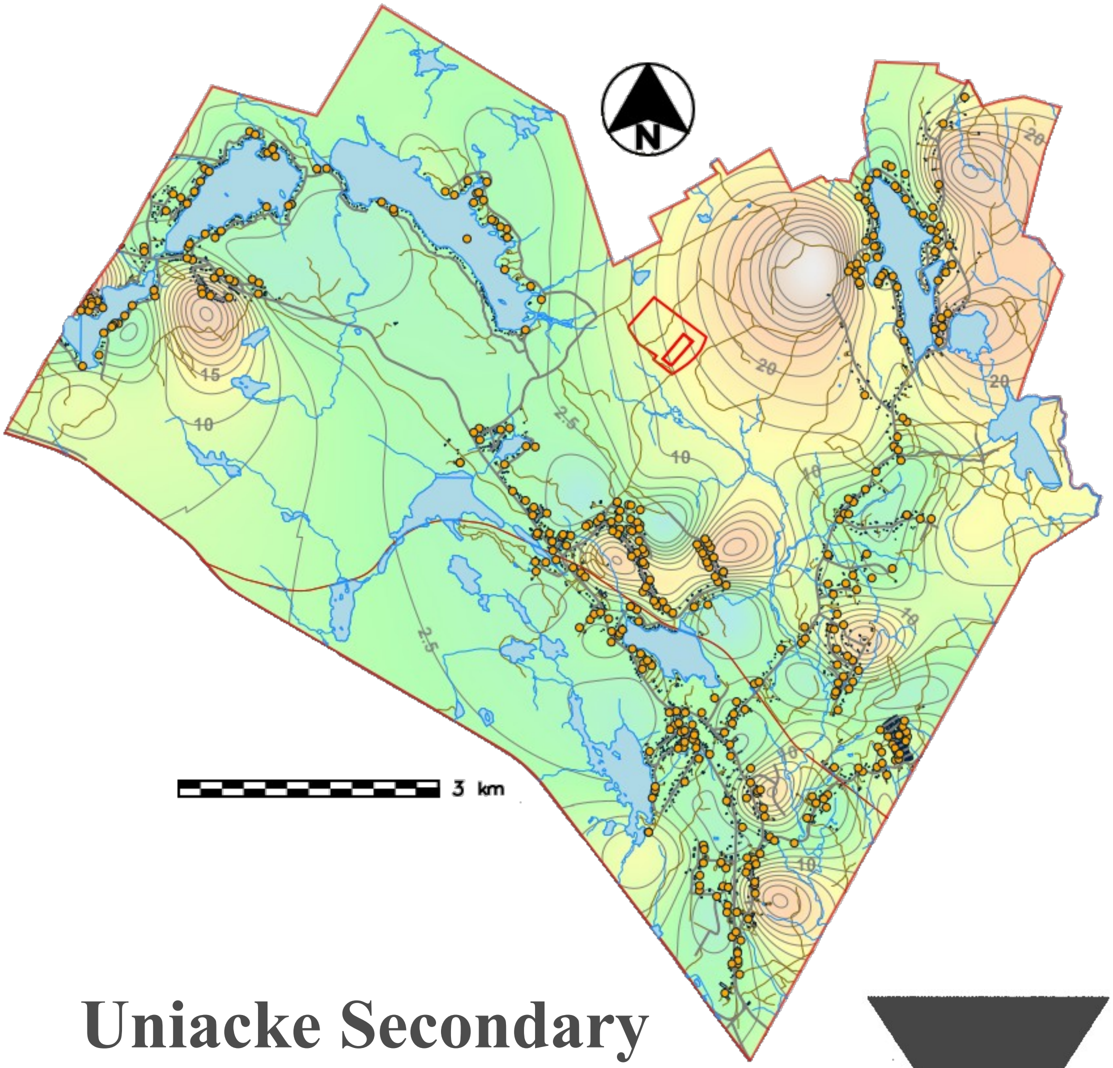

Uniacke Secondary Planning Strategy Groundwater Study

Prepared for:
Municipality of East Hants

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Study summary

The Uniacke SPS study area, and more specifically the Uniacke GMA within it, one in which the Municipal Planning Strategy is to promote and encourage residential and commercial growth. And due to the current national and local housing supply pressures, good highway access to and close proximity of the area to the Halifax urban centre, the Uniacke SPS study area should be expected to see significant and steady grown over the nearer and more distant future terms.

However, policy statements for the Mount Uniacke GMA indicate that Council will consider the provision of Municipal water and wastewater infrastructure only when the development density dictates the need and it is in East Hants' fiscal capabilities to do so. The appropriate density has not been achieved to date. As a result, East Hants is considering encouraging limited density increases through the use of on-site services, and those resources need to be properly understood.

When submitting applications for rezoning properties, developers are asked to demonstrate that their development will not adversely affect groundwater for existing residents and that there is sufficient groundwater for the proposed development. But this is costly and time consuming for developers, and those groundwater studies typically only deal with the specific properties to be developed, which may not be adequate in the long-term as more of the Mount Uniacke GMA and the Uniacke SPS areas as a whole become developed.

This study looks at the geology and hydrogeology of the entire Uniacke SPS area – it takes a holistic approach to help assess general groundwater quantity and quality of the study area; the technical suitability, potential strengths, and groundwater supply constraints that the area may present; and other facets of groundwater supply development for the entire Uniacke SPS area. Thus the purpose of this study is to serve as a resource for MEH staff to evaluate new development for the community, and to help Council in deciding where new growth can occur, how much growth might be able to be supported with on-site water services, or whether to use a more cautionary approach to development in specific areas.

As such, the scope of this assignment is to carry out a desktop review of currently available data, with mapping to be included as required to help support its findings, to:

- Identify groundwater supply issues for the existing property owners within the Uniacke SPS study area.
- Identify known water quality issues within the area and note whether those issues would be costly for homeowners to treat.
- Characterize the general availability of water in the community, such as:
    - areas where water quantity/quality would provide challenges to existing and new residents of that area, including poetntial well interference to existing residents,
    - areas where water is plentiful and be be promoted for development, and
    - expected impacts to existing and potential future water supply as the community develops.
- Recommend any further investigation or study as warranted.

This report includes two “primer” information sections – information necessary for readers to understand what this report presents in the later sections, and as required for them to make proper planning policy decisions for an area serviced by groundwater resources:

- one on aquifers that covers different types of aquifers and how they and wells work, and
- another on the complex and significant geologic history of Nova Scotia, which is entirely responsible for aquifer conditions present at the Uniacke SPS study area.

So readers unfamiliar with aquifers and local geology are encouraged to read those two sections.

The geology at the Uniacke SPS study area – which today is mostly rural area but with a past history of gold mining – is the result of a long (over 200 Ma) history of tectonic continent and mountain building – of the aggregation of foreign land masses and of submarine sedimentary deposits many kilometres thick to form what is now Nova Scotia. The rocks of these land masses were extensively folded and fractured as a mountain chain was created that many was comparable to today’s Himalayas. A a part of this process, granitic plutons floated into the roots of those mountains, serving as the engine for hydrothermal fluids to mobilize and concentrate mineral deposits at numerous locations within and around the Uniacke SPS study area.

That period of mountain building was followed by about 200 Ma of erosion and more recent glaciations. The result is the exposure today at or just below surface of tightly folded, mostly vertically dipping and heavily fractured thick sequences of metamorphosed sediments and granitic plutons through which the only pathway for groundwater is via their fracture systems.

The bedrock folds and related cleavage in the Uniacke SPS study area strike mostly northeast-southwest, whereas the bedrock joints, fractures and faults strike sub-parallel to the folds as well as strike mostly northwest-southeast, defining the directions in which groundwater flows.

A lineament analysis done for this assignment to augment the available limited data suggests that locally, lineament-interpreted faults strike in three primary directions and four secondary directions, many of them related with each other, with the primary faults trending east-northeast with 0.5 km to 3 km spacing frequency that parallels Provincial-wide thrusts and dextral strike-slip faults (one of which can be traced in shaded relief form the northern part of the Uniacke SPS study are to over 50 km northeast, with local drag folding and block rotations between faults); and two sets that strike west-northwest and northwest at 0.2 km to 1.6 km spacing frequency that parallel the province-wide sinistral strike-slip fault system that defines topographic fabric of the eastern shore of Nova Scotia.

The bedrock aquifer units (HUs) present at he Uniacke SPS study area include the Early Cambrian age coarser-grained metasedimentary Taylors Head Formation, and the finer-grained Beaverbank Formation (largely siltstone), Cunard Formation (black slate), and Middle to Upper Devonian granodiorite bedrock HUs. All of these depend entirely on secondary permeability (fracture flow) to deliver water to wells. The Taylors Head Formation HU underlies about 76.5% of the Uniacke SPS study area.

The bedrock HUs are overlain by three Quaternary HU's – two glacial tills that cover about 64% of the Uniacke SPS study area and each have different physical hydrogeological characteristics, and related drumlins, which all combined range from non-existent to slightly over 35 m in thickness (mean around 7 m, median of 5 m) within the Uniacke SPS study area.

The latest well log database (current to the end of 2020) contains records for 1,547 wells within the roughly 17km by 17km mapping area used for this study assignment, of which only 6 are dug wells (dug wells are grossly underrepresented in the database). Of the 1,571 drilled wells, 24 are reported to be commercial and/or for public use and one (in HRM) is municipal. However, many of these wells are poorly georeferenced, such that data from them can serve only for crude statistical analysis, and not to help characterize the individual bedrock HUs. But based on the width of the bedrock units at surface and known accuracy of their contact locations, a location accuracy threshold of 125 m for wells was deemed adequate to serve as data for more detailed evaluations. As such, of the 1,571 well log records, 781 could be used to assess individual bedrock HUs within the 17km x 17km greater study area, and 483 could serve to provide data within the Uniacke SPS study area. Of those, only two plot as being drilled into the granodiorite, an insufficient number to assess that bedrock HU.

The bulk of the data with accurate locations is from residential wells, which drillers typically advance only as deep as is required to meet domestic needs. So the database contains a mix of water yields and well depths from which it is difficult if not impossible to properly compare different bedrock HUs. So for this study, well yield data was individually normalized to the amount of open borehole (vertical distance from well bottoms to bottom of casings) for each of the 781 database records with accurate locations to obtain values of LPM/30m (litres per minute per 30 metres of exposed bedrock), a value that's akin to well specific capacity, which can be used to compare and assess different bedrock HUs and spatial aquifer capabilities. Such calculations were possible for 430 wells drilled within the Uniacke SPS study area.

Based on well data with good location accuracy, wells within the Uniacke SPS study area had slightly lower yields from all bedrock HUs combined than the average for the 17km x 17km greater study area, although none in the Uniacke SPS study area reported zero yield.

Within the Uniacke SPS study area, well yields from all bedrock HUs combined ranged from 0.5 to 97.9 L/min (average/median of 14.6/7.7 L/min), or 0.2 to 89 LPM/30m (average/median of 11.3/3.6 LPM/30m). Based on average LPM/30m values, the Cunard Formation HU appears to be the most highly productive (average/median 15.3/11.2 LPM/30m, but from only 27 data values), followed by the Taylors Head Formation HU (average/median 11.2/3.4 LPM/30m, from 348 data values), then the Beaverbank Formation HU (average/median 10.3/3.2 LPM/30m from 53 data values). The highest and lowest values were from the Taylors Head Formation HU (279.6 and 0.2 LPM.30m), followed by the Beaverbank Formation HU (139.8 and 0.3 LPM/30m), then the Cunard Formation HU (52.1 and 1.4 LPM/39m).

The higher maximum values for LPM/30m from the Taylors Head Formation HU are likely a function of the greater competence of that mostly greywacke bedrock unit, in which water-bearing fractures encountered at wells should be expected to extend greater distances from wells and have larger apertures. By comparison, water-bearing fractures encountered in wells drilled into the Beaverbank or Cunard Formation HUs, which due to their finer grained nature and thus, lower competence, would are expected to extend over shorter distances from wells and be filled with muds or clays smeared within them as material that had been ground up by the motion along fractures and fault zones.

There is publicly available pumping test data for 16 wells within the Uniacke SPS study area, and unpublished data for three wells located about 1.5 km outside the study area which we were able to access. The values for transmissivity (T) from all of these ranged from 0.03 to 8.13 m^2/day (mean 1.44 m^2/day), from which calculated safe yield (Qs_{20}) values ranged from 2.0 L/min to 88.8 L/day (mean 19.1 L/day), with values for storativity (S) from only four tests (three from outside the study area) ranging from $8.12x10^{-5}$ to $8.06x10^{-4}$ (mean $5.43x10^{-4}$), which suggest semi-confined to confining conditions for the water-bearing fractures in the wells tested.

Calculations suggest there is sufficient groundwater recharge within the Uniacke SPS study area to meet the needs of over 22,800 homes (assuming a need of 1,350 L/day/home), and sufficient aquifer water storage in the bedrock and Quaternary HUs to meet drought conditions for that number of homes for between over 9 to 37 years. However, well interference may be an issue. While there currently is insufficient data to calculate the degrees of well interference to expect across the Uniacke SPS study area, calculations done for other developments with similar bedrock geology suggest that new lots within the Uniacke SPS study area may need to be as large as 1.3 to 1.7 hectares to help avoid well interference in denser developments.

Total well depths reported within the Uniacke SPS study area range from 13.7 to 191.5 m (average 78.2 m) and casing lengths range from 2.4 m (no longer allowed, since the minimum casing length required for domestic wells under the current well drilling regulations is 6.12 m) to 28.1 m (average 11.7). Based on these numbers and from interpreted average overburden thickness, new well construction in the southwest central parts of the Uniacke SPS study area may be expected to cost \$5,800 to \$13,800 at lower driller price ranges, and \$7,400 to \$17,800 at higher driller price ranges. Due to the presence of drumlins and generally thicker overburden in the western, northern and eastern-southeastern boundary parts of the Uniacke SPS study area, new well construction in these locations may be expected to cost \$13,800 to \$20,700 at lower driller price ranges, and \$17,800 to \$26,800 at higher driller price ranges.

Overburden conditions (adequate saturation soil thickness, water depths that can be reached by excavators) appear adequate to construct dug wells over 40% of the Uniacke SPS study area.

No data is available on dug well water quality for the Uniacke SPS study area. However, dug wells should be expected to produce generally good quality water, although that water may be more corrosive to plumbing systems than water from produced from drilled wells, and dug wells are more prone to experiencing surface water contamination, or to having groundwater levels in them drop to below pump intakes, or below the bottoms of wells, than are drilled wells.

All three of the bedrock HUs for which there is water quality data is available were found to produce generally good quality, alkaline, moderately hard to hard, calcium-bicarbonate type waters with near to slightly above neutral pH. Some wells within the Uniacke SPS study area were found to produce calcium chloride type water due to contamination by road salt applications. Iron values may be elevated, but elevated manganese values appears to be a more frequent problem. Arsenic may also be expected to be elevated and require treatment. All of these metals are naturally inherent to the bedrock in the area.

That said, arsenic, iron, manganese, and perhaps mercury may arise as human-caused well water quality issues of concern at or near the former South Uniacke and Mount Uniacke Gold Districts. Also, harm may arise regarding both yields and water quality for wells located near the existing (and expanded) Mount Uniacke quarry, and also possibly in the northern-most parts of the Uniacke SPS study area, which is at the southern edge of a Wind Energy Zone – a community in Ontario is currently experiencing significant water quality problems due to infrasound emissions from windmills through their aquifer, and similar concerns appear to be rising in the UK.

Water treatment options for the issues at hand are provided.

As with any community with on-site domestic wells, care must be exercised to mitigate against possible growing urban-type sources of groundwater contamination. These may include road salt, petroleum product spills, fertilizers and pesticides, and leaking central sewage collection systems. A number of suggestions for MEH and developers to help increase the amounts of data and levels of understanding of the complex hydrogeology of the Uniacke SPS study area and to foster proper monitoring, maintenance and protection of those valuable well water resources.

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Report disclaimer

This report was prepared for the sole benefit of the Municipality of East Hants for the purpose of describing the nature of the source water for on-site water supply wells within the boundaries of the Uniacke SPS study area, East Hants, NS. This report cannot be used for any other purpose for by any other person or entity without the express written consent of earth-water Concepts inc., and the Municipality of East Hants.

The work and interpretations in this report are based solely on desktop evaluations and other data available at the time work was carried out. The data and interpretations presented in this report are based solely on the conditions present and data available when the work was performed. There are levels of uncertainty adherent to any geoscience desktop assessment of this sort which are subject to change as different information becomes available. Data obtained for this study represent conditions about a limited area surrounding the subject study area and as such, the information obtained can be expected to be variable with respect to location and time. This work is specific to the Uniacke SPS study area, conditions and land use considerations described herein, and cannot be used or applied under any circumstances to a location and situation that has not been specifically outlined.

The information presented in this report is based upon work undertaken according to sound geoscience practices by trained professional under a set scope of work and budget. Should future investigations provide information which supplements or differs from the information presented in this report, we request to be notified and permitted to reassess the results and interpretations provided herein.

THE ASSOCIATION OF PROFESSIONAL GEOSCIENTISTS OF NOVA SCOTIA
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Sr. Hydrogeologist/Hydrologist, President
earth-water Concepts inc.

1.0 Introduction

The Municipality of East Hants (MEH) has commissioned earth-water Concepts inc. (ewC) to complete a groundwater study for the Uniacke Secondary Planning Strategy (SPS) area, NS.

1.1 Background and purpose

The Uniacke SPS area (shaded in Figure 1) is mostly forested and sparsely populated, with most of the existing development limited to along main roads and around lakes. It is an area of East Hants with underutilized land that MEH considers would benefit from increased densification. The goal of the Uniacke SPS is to ensure that new development will promote and support high-quality design, and establish an appropriate mix of new residential and commercial land uses that will also reinforce the need for a healthy, vibrant, complete, and sustainable community.

The communities that are included in the Uniacke SPS process are not serviced by Municipal water or wastewater. Within the Municipal Planning Strategy for East Hants, part of the study area (shaded orange in Figure 1) is identified as the Mount Uniacke Growth Management Area (GMA) and is recognized as a community where a combination of residential and commercial growth is promoted and encouraged.

Policy statements for the Mount Uniacke GMA indicate that Council will consider the provision of Municipal water and wastewater infrastructure only when the development density dictates the need and it is in East Hants' fiscal capabilities to do so. The appropriate density has not been achieved to date. As a result, East Hants is considering encouraging limited density increases through the use of on-site services.

When submitting an application for the rezoning of a property, developers are asked to demonstrate that their development will not adversely affect groundwater for existing residents and that there is sufficient groundwater for the proposed development. But this is costly and time consuming for developers, and those groundwater studies typically only deal with the specific properties to be developed, which may not be adequate in the long-term as more of the Mount Uniacke GMA and the Uniacke SPS areas as a whole become developed.

This study looks at the geology and hydrogeology of the entire Uniacke SPS area – it takes a holistic approach to help assess general groundwater quantity and quality of the study area; the technical suitability, potential strengths, and groundwater supply constraints that the area may present; and other facets of groundwater supply development for the entire Uniacke SPS area. The purpose of this study is to serve as a resource for MEH staff to evaluate new development for the community, and to help Council in deciding where new growth can occur, how much growth might be able to be supported with on-site water services, or whether to use a more cautionary approach to development in specific areas.

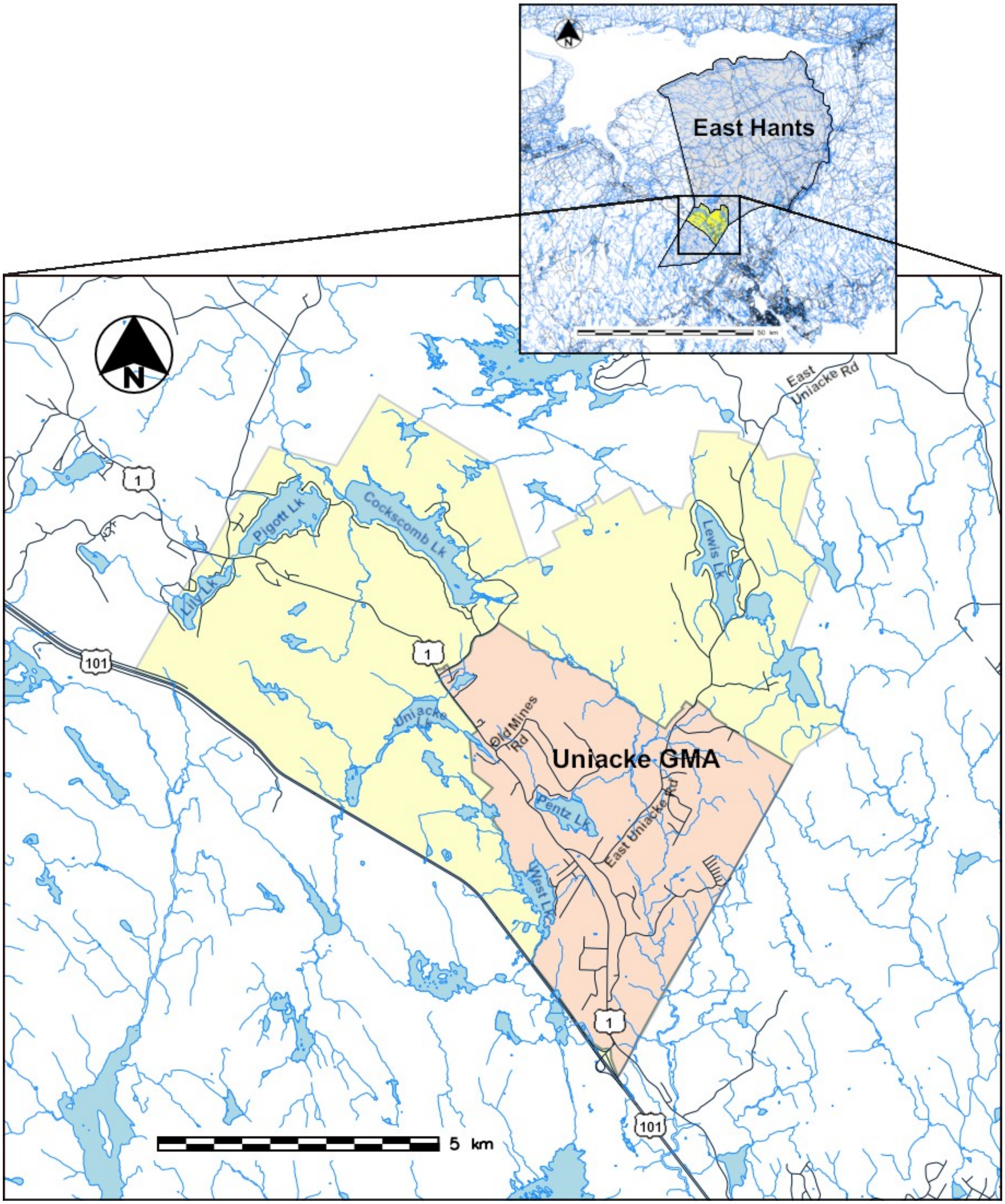

Figure 1. Uniacke Secondary Planning Strategy study area (shaded yellow and orange) and location of Uniacke GMA (shaded orange) within it (showing addressed roads only).

1.2 Scope of the study

The study’s terms of reference were for a desktop review only of currently available data, with mapping to be included as required to help support its findings. East Hants indicated that doing a feasibility study to provide the Uniacke SPS area with Municipal water may be considered in the future if development pressure warrants such a study, but for now the expectation is that drinking water would continue to be supplied from on-site wells. And while this study needed to look more broadly at the regional geology to properly define aquifer characteristics, its requested area of focus (see Figure 1) is on the local aquifer units in the Uniacke SPS area, to:

- Identify groundwater supply issues for the existing property owners within the Uniacke SPS study area.
- Identify known water quality issues within the area and note whether those issues would be costly for homeowners to treat.
- Characterize the general availability of water in the community, such as:
    - areas where water quantity/quality would provide challenges to existing and new residents of that area, including poetntial well interference to existing residents,
    - areas where water is plentiful and be be promoted for development, and
    - expected impacts to existing and potential future water supply as the community develops.
- Recommend any further investigation or study as warranted.

Since much of the available data for this study is spatially limited to along existing roads – thus leaving vast parts of the study area uncovered, and in light that the study area wells must depend entirely on secondary permeability (frequently referred to as fracture flow), and also that the structural geology of the study area has been generally poorly mapped, it was necessary to undertake this study in two parts. Namely:

1. one (not requested in the original MEH terms of reference) that looks at more broadly at the regional bedrock geology using LiDAR-based shaded relief lineament analysis to identify the locations of possible bedrock faults that may contribute to the characteristics of the groundwater regimes within (and beyond) the Uniacke SPS study area,
2. the other that is more tightly limited to the Uniacke SPS study area as defined by the shaded area in Figure 1 (as defined by the MEH in Exhibit 1 of RFQ50698), but with sufficient buffer around it as deemed necessary based on part one of the study – to completely characterize (statistically, and via point-data interpolation mapping, using output from the first part) the study area’s hydrogeology, which satisfies the scope above.

The details of these (and associated limitations) are provided Section 4 of this report.

1.3 How this report is organized

This report is presented in three general parts, as follows:

1. An “educational” part that is intended for laypersons who are not well versed in geoscience and hydrogeology, so they may obtain more value from this study report, where:
    - Section 2 of the report introduces what aquifers are, how they work, what affects groundwater flows and well yields, and what affects groundwater quality, and
    - Section 3 of the report that gives a general description of geologic history of Nova Scotia in regards to continental drift and plate tectonics, and the role that those global historic geologic events have had on creating the supercontinent we call Pangea, and Nova Scotia’s geology as we know it today, as relates to the report study area.

    Readers with knowledge of Nova Scotia’s geology who have an understanding of hydrogeology in general may wish to skip these two sections of the report.
2. A description in Section 4 of the approach used for this study, and in Section 5 of the study area, including the study area’s general land cover and ecosystem designations, current and historic land-use, topography, and surface water features.
3. A direct dive into the key technical matters for this study in the remaining Sections of the report, which include:
    - A clear and as complete as possible a description of the study area bedrock geology (stratigraphy, and structural geology, including the LiDAR-based shaded relief lineament analysis done for this assignment to better understand possible local faults likely to contribute to study area well yields) and Quaternary (soil) geology.
    - A general review study area’s general hydrogeology as relates to the local geology, including a description of the study area aquifer units and general hydrogeological characteristics, groundwater quality expectations, and groundwater recharge areas.
    - A more detailed review of the study area’s hydrogeological characteristics based on available well log data, pumping test data, and other sources of the study area’s physical hydrogeology (distribution of well, casing, soil depths, of groundwater elevations, well yields, etc., augmented by the LiDAR-based shaded relief lineament analysis results where possible, and of the study area’s groundwater quality, defining typical water quality issues, along with potential water treatment needs and methods.
    - Conclusions and recommendations for future work.

2.0 A primer on aquifers

Well water supplies (groundwater) within the Uniacke SPS area may come from one of a couple of aquifer types. But since aquifers are are underground, out of sight, and generally not included in most school curriculum, there are many misconceptions about what aquifers are, and how they work. The next few pages will explain what aquifers are in the broad context of the Uniacke SPS area – the aim is to inform readers so they can gain more value from this study.

2.1 An encyclopedic definition of an aquifer

An aquifer is a body of buried rock or sediment that contains and transfers subsurface water, or groundwater. Groundwater is the word used to describe precipitation or other surface water that has infiltrated into the subsurface and collected in tiny empty spaces underground – between the sand grains that make up the soils or sandstone bedrock, or in narrow cracks and in bedrock fractures and fault zones.

To be classed as aquifers, the subsurface soil or rock body media in which water is contained must also be able to that water to flow within the soil or rock matrix. Subsurface materials that may contain water but which do not allow that water to be transferred through them are called an aquitards, which allow water to flow through them only very slowly, or aquicludes, which do not

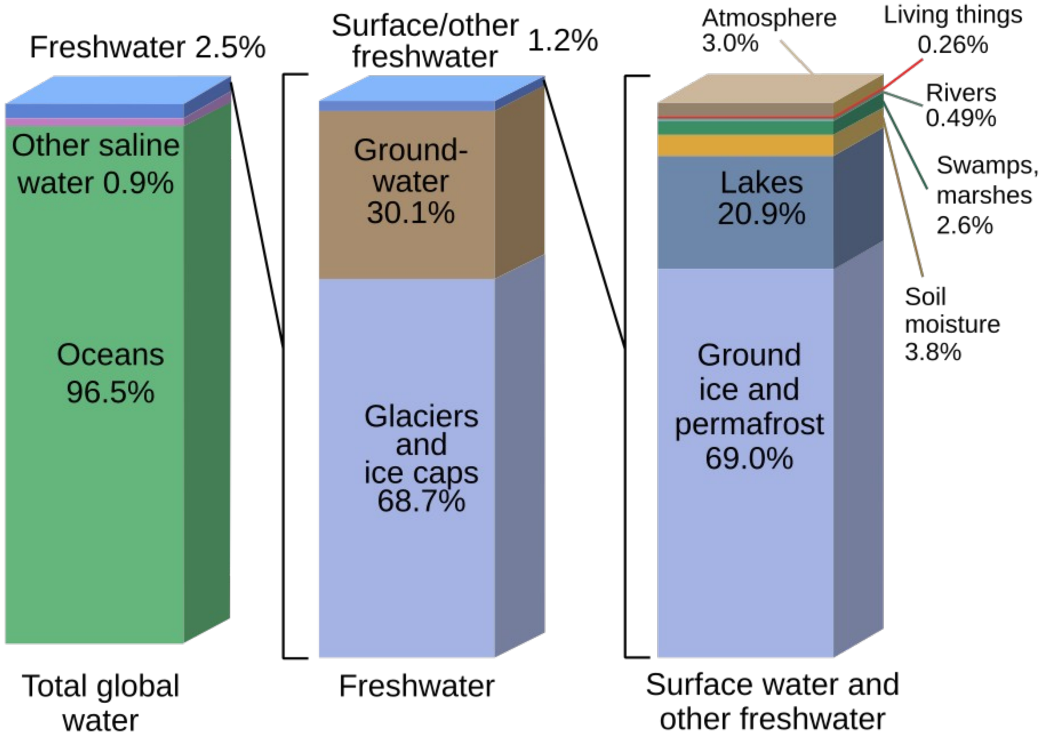

Figure 2. Graphical distribution of the locations of water on earth (USGS, 2024).

allow any water through them at all. Clay is an example of an aquitard or aquiclude material, which due to the very fine particles that make up clay and the equally very small spaces between them, does not allow water to flow through it.

Groundwater is a very important source of water, in that it represents approximately 97% of all of the earth’s fresh liquid water, with less than 3% being contained in lakes and rivers. The rest of the earth’s water is either present as salt water, or as fresh water locked up in glaciers and ice caps. Figure 2 shows those distributions graphically.

2.2 Visualizing groundwater

Figure 3 shows how the ground can become saturated with water (shaded blue). Only this saturated area is considered to be an aquifer. The "unsaturated zone" above the water table still contains water (after all, plants' roots live in this area), but it is not totally saturated with water, so it is not aquifer.

A common misconception about aquifers is that they are underground rivers or lakes.

While groundwater can seep into or out of aquifers due to their porous nature, because of the very tiny spaces in which it exists and the tortuous pathways though which it must flow between those tiny spaces, groundwater cannot move fast enough within aquifers to flow like a river. And groundwater also isn’t found in “seams”. The best analogy is to think of an aquifer as a

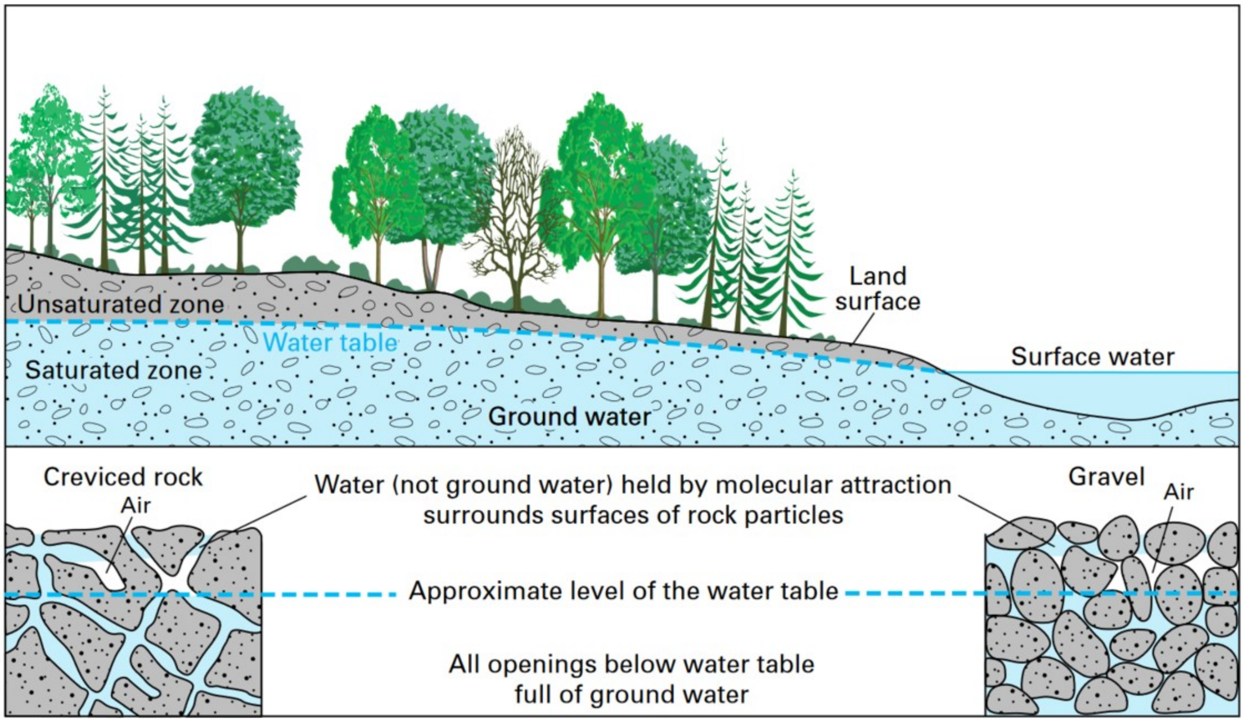

Figure 3. How groundwater occurs in soi and rocks (USGS, 2019).

household sponge; different sponges can hold different amounts of water and allow it to soak into and be removed from them at rates that depend entirely on what that sponge is made of.

The two drawings at the bottom of Figure 3 show close-ups of how water is stored in between underground soil and rock particles or within bedrock fractures. Figure 4 shows the three principle types of pore spaces that may be present in aquifers to store water.

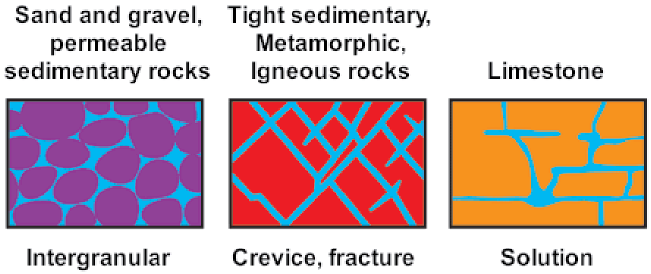

Figure 4. Main types of porosity and permeability.

Porosity is the space in which groundwater may be stored; as in household sponges, the rate that groundwater can flow trough an aquifer depends on levels of interconnection between pore spaces, or permeability of the aquifer matrix (the soil and/or rock and pore spaces that make up the aquifer). Note that permeability and porosity, although related (i.e. there can be no permeability in an aquifer if there is no porosity it), are two very distinct aquifer properties that are not mutually inclusive in all soil or rock.

For example, while clay may have 40-70% porosity (Freeze and Cherry, 1979) (this high porosity is why clay settles when it is built on and as water present in it is squeezed out over time due to the structure’s weight), due to the extremely small (microscopic) grain size and shape of the materials that make up clay, water cannot easily move between its pore spaces. By contrast, well-sorted coarse sand and gravel deposits, having 25-40% porosity, can allow groundwater to flow quickly since the pore spaces have better interconnections. For the reasons above, at larger local and regional scales at most locales, aquifer permeability can vary significantly both horizontally and vertically depending on where and what types of soil and/or bedrock are present underground.

Permeability (more specifically, hydraulic conductivity (K) is used in groundwater science), is defined as the velocity at which water will pass through an earth material of unit area and unit gradient (change in water height). There are two types of permeability: primary permeability – which occurs between earth material grains, and secondary permeability – which occurs in the apertures of bedrock fractures, (also known as fracture or crevice flow) or in subterranean caves (solution flow). Table 1 lists typical values for K (Freeze and Cherry, 1979) in the conventional units of centimetres per second (cm/s).

Saturated soil or bedrock materials with high permeability are referred to as aquifers. Those with low permeability with very slow or no groundwater flow are referred to as aquicludes. Both aquifers and aquicludes are present within and around the Uniacke SPS area.

Table 1. Typical hydraulic conductivity values.

Primary permeability		Secondary permeability	
Aquifer matrix	**cm/s**	**Aquifer matrix**	**cm/s**
Clean sand	$1 - 10^{-3}$	Karst limestone	$1 - 10^{-4}$
Silty sand	$10^{-2} - 10^{-5}$	Basalt	$1 - 10^{-5}$
Glacial till	$10^{-4} - 10^{-9}$	Fractured igneous, metamorphic Rocks	$10^{-1} - 10^{-6}$
Sandstone	$10^{-4} - 10^{-8}$		
Limestone	$10^{-3} – 10^{-7}$	All permeability in the metamorphic and igneous rocks of the Uniacke SPS study area is secondary.	
Shale	$10^{-7} - 10^{-11}$		

2.3 Confined versus unconfined aquifers

There are three general types of aquifers: confined, unconfined, and perched. Figure 5 shows the geologic and topographic controls affecting groundwater flow from wells drilled into all three types of aquifers, and the related terminology used for them. In Figure 5, the saturated zones are shaded blue and grey, unsaturated zones are yellow.

Confined aquifers have an impermeable rock or clay layer above them, while unconfined

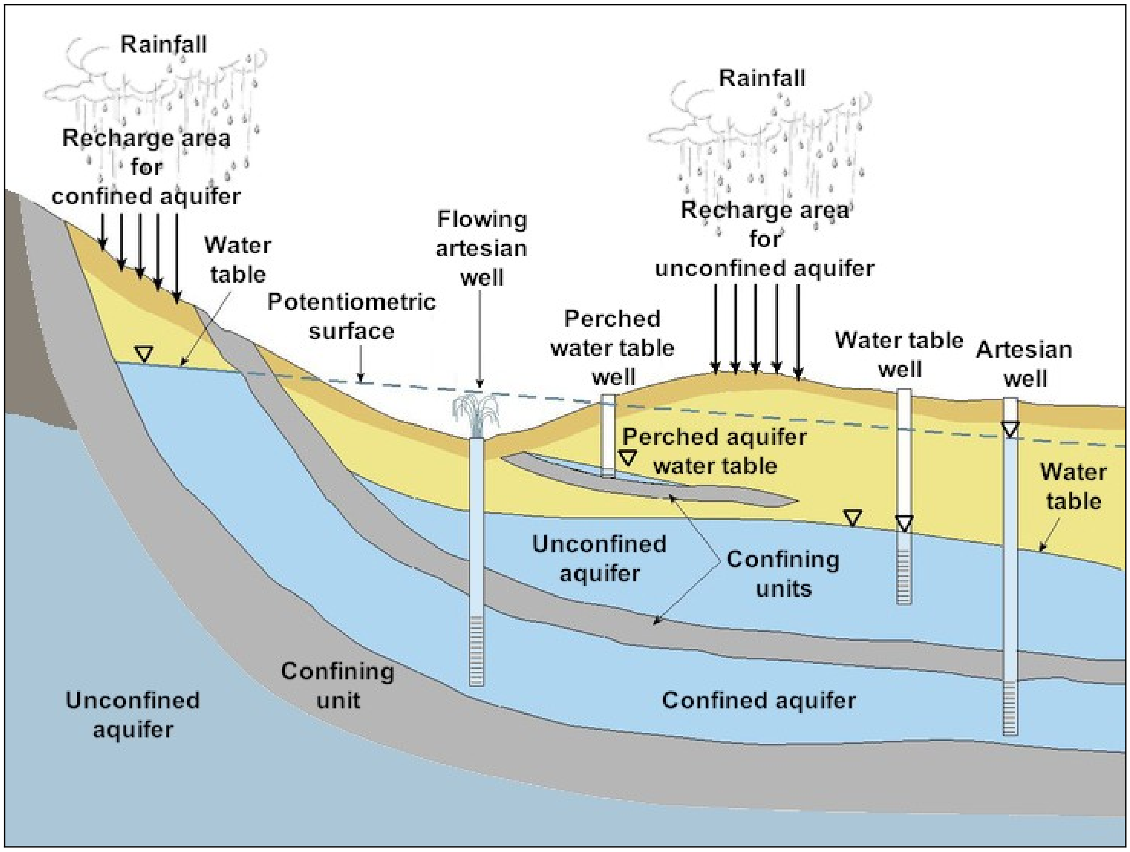

Figure 5. Geological and topographical groundwater flow controls on wells drilled in confined and unconfined aquifers. Modified from NGWA (2007).

aquifers consist of or lie below a permeable layer of soil in hydraulic communication with the surface. Perched aquifers – another form of unconfined aquifer – have impermeable rock or clay under them that prevents infiltrating waters (groundwater recharge) from reaching deeper aquifer materials. Drilling through the layers below perched aquifers may also cause them to drain.

Some confined aquifers may not be confined over their entire extent, but are in hydraulic contact with the surface to receive recharge at locations of higher elevation. Figure 5 shows an example of that. The potentiometric (also called piezometric) surface shown by the dashed line is the level at which water would rise in wells drilled into the confined unit. Wells drilled into confined aquifers where the ground surface is below that piezometric surface will naturally flow.

Some confined aquifers may be buried so far underground that they cannot receive direct recharge from surface – water becomes trapped in aquifer sediments as confining deposits are laid over-top of them. Those produce what's often called prehistoric water, which can be tens to hundreds and even thousands of years old.

2.4 What drives groundwater flow?

We all know surface water runs downhill according to slope and shape of the land. It's no different for groundwater flow.

2.4.1 Groundwater flow in unconfined aquifers

In unconfined aquifers, the water table (surface of the saturated zone) generally follows surface topography, but in a subdued manner. That's because the depth and shape of the water table are controlled by recharge rates and aquifer permeability; the higher the aquifer permeability, the more quickly groundwater can flow and thus, the flatter the water table can become.

The resistance to flow in aquifers also creates sloped gradients in water tables. Groundwater flow is in the direction and at velocities defined by those gradients. Thus in the examples in Figures 3 and 5, the slope of the water tables follow the lay of the land, so too will groundwater flow, from left to right in both Figures, at rates relative to aquifer permeability and water table gradient.

2.4.2 Groundwater flow in confined aquifers

In confined aquifers, groundwater also flows down-gradient, from areas of high piezometric elevation to areas of lower piezometric elevation. However, unlike water table surfaces in unconfined aquifers, piezometric gradients do not follow surface topography, but are controlled by water withdrawal. That withdrawal may occur where the aquifer is exposed at surface (it is no longer confined), such as at springs, in streams, at or beneath lakes, or ultimately as discharge to the ocean, or by pumping at wells. Sections 2.4.3 and 2.4.4 below give brief descriptions.

2.4.3 General surface-water and groundwater interactions

Groundwater's role in the hydrologic cycle is huge, not only in terms of water removals by overland infiltration, which can range from 14% or more of total annual precipitation at and around the Uniacke SPS area, to 25% in parts of Cape Breton, the Eastern Shore, and South Nova Scotia (Kennedy et al, 2010), but also through groundwater's direct interaction with surface water bodies and the hydrologic cycle generally by other means. Examples include:

- the reintroduction of water to atmosphere by evaporation and evapotranspiration from plants where aquifers are shallow,
- direct influx/outflows of groundwater at wetlands,
- seepage of water from streams and lakes into aquifers as groundwater recharge,
- discharge as springs (initiating streams) at breaks in land topography, or as baseflow

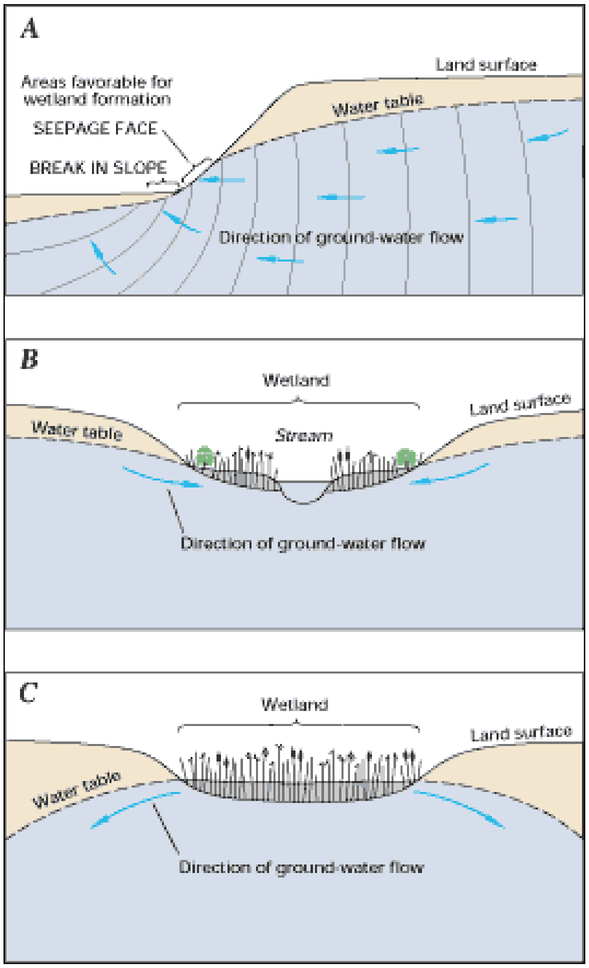

Figure 6. Wetlands (A) at breaks in slopes, (B) fed by groundwater at low elevations, and (C) serving as groundwater recharge.

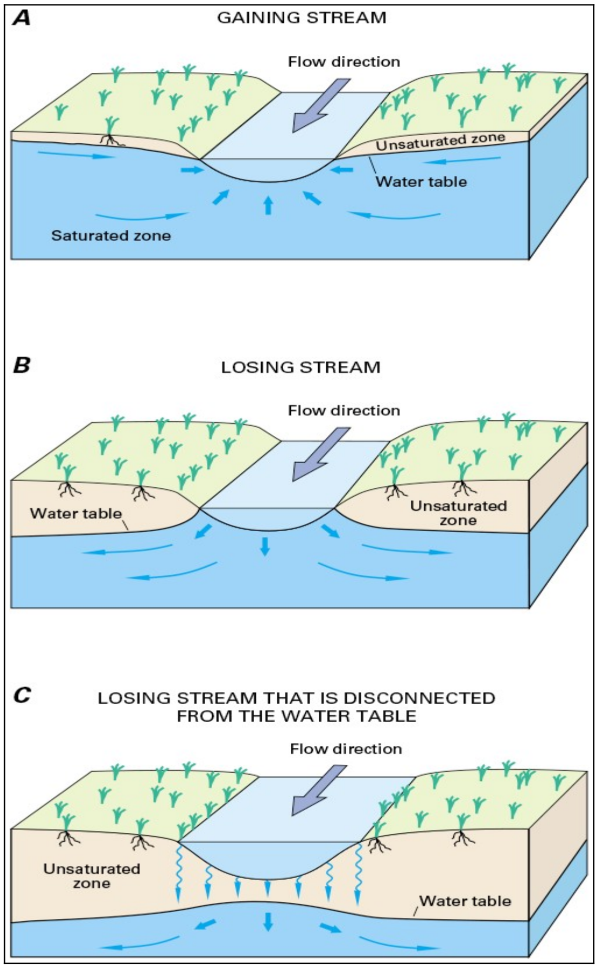

Figure 7. Groundwater and (A) gaining streams, (B) loosing streams, and (C) loosing streams disconnected from the water table.

(groundwater can contribute up to 100% of a steam’s flow in droughts periods and maintain temperatures for fish) at river banks and stream-beds, or as springs at lake bottoms, and

- seepage of groundwater to the ocean.

Figure 3 shows one instance of groundwater interacting with surface water (i.e. lakes can serve as windows onto groundwater tables). Figures 6 and 7 (modified from Winter et al, 1998) on the next page show examples of spring/wetland and river/lake interactions.

2.4.4 General effects of pumping wells

Where aquifers are shallow and permeable enough to allow water to move in them at a rapid-enough rate, then people can drill wells into them and withdraw water. The level of the water table can naturally change over time due to changes in weather cycles and precipitation patterns, stream-flow and geologic changes, and even human-induced changes, such as the increase in impervious surfaces (roofs, roads) on the landscape.

The pumping of wells can also have a great deal of influence on water levels in aquifers, especially in the vicinity of the wells, as the diagram in Figure 8 shows. If water is withdrawn from the ground at a faster rate that it is replenished by infiltration from the surface or from streams, then the water table can become lower, resulting in a "cone of depression" or drawdown around the well. The amount of drawdown depends on the geologic and hydrologic aquifer conditions and the pumping rates used, and can range from very small to many tens of metres. Total drawdown and the lateral extent of cones of depression can be determined from well pumping tests and use of observation wells.

The pumping of wells can cause groundwater flow to change direction locally, as shown in (A) of Figure 8. The bottom (B and C) shows that where two or more wells are pumping together and their cones of depression overlap, the amount of drawdown at each well is equal to the sum of the drawdown from

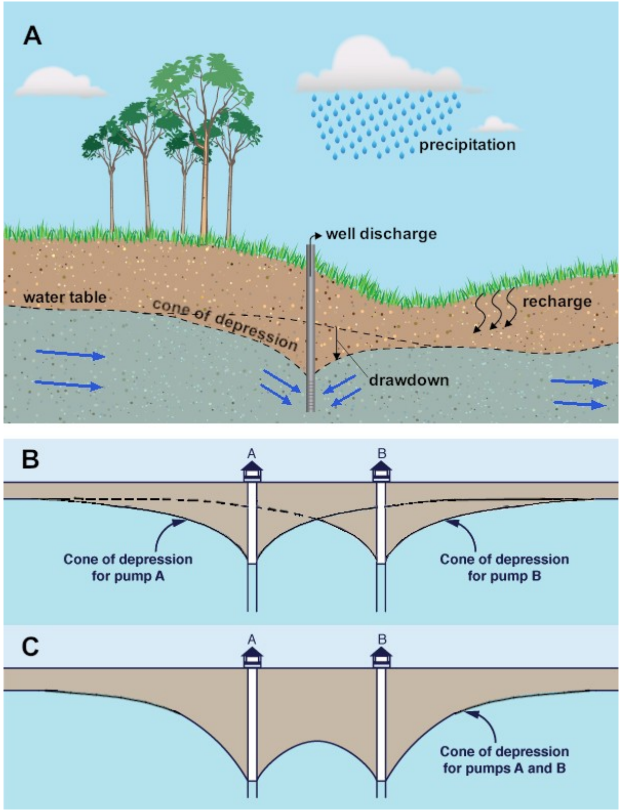

Figure 8. Schematics showing (A) cone of depression around a pumping well (note change in groundwater flow direction from pumping), (B) drawdown from pumping at either well A or well B, and (C) drawdown interference from pumping at wells A and B together. (Modified from USGS, 2019)

each cone of depression produced with the wells pumping individually. This is referred to as well interference – a situation where “Peter robs Paul”.

Over pumping wells can lower the water table so much that wells can “go dry” and no longer supply water. The impact on the water table level can be short-lived or last decades depending on the nature of the aquifer and the availability of recharge.

2.5 General groundwater quality

The natural chemical reactions that affect the geochemical characteristics and quality of groundwater include (1) acid-base reactions, (2) mineral dissolution and precipitation, (3) sorption and ion exchange, (4) oxidation-reduction reactions, (5) biodegradation, and (6) the dissolution and exsolution of gases.

Rain and snow-melt typically contain low concentrations of dissolved solids and have low pH. When that water first infiltrates the land surface, microorganisms in the soil have a significant effect on the evolution of the water chemistry. Organic matter in soils is degraded by microbes, producing high concentrations of dissolved carbon dioxide (CO_2). This process further lowers the water pH by increasing the carbonic acid (H_2CO_3) concentration in the soil water.

The production of carbonic acid starts a number of mineral-weathering reactions, which result at first in bicarbonate (HCO_3^-) usually being the most abundant anion in groundwater. Where contact times between the water and minerals in shallow groundwater flow paths are short (typically the case for dug wells constructed in glacial till), then the concentration of dissolved solids in the water generally is low. In such settings, limited chemical changes take place before groundwater is discharged either to surface water or is pumped from wells.

But in deeper groundwater flow systems, the contact time between water and minerals is much longer than in shallow flow systems. As a result, the initial importance of reactions relating to microbes in the soil zone are superseded over time by chemical reactions between minerals and water (geochemical weathering). As weathering progresses with age and flow distance, the concentration of dissolved solids increases, and depending on the chemical composition of the minerals that are weathered, the relative abundance of the major inorganic chemicals dissolved in the water changes – the groundwater chemistry evolves – bicarbonate generally decreases and sulphate (SO_4^{2-}) and then chloride (Cl^-) increase with time and flow distance travelled.

At and around the Uniacke SPS area, those minerals that may become dissolved and most commonly naturally affect groundwater quality may include:

- calcium and magnesium carbonates form the minerals that typically fill or partially fill bedrock fractures, which can make groundwater hard, and
- soluble iron and manganese oxides and carbonates, and other trace metals and elements

present in the bedrock, such as pyrite and arsenic, that may have been concentrated in places (old gold districts) during deformation of the bedrock (described in the next report section).

Human land use within the study area also affect (detrimentally) groundwater quality by introducing unwanted chemicals into groundwater recharge: automotive fuel, heating oil, and chemical storage tank leaks and spills; fertilizer and pesticide use; road salt; leaky sewage collection systems; and failed septic systems.

3.0 Introduction to Nova Scotia’s and the study area’s complex geological history

Many may know about continental drift – that Africa collided with North America to form the supercontinent Pangea. But our geologic history is complex and involved more than just one single tectonic collision.

Nova Scotia’s geography, and that of the Uniacke SPS groundwater study area, are the result of numerous tectonic events, which have divided the province geologically in two parts: a southern part (Meguma Terrane) south of the Bay of Fundy that extends from Yarmouth to Chedabucto, and an assemblage of other exotic terranes[1] that compose the northern part (past locations known from paleomagnetic studies[2]), which southern boundary is the Cobequid-Chedabucto Fault system. That major fault system extends from the US Northeast and New Brunswick, along the north Minas Basin shore and base of the Cobequid Hills, into the Antigonish Highlands, and to the south of Newfoundland into Europe, as parts of the fault system were separated from North America as the Pangea later broke up to form the Atlantic Ocean.

The discussion that follows shows how and where the Maritimes and Nova Scotia’s exotic terranes were positioned over time in terms of global plate tectonics, their ultimate location at the centre of Pangea, the related local structural, depositional and climate environments responsible for the types and emplacement of the bedrock materials of interest within the study area, and the roles those all had on characterizing the aquifer units under review.

3.1 Supercontinent building – tectonic settings, terranes, orogenies

Figure 9 shows the tectonic terranes that make up the Maritimes. The Meguma Terrane that constitutes southern Nova Scotia and directly underlies the Uniacke SPS study area extends beneath and serves as part of the basement bedrock complex[3] for the Carboniferous and younger

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1. An exotic terrane is an Earth crust fragment that is formed on (or broken off of) a tectonic plate and which is accreted or “sutured” onto crust lying on another tectonic plate. The crustal block preserves its distinctive geologic history, which can be very different from the surrounding area – thus the term “exotic terrain, a term that among a small handful of others was first coined in the late 1970’s by Ted Irving (1927-2014), a former research colleague who for his PhD thesis (rejected at the time (Opdyke, 2014; Burgess, 2018); https://en.wikipedia.org/wiki/Edward_ A._Irving; https://en.wikipedia.org/wiki/Paleomagnetism) developed the instrumentation for measuring remanent magnetism (see footnote 2).
2. Paleomagnetism is the study of magnetic fields (remanent magnetism) recorded in certain rocks at the time they were formed (thus identifying the azimuth and declination global location of the north and south poles relative to the rocks). By measuring that remanent magnetism in many rock cores samples for which their orientation in outcrop is recorded and knowing the ages of those rock core samples, computer models can be used to back-trace the locations of stacked bedrock units over geologic time.
3. Basement rock is the thick foundation of ancient, and oldest, usually metamorphic and igneous rock that forms the crust of continents. Locally, the rocks of the Cobequid Hills and Antigonish Highlands, and their extension beneath younger rocks, are a part of the regional and local basement rock complex.

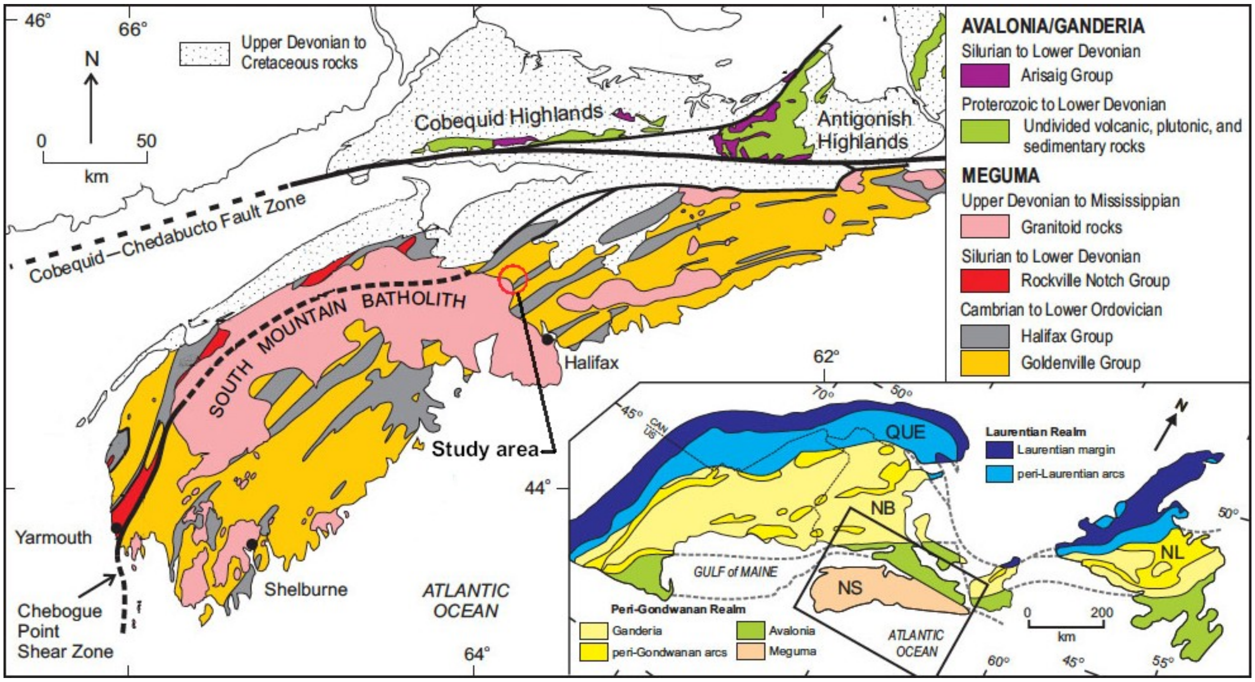

Figure 9: The tectonic exotic terranes that make up the northern Appalachians and the Maritimes (after White and Barr, 2017).

rocks (shaded grey in Figure 9, described later in this report) northward to the Cobequid-Chedabucto Fault system.

The assemblage of terranes (the Avalonia, Ganderia, the Bras d'Or-Brookville and Blair River Terranes) that make up northern Nova Scotia, parts of New Brunswick, and Newfoundland, are situated north of the Cobequid-Chedabucto Fault. As noted in the paragraph above for the Meguma, the grey areas that represent Carboniferous and younger rocks have also buried and overlie the older rocks of these terranes north of the Cobequid-Chedabucto Fault system.

Avalonia and Ganderia together make up the Antigonish Highlands, the Cobequid Hills, and the buried basement rocks in the north part of Figure 9. They make up Caledonia to the west, and in the east along with the Bras d'Or-Brookville terranes, they make up most of Cape Breton, except for the very northern tip, which comprises much older rock of the Blair River Terrane (a part of the Humber zone)[4].

These terranes came together in a series of tectonic collisions that over a period of than 100 million years to form what today is Nova Scotia and the rest of the Maritimes. Figure 10 shows the geologic time scale and the time periods over which these tectonic events took place.

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4. Due to the breakup of Pangea about 120 Ma after its formation, and thus the separation of North America from Europe and Asia, the eastern-most parts of Gandaria and Avalonia, along with some of the Cobequid-Chedabucto fault system, were moved east as the Atlantic Ocean opened to become parts Wales, Scotland, and Ireland.

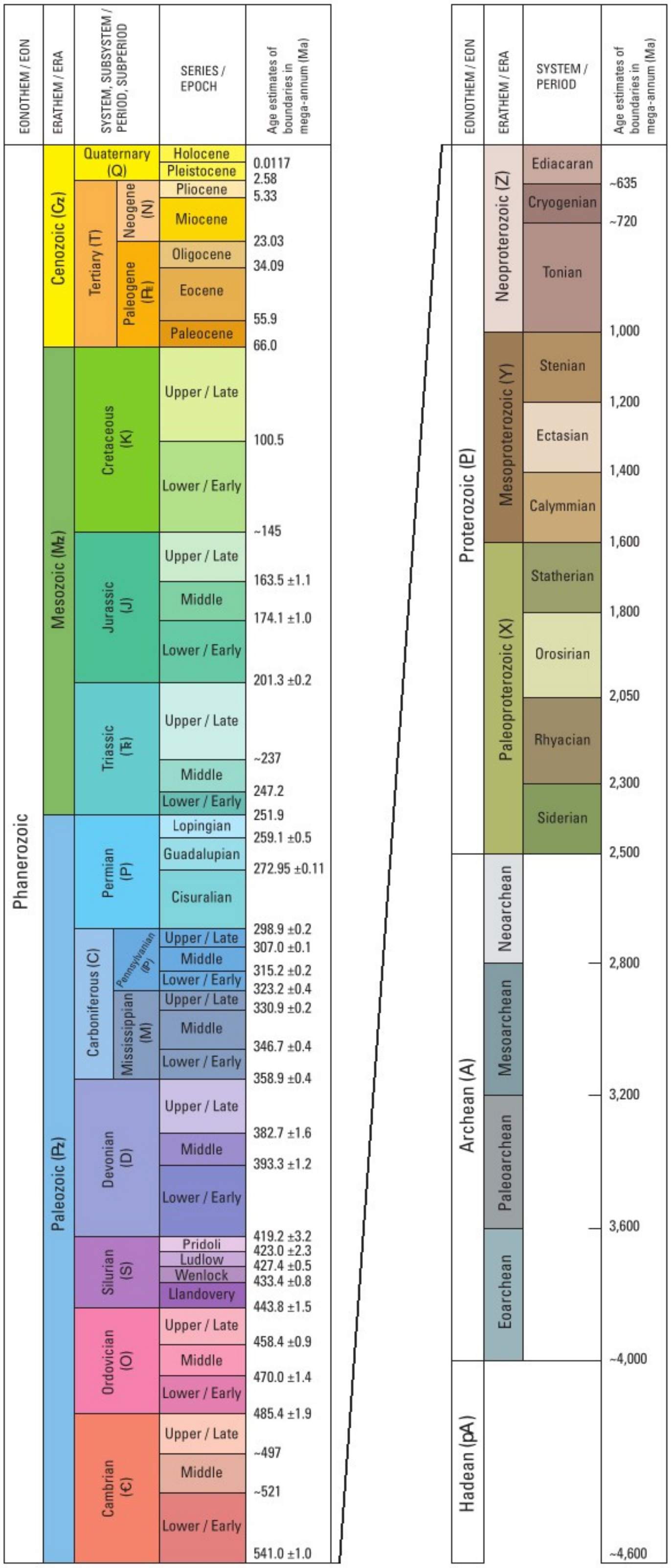

Figure 10: Geologic time scale.

3.1.1 The Caledonian and Avalonian orogenies[5]

The basement rocks north of the Cobequid-Chedabucto Fault system (i.e. within Nova Scotia, the Cobequid Hills to the west and the Antigonish Highlands to the east, were deposited when prehistoric continents Laurentia (early North America, more than 1,000 million years (Ma) ago) and Eurasia (early Europe and Asia) drifted together and collided in the Early Cambrian to Precambrian periods some ~650 to 600 million years ago. This was followed by tectonic extension (rifting, or breaking apart) in the Cambrian to Lower Ordovician Periods (~540 to 470 Ma), during which rocks of the Iron Brook Group were deposited, then by further rifting in the Late Ordovician to Early Devonian (~445 to 410 Ma), as evidenced by Arisaig Group rocks.

This assemblage of rocks, comprising of tectonic terranes Avalonia and Ganderia, was thrust onto Laurentia (the light and dark blue Notre Dame Terrane and Humber Zone (itself an assemblage of tectonic terranes) in Figure 9) to form the prehistoric continent Laurasia (some spell it Laurussia). This represents the early start of the building of the Appalachian Mountains.

3.1.2 The Taconian and Acadian orogenies

Shortly after and as a continuation of the displacements that started during the Caledonian and Avalonian orogenies, Laurasia and Gondwana (current-day Africa) drifted together and started to collide during the Late Devonian to Middle Mississippian Epoch (Lower Carboniferous Period) ~400 to 335 Ma, trapping the Meguma Terrane between them, to build yet more mountains within the newly created supercontinent that we call Pangea.

The traditional thinking is that Meguma sediments were deposited in a passive continental shelf type environment on the west coast of Gondwana and subsequently compressed onto the Avalon Terrane. However, recent stratigraphic, sediment provenance, and paleomagnetic studies by Culshaw and Lee (2006), White et al (2007), Waldron et al (2009), White and Barr (2017), Shellnutt et al (2019) and others, suggest that the Meguma was instead likely deposited at least partly on the Avalon basement in a rift zone located between the Avalon Terrane and Gondwana, with terrane sediment deposition and deformation occurring within a sequence of tectonic plate spreading and subduction events that spans the Middle Cambrian to Upper Devonian.

The Taconian and Acadian orogenies continued to build the interior of the Appalachian Mountains through further structural deformation of existing rocks, and the building of an outer mountain chain (i.e. the Meguma Terrane) as the Cambrian to Ordovician age turbidite (continental shelf slump deposits) and deep ocean sediments of the Goldenville and Halifax Groups (re-classed today as the Meguma Supergroup) were and folded and thrust onto Laurasia.

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[5] The term Orogeny (or orogenesis) derives from the Greek *oros*, which means mountain, and *genesis*, which means origin or mode of formation. It refers to the process of continent and related mountain building, where the rate of surface uplift exceeds that of erosion. It involves deformation imposed during the convergence and accretion of tectonic plates, and is driven by compression, gravity, heat, and climate.

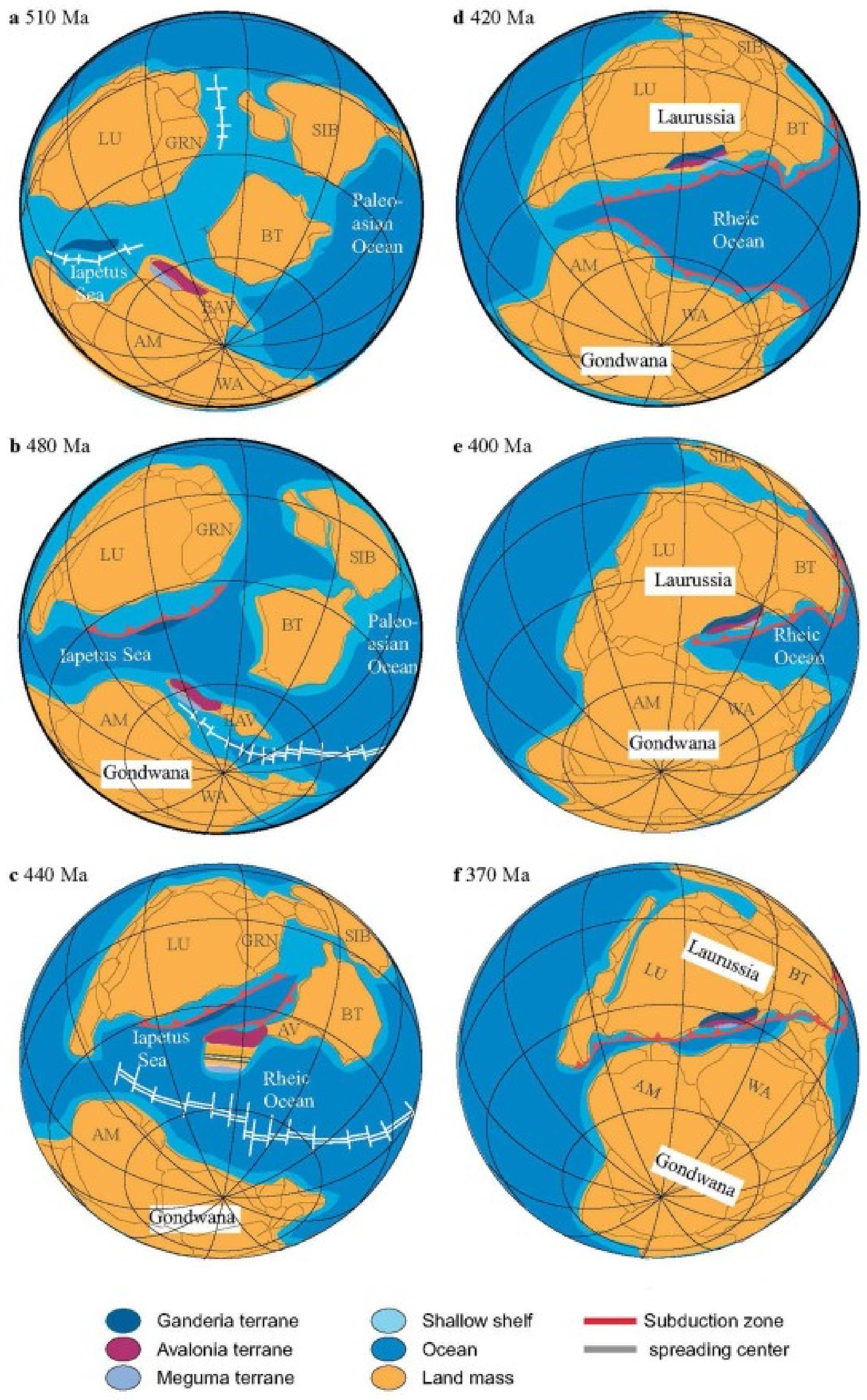

Figure 11: Palinspastic reconstructions during the Early Paleozoic time (510-370 ma) period (from Shellnutt et al, 2019). AM = Amazon, AV = Avalonia, BT = Baltica, EQV = Eastern Avalonia, LU = Laurentia, GRN = Greenland, SIB = Siberia, WA = West Africa.

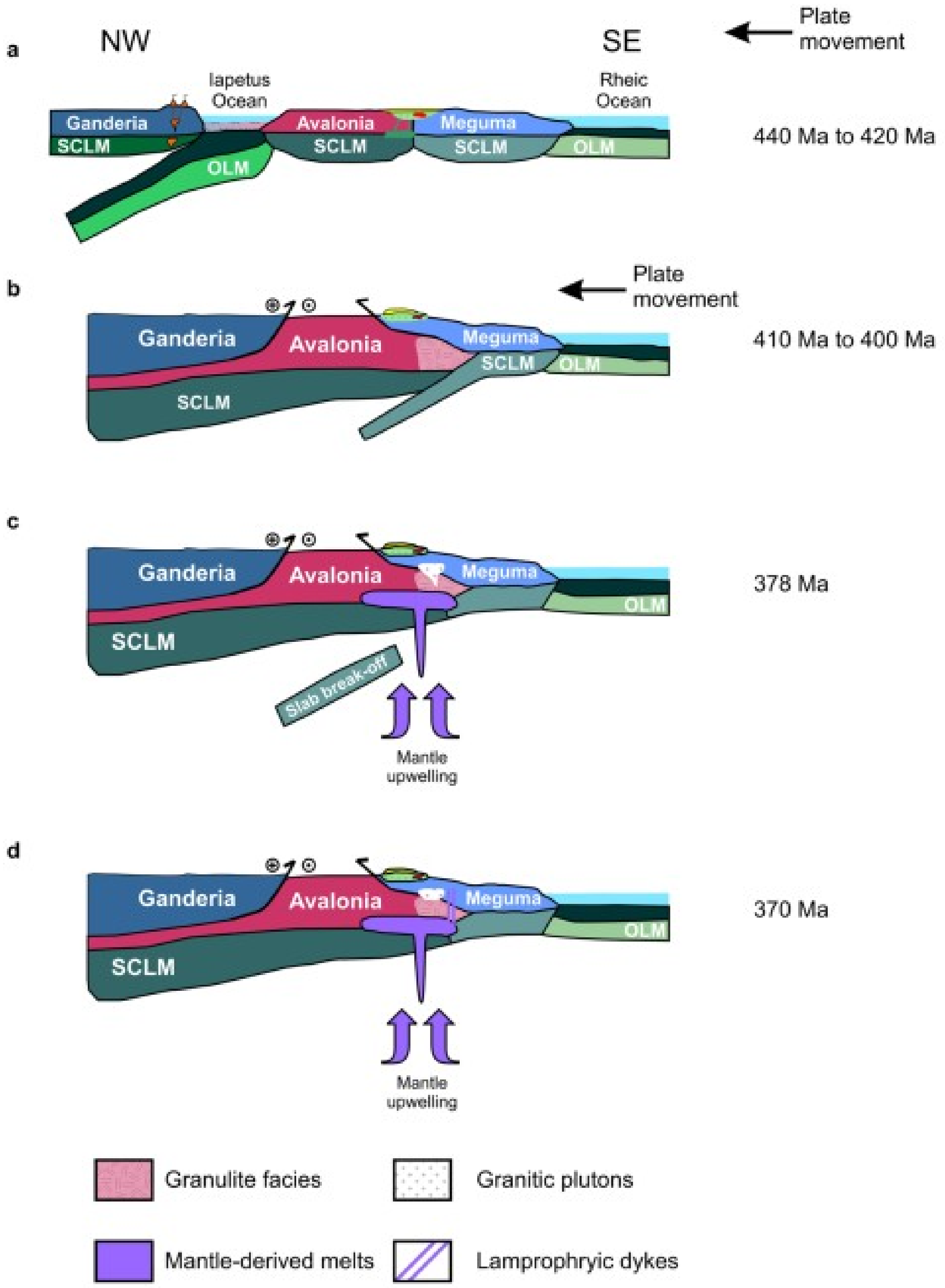

Figure 12: Tectonic evolution showing the possible relationship between Avalonia and Meguma during the Late Silurian to Late Devonian (modified from Shellnutt et al, 2019). SCLM = subcontinental lithospheric mantle. OLM = oceanic lithospheric mantle.

3.2 Continental drift reconstruction in pictures and videos

3.2.1 The evolution of Pangea as illustrated in pictures

Figures 11 and 12 together summarize the locations over time of the land masses that compose today's Maritimes and Nova Scotia, and their related tectonic processes. In Figure 10:

(a) The Ganderia, Avalonia, and Meguma terranes are reconstructed to surround the South America craton around 510 Ma following the breaking up of Pannotia (an earlier supercontinent that broke up about 600 ma).

(b) Separation of the Ganderia terrane from the South America craton as the Iapetus Sea opened. Separation of Avalonia, Eastern Avalonia terrane, and Meguma terrane from the edge of the Amazon craton as the Rheic Ocean opened at 480 Ma.

(c) Closure of Iapetus sea and continuous spreading of the Rheic ocean bring the Ganderia, Avalonia, Eastern Avalonia terranes closer to Laurentia, but regional extension between Avalonia and Meguma occurred at 440 Ma.

(d) Formation of Laurasia during 420 Ma as Ganderia, Avalonia, and Meguma terranes amalgamated into Laurentia, and Eastern Avalonia terrane amalgamated into Baltica. Folding of Meguma strata.

(e) Further closing of Rheic Ocean around 420 Ma caused the Meguma terrane to be thrust over Avalonia. Brittle faulting of the Meguma terrane, accompanied by granitic magmatism triggered by mantle detachment from Meguma folding, with related hydrothermal gold mineralization in folds and shear zones.

(f) The closure of Rheic Ocean brought Laurussia and Gondwana closer to form the supercontinent Pangea around 370 Ma.

Starting at a 440 ma, between the Taconian and Acadian orogenies, as shown in the cross section schematics of Figure 11:

(a) Late Silurian just prior to the Acadian orogeny.

(b) Initial stages of the Acadian Orogeny and peak granulite facies metamorphism (see Figure 17) in the underlying Avalonia rocks.

(c) Middle Devonian silicic magmatism and high temperature deformation episode.

(d) Late Devonian dyke emplacement and entrainment of the granulite xenoliths.

3.2.2 The evolution of Pangea as shown in video

They say a picture is worth a thousand words. So a video must be worth a thousand pictures? What appears to be the best short videos publicly available to show plate tectonics in "action" and continental drift reconstructions (more detailed reconstructions are available in scientific literature, but most cover only small parcels of land or sections of the globe), are presented on the Scotese (2023) YouTube channel. We urge readers to visit his site.

We draw attention to one of his videos at https://www.youtube.com/watch?v=bzvOMee9D1o (Scotese, 2020) because it shows continental reconstructions from the start of the Cambrian Period to today[6] (the period of geologic history of concern in this report), with the geologic time scale at the bottom of the screen (easier for viewers to keep track of geologic time during the reconstruction), and presents Earth as two hemispheres to avoid distortions around the poles.

The video shows deep oceans as dark blue, shallow oceans and inland seas in light blue, dry land in green, and mountains in shades of brown to black. This video also shows the ice ages that occurred from the Cambrian Period to today as white blotches over land and sea (460-430 Ma (Andean-Saharan), 360-260 Ma (Karoo), and 2.6 Ma to present (Quaternary)).

We suggest that the main focus be placed on the hemisphere displayed on the left side of the screen as it shows Nova Scotia centred in that hemisphere throughout most of the video. Note that the east shore of Laurasia, and Ganderia, Avalonia and Meguma, were located at or near the equator from the start of the Devonian (before the creation of Pangea) and Carboniferous (when Gondwana and Meguma docked onto Laurasia) and afterwards to the Jurassic Period.

It must be noted that continental drift and tectonic processes occur slowly (at a rate generally of about 10 cm/year, or at about the rate fingernails grow). Scotese and Zahirovic (2020) and Scotese and van der Pluijm (2020) have produced a video in which continental location are tracked over time to show tectonic plate velocities at https://www.youtube.com/watch?v=pps3T37nT_I to help put timings into some perspective. In their video, plate velocities have been calculated and are shown range from 1 to 18 cm/year, which while appearing very slow, represents several kilometres of displacement per million year (i.e. 10 cm/yr – 111 km/my).

3.2.3 Tectonic terrane suture zones

The suture zone (faults) along which Ganderia and Avalonia accreted runs along the east shore of the Aspy peninsula and the north shore of Bras d'Or Lake to Little Judique, veers north then west beneath mid-PEI and beneath Moncton, Fredericton[7], and beyond (Cardenas-Vera et al, 2022).

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[6] The plate tectonic computer models used to produce the videos referenced here employed thousands of accurately georeferenced data points, each representing remanent magnetic north pole azimuth and declination paleomagnetic information from rock samples that were collected (as required to determine remanent magnetic data, with orientations in the outcrops recorded) from across the globe, and which were dated using 40Ar/39Ar, Rb-Sr, and U-Pb and other rock dating methods. Linear magnetic anomalies on the ocean floor were used to preserve (correct for) reversing polarity of the Earth's magnetic field over time, and the positions of the continents and their velocities were defined by back-tracking the paleomagnetic data geochronologically.

[7] The general location of this suture zone where it is underwater or beneath younger bedrock is known based on seismic data and from drill cuttings and cores brought to surface during petroleum exploration.

The Cobequid-Chedabucto fault[8] system (or Minas Fault zone) is the suture zone along which Gondwana and Meguma docked onto Laurasia. It is an anastomosing[9] transform[10] fault system (Mawer and White, 2014) along which there was brittle[11] and ductile[12] dextral[13] displacement (Waldron et al, 2015). Motion along these faults spanned throughout the building of Pangea from the Devonian(Boehner, 1981; Giles and Boehner, 1982; Waldron et al, 2010; Keppie Sr, (undated); Javaid, 2011; Keppie Jr, 2013), Late Carboniferous (Bachtadse et al, 2018) to the Permian (Irving, 2004, 2005; Muttoni et al al, 2003), and Lower Cretaceous (Stea and Pullan, 2001; Piper et al, 2005), ending around 40 million years ago. However, some suggest the1929 Newfoundland earthquake may have been the result of reactivation of the Cobequid-Chedabucto system (Trifunac et al, 2002) and/or Newfoundland Fracture Zone (Pe-Piper and Piper, 2004).

3.3 Larger scale to more local views of Meguma Terrane evolution

3.3.1 Association of the Meguma Terrane with other terranes within Pangea

The Mesoproterozoic to Neoproterozoic age[14] Ganderia Terrane and the Edicarian to Cambrian and Early Ordovician to Avalonia Terrane are both considered to have originated as microcontinent island arcs and backarc marine basins, comprising of sedimentary sequences and volcanic deposits, along with some of their Mesoproterozoic and older basement rocks from

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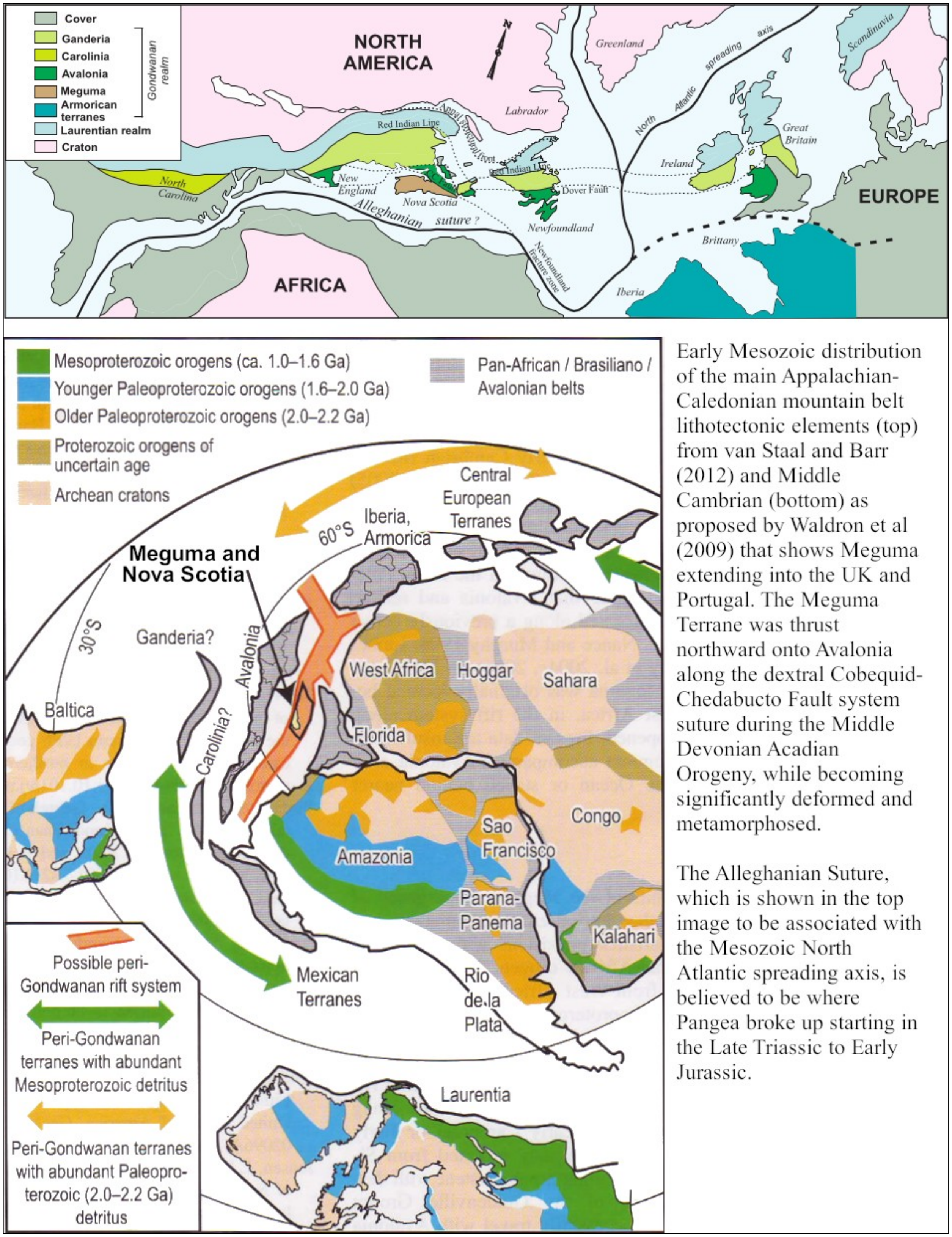
8. Faults are are breaks in rocks where both sides of the plane of breakage have moved relative to each other, in a direction parallel to the plane. There are three primary types of faults: normal, reverse, and strike-slip. A normal fault is a high angle dip-slip fault on which the hanging wall (upper rock block) had moved down relative to the footwall (bottom rock block). They are extensional in nature (often referred to as detachments). A reverse fault is a dip-slip fault along which the hanging wall has moved up relative to the footwall. These are compression faults. Strike-slip faults usually have very steep or vertical dips and the relative movement between the adjacent blocks is horizontal, parallel to the strike of the fault plane. Large strike-slip faults are referred to as transcurrent and wrench faults.
9. Anastomosing refers to a branching and re-joining network of irregular surface or fault lines interlaced like braided streams or veins.
10. A transform fault is a strike-slip (horizontal displacement) fault at tectonic plate boundaries. There are three types: Ridge-Ridge, Trench-Trench, and Ridge-Trench, which link to segments of constructive plate boundary, destructive plate boundary, and constructive plant boundary to destructive ones. The Cobequid-Chedabucto Fault system is a Ridge-Ridge type transform fault.
11. A brittle fault is where there is a discrete fracture between blocks of rock displaced relative to each other.
12. A ductile faults occur as shear zones – regions of localized but continuous displacement, formed under conditions of elevated temperature and/or confining pressure.
13. The terms dextral (right-lateral, or clockwise) and sinistral (left-lateral, or counterclockwise) describe the sense of a strike-slip displacement. A fault is dextral if, to an observer standing on one block and facing the other, the opposite block is displaced to the observer's right.
14. Age referring to any geologic unit or Terrane is in reference to the age of the deposition of the sediments and/or volcanism "creating" those land mass, and not the tectonic collision of those land masses. That said, tectonic activity can often (and usually does) result in new deposition and/or volcanism, such that their "creation" ages and age of tectonism may coincide.

Figure 13: Location of Nova Scotia within Pangea in reference to the modern world.

Gondwana (van Staal et al, 2012; Willner et al, 2014; Shellnutt et al, 2014; Keppie and Keppie, 2014). Much of the deposition and volcanism responsible for these land masses occurred before, during, and after their separation from Gondwana and transport to and collision with Laurentia.

The Meguma Terrane of Nova Scotia is the most outboard and youngest of the peri-Gondwanan terranes in the Atlantic Canadian Appalachians. The Meguma is considered in some reconstructions to have remained attached to Gondwana throughout much of the Paleozoic, whereas other interpretions show it as travelling with Avalonia and having deposited on both the



Early Mesozoic distribution of the main Appalachian-Caledonian mountain belt lithotectonic elements (top) from van Staal and Barr (2012) and Middle Cambrian (bottom) as proposed by Waldron et al (2009) that shows Meguma extending into the UK and Portugal. The Meguma Terrane was thrust northward onto Avalonia along the dextral Cobequid-Chedabucto Fault system suture during the Middle Devonian Acadian Orogeny, while becoming significantly deformed and metamorphosed.

The Alleghanian Suture, which is shown in the top image to be associated with the Mesozoic North Atlantic spreading axis, is believed to be where Pangea broke up starting in the Late Triassic to Early Jurassic.

Figure 14: Reconstructions showing the relative locations of the Meguma Terrane.

west and east sides of it during the opening of the Rheic Ocean, then parts of it being overthrown onto Avalonia as the Rheic Ocean closed to form Pangea.

Figure 13 shows the location of Nova Scotia, which was at the centre of Pangea, in reference to the modern world. Nova Scotia (the Meguma Terrane) was also situated at the equator during Pangea time and up until around the Early Cretaceous. Figure 14 shows the relative positions of Avalonia, the Meguma Terrane (and Nova Scotia) and of Laurentia and Gondwana in Early Mesozoic (Staal and Barr, 2012) and Middle Cambrian (Waldron et al, 2009) which supports the possible presence of the Meguma (buried/unexposed) also in the UK (Waldron et al, 2011; Nance et al, 2015) and Portugal (Braid et al, 2012).

3.3.2 Meguma sediment provenance, deposition, stratigraphy, and deformation

Sediment provenance, deposition, and general stratigraphy

The Meguma Terrane stratigraphy is dominated by thick (>13 km (Barr et al, 2022)) Cambrian to Early Ordovician age turbidite successions deposited in a marginal to mid-oceanic rift zone (White et al, 2008; Waldron et al, 2009; White, 2010; White and Barr, 2012; Barr et al, 2022) as a submarine fan system comparable in size to modern large rifted-margin fans (such as today's Atlantic continental shelf).

White et al (2008) and White and Barr (2012) best describe the provenance and general deposition of the Meguma Terrane.

Sandstone samples from the stratigraphically lowest part of the succession are of Early Cambrian age, as indicated by the presence of the trace fossil Oldhamia. These samples yield remarkably uniform populations of zircon grains with isotopic U-Pb ages[15] in a single broad cluster in the late Neoproterozoic and rare older Proterozoic grains, which together with positive epsilon-Nd

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[15] Zircon is a hard, wear-resistant mineral, and is thus preserved in source sediments, in which there are frequently inclusions containing radioactive elements, notably uranium and samarium (a rare earth element). Knowing their radioactive decay rates, the the U-Pb (uranium to lead) ratio can be used date the source sediments present within geologic depositional units, and the Sm-Nd (samarium to neodymium) ratio is used to assess source. The usefulness of Sm-Nd dating stems from the fact that these two elements are generally not susceptible to partitioning during sedimentation and diagenesis and neodymium is less compatible in the mantle than its radiogenic parent ^{147}Sm. Therefore, Nd contents of melts are enriched in Nd relative to Sm. The residual is then enriched in Sm, which continues to produce ^{143}Nd at a faster rate than the melt. Consequently, ^{143}Nd/^{144}Nd ratios in the residual mantle increase at a faster rate than that of the melt. The epsilon (ε) Nd notation was created using ^{143}Nd/^{144}Nd ratios relative to the ^{143}Nd/^{144}Nd ratios of a standard, like the "primitive mantle", where $\varepsilon_{\mathrm{Nd}} = [(^{143}\mathrm{Nd}/^{144}\mathrm{Nd}_{\mathrm{sample}})/(^{143}\mathrm{Nd}/^{144}\mathrm{Nd}_{\mathrm{standardd}})-1]*10{,}000$. Using this system and notation provides a quick glimpse into possible melt sources. Very low, negative epsilon-Nd values are generally found in continental crusts where the Nd system has been separated from the Sm "enriched" mantle for millions of years, whereas positive epsilon-Nd values are commonly found in mantle derived melts. Igneous rocks can acquire a wide range of epsilon-Nd values depending on the processes under which they are formed, and the types of rocks they interacted with prior to eruption.

values suggest derivation of the sediment from juvenile late Proterozoic crust associated with Pan-African orogens.

A Middle Cambrian Meguma sandstone, collected from a rare shelly fossil locality higher in the succession, yields a diverse population of zircon grains with source sediment origin radiometric age peaks in the late Neoproterozoic (~600 Ma), and mid-Paleoproterozoic (~2 Ga) and has negative epsilon-Nd, suggesting derivation from more distant sources in the Eburnian or Amazonian orogens. Rare late Mesoproterozoic (1.0-1.2 Ga) zircon indicate input also from South America.

Younger samples show consistently negative epsilon-Nd, suggesting that the Meguma terrane continued to receive sediment from a rising (uplifted) Gondwana until at least the Early Ordovician. The transition from relatively juvenile sources early in the history of the Meguma Supergroup, to much more broadly distributed, ancient sources higher in the stratigraphy, is consistent with deposition on an evolving rifted margin, in which subsiding rift flanks allowed progressively more distant sources to contribute sedimentation.

The bedrock of the Meguma Terrain, referred to as the Meguma Supergroup[16], is comprised of the mostly coarser-grained (conglomerate to siltstone) Cambrian age Goldenville Group (13 formations depending on location and stratigraphic position), overlain by finer-grained (mostly slate) Early to Middle Ordovician age Halifax Group (5 formations depending on location and stratigraphic position). Manganese, iron, and phosphorous concentration patterns within the Halifax Group formations indicate that the basin became progressively more reducing (lower oxygen levels) with time (White and Stanley, 2009), pointing to deeper, more distal deposition of these upper units. More details are provided in Section 6 of this report.

The final “crunch” – Meguma deformation and metamorphism

By all published accounts, the Meguma sediments had become largely fully indurated[17] before being thrust northward against and onto a wedge of Avalon basement during the Middle Devonian Acadian Orogeny. The tectonic model in Figure 15 shows the position of the Meguma

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[16] The Meguma Terrane as a unit is stratigraphically referred to as the Meguma Supergroup. In stratigraphy, various geologic units are identified and referred to chronologically and by common characteristics in terms of rock type (sedimentary, igneous, or metamorphic), composition, general grain size distribution in the case of some sedimentary rock units, and terrestrial and/or climatic environment in which they are formed. In stratigraphy, such units are referred to (from smallest to larger or more major) as Members, then as Formations, which may contain one of several Members, then as Groups, which may contain one or many Formations, then as Supergroups, which contain a collection of Groups.

[17] Induration, or the process of diagenesis, is the turning of unconsolidated sedimentary deposits into rock. This can happen either via chemical processes where reactions between sediments and water flowing through them create cements between the sediment grains to lock them together into rock, or via chemical changes brought about in sediments by pressure from deep burial, or both.

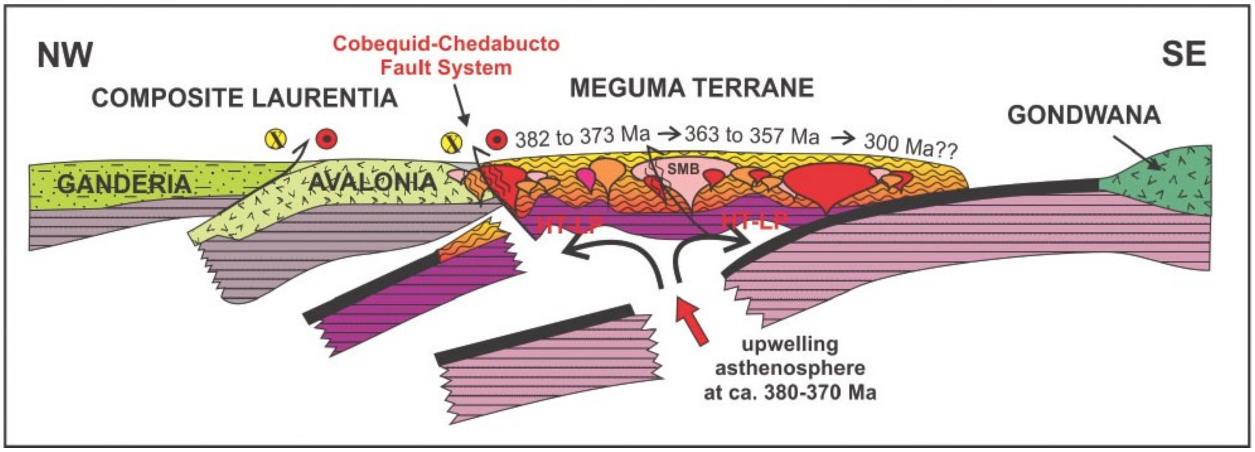

Figure 15: A tectonic model for the Neoacadian Orogeny and related pluton emplacement, which may have been related to subduction of the Rheic Ocean lithosphere outboard of the Meguma, likely combined with slab-breakoff which also likely caused high-temperature/low-pressure (HT-LP) metamorphism. From White and Barr, 2012.

Terrane relative to Avalonia, the subducting Rheic Ocean lithosphere[18], and magmatic activity and relative levels of metamorphism (more on that below) as Gondwana approached Laurentia.

The compressional forces that were exerted onto the Meguma Terrane as the Rheic Ocean closed caused the originally mostly horizontal Meguma strata to become deformed into regional scale, tight, upright, northeast-trending folds – much like a pile of paper sheets would to produce tight accordion style folds – cut (by shearing) by province-scale northeast trending dextral[19] strike-slip and thrust faults[20] and related sinistral strike-slip, normal and reverse northwest faults that define

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[18] The rigid, outermost rocky shell of of the earth. Oceanic lithosphere (oceanic crust) can range in thickness from around 10 km to 40 km, and is denser than continental lithosphere, and also after several million years becomes heavier than the asthenosphere (the shell that forms the top of the mantle – defined by the difference in the response to stress), so oceanic lithosphere will typically become subducted (sink by gravity) below continental lithosphere when under tectonic pressure. Continental lithosphere can range in thickness from 40 km to 250 km. It is distinguished from the upper mantel by the changes in chemical composition that take place at the Mohorovičić (Moho) discontinuity, which is identified by a change in the velocity of seismic waves as they travel from the surface of the earth into the mantle.

[19] Clockwise or right-hand motion of two land masses relative to one another along a fault as viewed from above as opposed to sinistral motion, which is counterclockwise.

[20] A planar fracture or discontinuity in rock across or along which there has been significant displacement as a result of rock-mass movements. Large faults result from the action of plate tectonic forces, with the largest forming the boundaries between continental plates, such as subduction zones or transform faults. The energy release associated with rapid movement on active faults is the cause of most earthquakes. Faults may also displace slowly. A fault plane is the plane that represents the fracture surface of a fault. A fault trace or fault line is a place where the fault can be seen or mapped on the surface. A fault trace is also the line commonly plotted on geologic maps to represent a fault. A fault zone is a cluster of parallel faults. However, the term is also used for the zone of crushed rock along a single fault. Prolonged motion along closely spaced faults can blur their distinction, as the rock between the faults is converted to fault-bound lenses of rock that are then progressively crushed. Strike-slip faults have lateral or horizontal displacement along a vertical or inclined

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much of the province’s current geographic/topographic fabric (i.e. shoreline and river orientations). Figure 16 shows southeast-northwest cross sections across the Meguma of these regional folds, with a photo below from Porter’s Lake to show (via the white, bedding parallel (horizontal at one time) quartz vein) locally how tightly the Meguma strata have been folded.

The top cross section in Figure 16 shows the extrapolated Goldenville/Halifax Group boundary and how much of the Meguma strata has been denuded by erosion, today exposing remnants of the younger Halifax Group rock within fold synclines[21] (see Figure 30 in Section 6 of this report). Note that the vertical and horizontal scales in the lower Figure 16 section are equal – a testament to the size of the mountains that existed in central Pangea before they were eroded. The greatest elevation of the central Pangea mountain range (at the Uniacke SPS study area and elsewhere in Nova Scotia) at the end part of the Permian Period was comparable to the present Himalayas, which are forming today by tectonic process (India colliding with Asia) similar to those that created the Pangea.

More details are provided on the local structural geology (folding and faulting) of the Uniacke SPS study area and environs in Section 6.5 of this report.

During and after their folding, the Meguma strata were intruded by granitic plutons[22] that rose up into the roots of the mountain range, many of which are visible today as granite bedrock at surface due to the denudation of the mountain range since the Late Permian. Early research using offshore seismic work found no evidence (PePiper and Jansa, 1999) of the rise of those plutons being directly related to Rheic Ocean floor subduction, but more recent work suggests otherwise, with upwelling of the asthenosphere from below the Meguma Terrane being responsible for the granitic rock intrusions, as portrayed by Figure 15. The most prevalent of these are the South Mountain Batholith and Musquodoboit Batholith, which constitute over ¼ of the Meguma

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...cont'd from page 27 fault line, whereas thrust faults are reverse fault in which he fault plane is nearly horizontal. Thrust faults can result in significant crustal shorting and vertical stacking of strata in cases were multiple, sequential thrust faults are present. The Meguma being pushed above Avalonia is an example of a thrust fault.

Normal and reverse fault motions describes vertical or inclined dip-slip displacement. In normal faults the block of rock above the inclined break line is displaced downward along the break; these are typical of extensional (spreading) stresses. In reverse faults the block of rock above the inclined break line is displaced upwards; this is typical of compression stresses (i.e. as in a thrust fault) and results in shortening of the crust. In both types of faults the section of rock that’s below the fault line is referred to as the footwall, and the section of rock that’s above the fault line is referred to as the hanging wall.

[21] A syncline is the trough which fold axis are at the bottoms of folds, versus anticlines, which fold axis are at the the peaks of folds.

[22] A pluton is a deep-seated intrusion of igneous rock that made its way upwards into pre-existing rocks, either as a melt or as a hot plastic mass, by gravity (i.e. the minerals that make up igneous plutons are less dense (lighter) than the rocks they rise up into, so they actually advance toward the surface by “floating” up through the pre-existing country rock) for from deeper magmas located several kilometres below the surface. Plutons do not rise to the surface as would magma from a volcano, but remain trapped in the subsurface and become exposed by denudation of the rock into which they have risen.

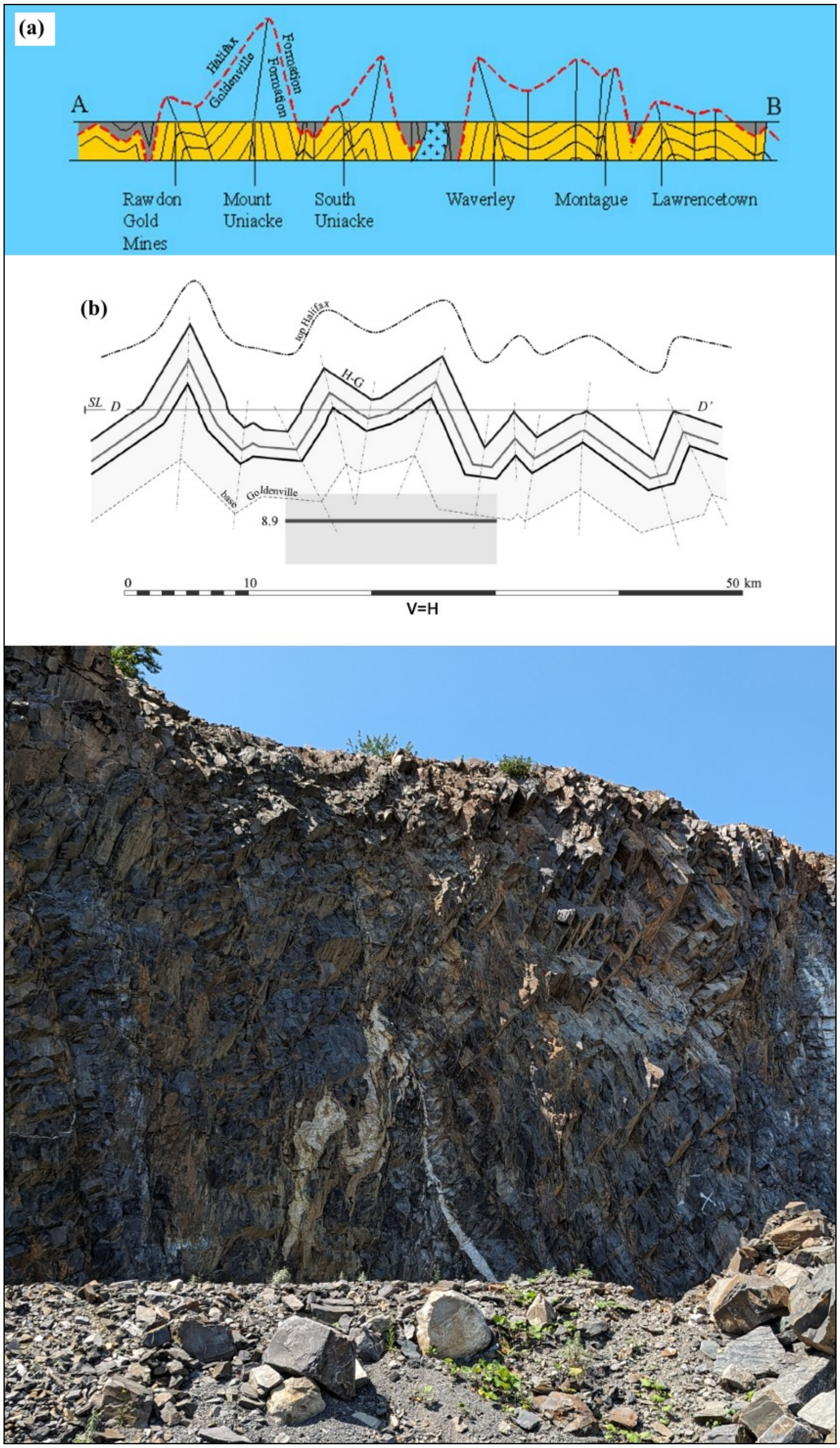

Figure 16: Cross sections (top) of regional folds of the Meguma Supergroup (after Horne and Kontak, 2022) and photo (Aug. 2023) of tight upright folds in a Porters Lake quarry. The white quartz vein in the photo is parallel to bedding that was originally horizontal.

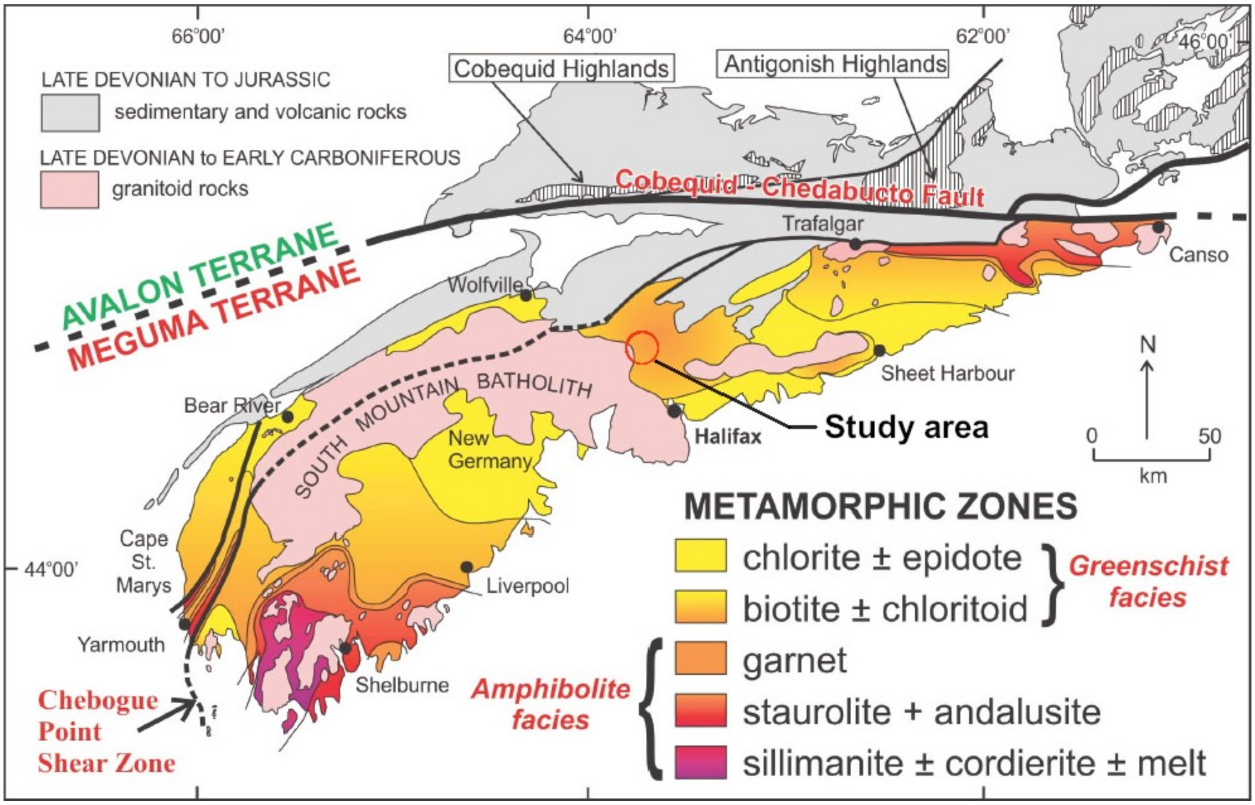

Figure 17: Regional metamorphic isograd map for exposed parts of the Meguma Terrane (coloured) as compiled from published and unpublished data (White and Barr, 2012).

Supergroup. The easternmost part of the South Mountain Batholith underlies the southwest part of the Uniacke SPS study area.

The compressional forces that were exerted onto the Meguma strata to create the tight folds and the heat from the plutons rising up from beneath them resulted in regional and contact metamorphism[23] of the rocks of the Goldenville and Halifax Groups that is variable, but systematic – which ranges from chlorite and biotite facies in the central region up to andalusite-staurolite-cordierite facies and sillimanite facies in the eastern and southwestern ends of the

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[23] Metamorphism is the process by which rocks are altered in chemical composition, texture, or physical internal structure by extreme pressure from burial or tectonic forces or heat caused by deep burial (regional metamorphism), or by extreme heat from the rise of magma through existing rock (contact metamorphism).

While metamorphic type and grade are a result of temperature, pressure, and protolith (the original type of unmetamorphosed rock), a convenient way to indicate the range of possible metamorphic rocks in a particular setting is to group those possibilities into metamorphic facies (to group together metamorphic rocks that form under the same pressure and temperature conditions, but which have different protoliths). That is done using index minerals – sets of minerals that typically form as a functions of the metamorphic alterations depending upon temperature and pressure – noting that which minerals develop will depend on a number of different factors, such as pressure, the amount of water present, and the overall composition of the original rock. Even though these types of alterations and stability ranges are vague, the stability range of each index mineral is still small enough that these minerals can be used as markers for those metamorphic conditions.

Meguma Supergroup. Figure 17 shows the metamorphic grades across the exposed parts of the Meguma Supergroup.

The granitic plutons that intruded into the folded Meguma strata resulted in the presence of well developed, well defined hornblende-hornfels facies (low pressure, moderate to very high temperature) contact metamorphic aureoles (not shown in Figure 17) that range 0.5 to 2.5 km in width around the plutons (Taylor and Schiller, 1996).

Figures 18 and 19 are included here to help illustrate metamorphic types, grades and index minerals and where they typically occur, and the kinds of grades to be expected with varying depths of sediment burial within the Meguma Supergroup, respectively. The colours representing metamorphic zones in Figure 19 are per those in Figure 17.

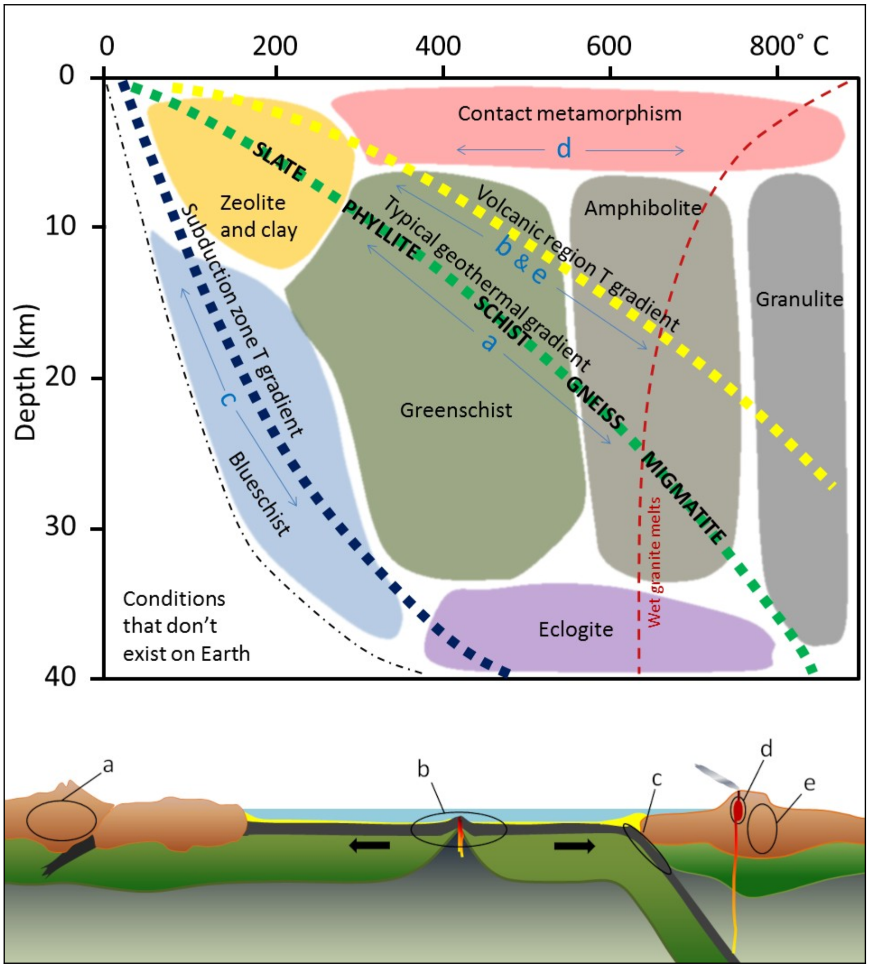

Figure 18: Metamorphic facies/types in the context of depth and temperature. The rocks formed from a mudrock protolith under regional metamorphism with a typical geothermal gradient are listed. The letters above correspond to metamorphic environments shown in the lower part of the figure (mod. from Panchuk, 2024).

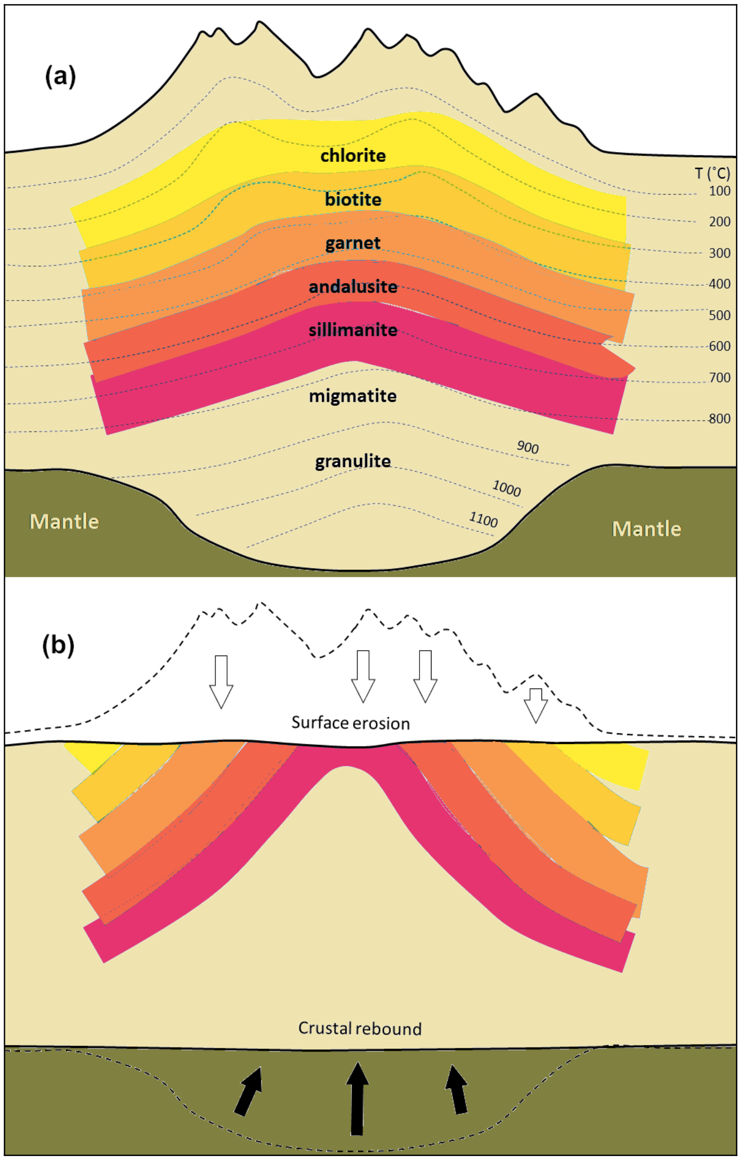

Figure 19: Schematic cross-section through the Meguma Terrane, showing: (a) metamorphic zones and temperatures when mountain-building processed thickened the crust, and (b) after the mountains have been eroded, exposing at surface matamorphic rocks that formed deep within the mountains. The colours representing metamorphic zones are per Figure 17. (modified from Panchuk, 2024)

3.4 Closing on Sections 2 and 3 of this report

We understand that for most laypeople moving straight into and trying to understand complicated and foreign technical material can be frustrating. As such, We trust that the material presented in Sections 2 and 3 of this report will have armed its readers with an appreciation of the study area's complex geologic history, and an adequate knowledge o aquifer basics, to allow them to more comfortably move forward through the technical Uniacke SPS study area subject matter to follow.

For those wanting to do a more in-depth and broader review of Nova Scotia's geology and geological history, readers may wish to read "*The Last Billion Years*", second edition, 2022, edited by Robert Fensome and Graham Williams for the Atlantic Geoscience Society and printed by Nimbus Publishing. That 260 page book is easy to read and presents its subject material in a manner that should be easy for most non geologists to understand.

4.0 Study approach, data sources, and data accuracy

Beyond that done for Section 3 above, completing this study meant drawing from and expanding upon earlier published work by Faribault (1901, 1902), Horne et al (2009a, 2009b, 2009c, 2009d), White et al (2014), MacDonald et al (1994), MacRae et al (2024), O'Neill et al (2023), Hennick and Poole (2024), Kennedy (2018, 2021, 2022), Kennedy and Fisher (2022), and King (2006a, 2006b), and various provincial mineral assessment files, and unpublished work by Gagné and Wait (1988) and ewC (2007, 2014, 2018, 2020a, 2020b, 2021a, 2023), and others. This required first doing a careful review of the regional bedrock and surficial geology, borehole data, water well data, and other information at different scales to help gain a clear understanding of the locations of the area aquifer units and their characteristics.

Armed with this regional knowledge, it was then possible to zoom in and focus on the Uniacke SPS study area – to delineate and characterize the local bedrock and surficial aquifer units within the study area, to identify the water supply options available to its current and future residents and businesses, and thus to define any related water quality and quantity concerns relating to current water use and to possible future water use with development growth within the area.

4.1 Extent and scale of the map and data reviews carried out

4.1.1 Initial, small-scale reviews

An initial review of the regional bedrock geology and related general well water quantity and quality characteristics was carried out that encompassed an area of approximately 40 km (east-west) by 28 km (north-south) at and around the study area of the Meguma Supergroup as mapped by Horne et al (2009a, 2009b, 2009c, 2009d). This served as a review of the general distribution of the geologic units within and immediately surrounding the Uniacke SPS study area, to define what hydrogeological and data was available for this study, and how to best proceed with the more detailed aspects of the study.

4.1.2 Mid-scale reviews

Then an area including at least 3 km around the Uniacke SPS study area boundaries (18 km east-west by 17 km north-south) was used to do further bedrock mapping, and within which to:

- download and stitch together 1 m resolution LiDAR DEM data (Geonova, 2024a), for:
    - detailed mapping of study area elevations,
    - generate shaded relief images of the Uniacke SPS study area and environs from

which to carry out lineaments[24] and PCA[25] analysis to help decipher the structural geology of the study area, and

- look at well production (yield) and water quality characteristics in finer detail.

It was important for this phase of the work to use only data for which mapping locations were accurately known and defined. Therefore, the mapping reviews that were done at this scale looked only at those water wells within the well log database records (NSE, 2016, 2018; Kennedy and Fisher, 2022) for which given UTM coordinate location accuracies[26] were reported to be within 200 metres.

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24. A lineament is a linear feature in a landscape that is an expression of an underlying geologic contact or geological structure, such as bedding folds, or faults and shear zones. Faults may generate subtle or significant escarpments, straight-line valleys, or subtle linear depressions in the landscape because where the bedrock gets physically displaced and/or broken up, it becomes more easily eroded.

Lineaments are often apparent in topographic maps and on aerial or satellite photographs as generally straight shorelines, or in the linearity streams and rivers. They also become evident in hill-shade images created from DEM obtained either form air photos or LiDAR.

For this study, lineaments were identified using shaded relief images created from 1 m resolution LiDAR based DEM with approximately 15 cm vertical resolution. Using the Principal Component Analysis (PCA) module within GRASS GIS, eight shaded relief (hill shade) images and PCA red-blue-green images were generated with the sun positioned 30 degrees above the horizon and at 0, 45, 90, 135, 180, 225, 270, 315 degrees azimuth to cast shadows from eight different directions, with a 25x vertical exaggeration applied to enhance the shadows produced. While the PCA image identified numerous lineaments indicative of possible faults, the shaded relief images and related (watercourse) trends were carefully studied one by one, and lineaments were identified from each shaded relief image, digitized as separate vector data layers, then the nine separate vector files where patched together for display onto a geologic map of the study area to show: (a) topographic feature strength based on relative numbers of individual lineaments present within groupings, and (b) to help define relative locational accuracy of the lineaments within each group. The orientations (azimuth) and lengths of those lineament traces were also extracted from the patched vector file to generate the rose diagrams for further analysis of the structural geology of the study area.

25. Principal Component Analysis, or PCA (Shlenz, 2014), is a dimensionality reduction technique that applies a linear transformation on highly correlated multidimensional data. The input dimensions are transformed in a new coordinate system in which the produced dimensions (called principal components) contain, in decreasing order, the greatest variance related with unchanged landscape features. In the case of using PCA for shaded relief analysis, the GRASS GIS PCA module takes care of producing any desired number of shaded relief images (eight in the case of the analysis for this assignment) with specified sun locations, conducts the PCA calculations from those images, then assigns a red, blue, green colour value with intensity relative to the pixel values for the first, second and third primary principal components, to produce a single RGB image. The resulting RGB image frequently makes it possible to identify features that may not be able to be identified from the individual shaded relief images used for the PCA. The RGB images will also assign the same colours for certain types of topographic features. For example, in most PCA RGB terrain images, glacial drumlins (more details later in this report) are typically coloured reddish-orange on their eastern sides and green on their western to northwestern sides, making them very easy to identify within topographically complex terrains. Features like sinkholes will also be uniquely coloured, as will certain linear features.

26. Drillers did not start to use GPS devices (accurate typically to about 10 m to 15 m) to locate wells until after mid-2006. Before that, well locations were identified (often guessed at) to within about 1 km (at time worse) using map books. Within the available well log database files, the locations for wells drilled prior to 2006 are defined either as the centroid of the 1 km UTM grid in which they are thought to have been

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4.1.3 Final, larger-scale reviews

Finally, the map study area was tightened to include an area extending about 1 km around Uniacke SPS study area boundaries, in which to summarize all that was learned during the earlier phase reviews for general statistical analysis of all wells (both accurate and non-accurate locations) that are understood to be located inside the boundaries of study area.

4.2 Study information sources

This study made extensive use of GIS to compile and manage, review, and interpret all relevant publicly available and some of the unpublished available information. The following general data sources were used for this study:

- published bedrock and surficial geology maps in paper and digital formats,
- reports published for other places in Nova Scotia on stratigraphically similar or equivalent geologic units to those present at and near the Uniacke SPS study area,
- local published and unpublished technical studies and reports on water resources as done by consultants on behalf of different levels of government,
- mining assessment reports relating to the bedrock mineral and/or shallower sand and gravel resources of the area, and
- numerous digital databases, including but not limited to:
    - the NS Well Log database (NSE, 2016, 2018; Kennedy and Fisher, 2022), for general well construction information, depths to bedrock, casing lengths to assess production zones, and general well performance and well yields,
    - the NS Well Pumping Test database (published (Kennedy, 2022) and unpublished (John Drage, pers. comm., 2017) versions), and ewC (2007, 2014, 2018, 2020a, 2020b, 2021a, 2023), for more detailed well and aquifer performance information than can be obtained from the Well Log database,
    - the NS database on Groundwater Chemistry (from private sources and mined from public sources (Kennedy, 2018, 2021), for general groundwater quality, and

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...cont'd from page 35 drilled, or as the centroid of the community they are reported to be in, and in some cases, the centroid of building lots where drillers have reported either civic addresses or property identification (PID) numbers. While most well logs include well owner names, many have no address, so the only way to locate those wells is by doing title searches, which is typically well beyond the scope of most HRM Level 1 and 2 groundwater assessments. Therefore, in GIS, many wells are found plot incorrectly at the same location (i.e. at 1 km UTM or community centroids).

Fortunately, the more recent NS well log database versions report the levels of location accuracy. But with the advent of smart phones with GPS, many drillers choose to use those to report well locations, which are not as accurate (particularly older phones) as the dedicated handheld GPS instruments that are assumed to be used – and there are no provisions on the driller log reporting forms to indicate how locations are measured.

  - NS Exploration Borehole Database (O’Neill and Poole, 2023), for depths to bedrock.

Searches were done of the GeoScan and NovaScan bibliographic databases to locate and retrieve Geological Survey of Canada and Nova Scotia Natural Resources Geoscience and Mines Branch publications and relevant mineral assessment reports on the Meguma and Quaternary geologic deposits of the greater study area.

Follow-up Google searches were done to help retrieve documents referenced in these databases that were not directly accessible for download from the government Web sites.

4.3 Mapping coordinate and elevation datum used in this study

Unless noted otherwise, all coordinates and maps in this report are in reference to UTM projection/datum NAD 83, Zone 20. Some of the data used for this report was taken from air photos or maps created using older survey methods for which coordinates may be approximate. All ground elevations are in reference to vertical datum GCVD2013.

5.0 Study area description and surface characteristics

The Uniacke SPS study area (Figure 1) is situated in the southwest part of East Hants County, immediately northeast of Highway 101. The study area represents about 66% of the Uniacke Policy Area and encompasses an area of approximately 8,030 ha, with the Uniacke GMA encompassing 2,410 ha within the southern corner of the study area.

Access to and within the Uniacke SPS study area is via exit 3 from Highway 101 to Highway 1, and via the East Uniacke Road from Beaverbank Road.

5.1 Present study area cover and land use

The map in Figure 20 shows the study area's land use and cover, and Table 2 summarizes the surface areas (unadjusted for topography) for the different land cover/used types for the Uniacke SPS study areafor the Uniacke GMA only, and for the Uniacke SPS study area excluding the Uniacke GMA.

Table 2. Relative distribution of land use and cover for the entire Uniacke GMA and within the Uniacke SPS study area.

Land cover/use Description	Total land cover/use category area (m^2)			Percentage of total area		
	Entire Uniacke GMA area	Uniacke SPS study area only	Uniacke GMA area minus Uniacke SPS study area	Uniacke GMA area	Uniacke SPS study area only	Uniacke GMA area minus Uniacke SPS study area
Softwood	34,562,622	7,974,758	26,587,864	43.04	33.08	47.32
Mixedwood	20,214,414	6,496,839	13,717,576	25.17	26.95	24.41
Hardwood	5,151,392	2,733,643	2,417,749	6.42	11.34	4.30
Alders <75% coverage	104,388	43,487	60,901	0.13	0.18	0.11
Alders >75% coverage	72,757	61,085	11,672	0.09	0.25	0.02
Clear cut	626,420	55,216	571,204	0.78	0.23	1.02
Wetlands, general	1,563,514	633,321	930,193	1.95	2.63	1.66
Beaver flowage	149,111	59,358	89,753	0.19	0.25	0.16
Open bogs	1,674,361	419,504	1,254,857	2.09	1.74	2.23
Treed bogs	1,657,355	378,924	1,278,431	2.06	1.57	2.28
Lake wetland	533,074	74,436	458,637	0.66	0.31	0.82
Lakes and rivers	5,926,639	457,287	5,469,352	7.38	1.90	9.73
Barren (<25% live tree)	94,923	94,923	0	0.12	0.39	0.00
Agriculture	282,587	123,202	159,385	0.35	0.51	0.28

Table 2. Relative distribution of land use and cover for the entire Uniacke GMA and within the Uniacke SPS study area.

Land cover/use Description	Total land cover/use category area (m^2)			Percentage of total area		
	Entire Uniacke GMA area	Uniacke SPS study area only	Uniacke GMA area minus Uniacke SPS study area	Uniacke GMA area	Uniacke SPS study area only	Uniacke GMA area minus Uniacke SPS study area
Urban	6,018,600	3,460,478	2,558,122	7.50	14.36	4.55
Miscellaneous	57,498	0	57,498	0.07	0.00	0.10
Gravel pit	487,763	436,601	51,162	0.61	1.81	0.09
Power line corridor	42,701	39,739	2,962	0.05	0.16	0.01
Road corridor	895,440	458,765	436,675	1.12	1.90	0.78
Rail corridor	183,233	104,601	78,632	0.23	0.43	0.14
Totals	80,298,791	24,106,167	56,192,624	100.00	100.00	100.00

The land forest cover and land use data layer (Geonova, 2024b) from which Figure 20 and Table 2 were produced is based on data from air photos that were flown in early 2013, so they do not include the newly constructed Northumberland Capital Corp. Inc. Mount Uniacke quarry, for which, based on Google Earth historic satellite images, tree clearing did not start until some time between February and May 2013 and work in the quarry did not begin until some time between July and September 2015. However, if the Mount Uniacke quarry were to be included in Table 2, then the percentages for gravel pits and quarries would, for the entire Uniacke SPS study area and for the Uniacke GMA area alone increase to 0.66% and 1.98% for a 4 ha quarry, and 1.11% and 3.47% for a proposed 40 ha quarry, respectively, with equal decreases in mixed wood forest.

Many of the designated areas (Geonova, 2024b) identified within the Uniacke SPS study area include pits, with a few representing industrial, storage, or parking areas, and one as a golf course (approximately 291,765 m^2) located just outside the Uniacke GMA south of Uniacke Lake and north of the railway, accessible via Alder Ln. off Highway 1.

5.1.1 General zoning and study area domestic and industrial land use

Figure 21 shows the latest zoning (MEH, 2023) within the Uniacke SPS Study area. Approximately 55.36% of the study surface area is zoned rural (which includes pits and quarries), 15.35% is zoned open space, and 24.26% is zoned residential (12.81% R1 and R2, 9.03% lake-shore residential, 2.19% country residential, and 0.23% mobile home). Roughly 3.23% of the study area is zoned commercial and industrial (including the Uniacke Business Park), with all other zoning making up only 1.8% of the entire Uniacke SPS study area.

Commercial/industrial establishments include service stations, convenience stores, a farmer's market, a couple of restaurants, and a machine shop along Highway 1, and storage and repair shop type facilities along Ether Road near Highway 1.

While there is some forest harvesting happening within the Uniacke SPS study area, except for borrow pit activity (mostly along the now-abandoned railway east of Pentz Lake and off of Beamish Rd. southwest of Lewis Lake), former quarry activity (abandoned shale pit at the end of Withrow Ln. west of the Valley Gate Mobile Home Park), and current activity at the Mount Uniacke Quarry work and at the end of the South Uniacke Rd. (where allegedly blasting was done about 10 years ago, which appears to have affected the yields of some nearby wells), much of the rural zoned land remains as undeveloped forest.

5.1.2 Historic land use

Based on satellite images dating back to the early 1980's (Google Earth) and on air photos dating back to the 1970's (Geonova, 2024c) and as far back as WWII (NSDNR Mines Branch library), historic land use within the Uniacke SPS study area appears to have included forest harvesting, some borrow pit activity, and most notable in terms of their possible local legacy on groundwater resources quality, mining at the former South Uniacke and Mount Uniacke gold districts, plus the associated rural residential development that occurred in support of those early industries.

The locations of the South Uniacke and Mount Uniacke gold districts and associated tailings dumping areas are shown in Figure 30, and discussion on same, along with discussion on general natural geological influences on groundwater quality, are provided in Section 6.6 of this report.

5.1.3 Protected areas and special species designations

A brief review was done of the ecological zones and wetland and other protected areas and special species designations per NSDNR (2024a).

Within the Figure 20 and 21 areas, protected areas under the NS Protected Areas System (Geonova, 2024b) include a part of the Devils Jaw Wilderness Area immediately outside the north boundary of the Uniacke SPS study area, and the Pockwock Wilderness Area, which encompasses the area from the southwest shore of West Lake, extending to outside of the study area southwest of Highway 101, and the Sackville River Wilderness Area that is located outside of and about 2 km southeast of the study area and to the north and south of Highway 101.

Uniacke Lake is shown as a habitat of concern (NSDNR, 2024a), but the species of concern is not provided. A strip of land including 0.5 to about 1.5 km along the southwest boundary of the Uniacke SPS study area, west of Uniacke Lake to south of Lily Lake, is designated as a Special Management Practice Zone for mainland moose.

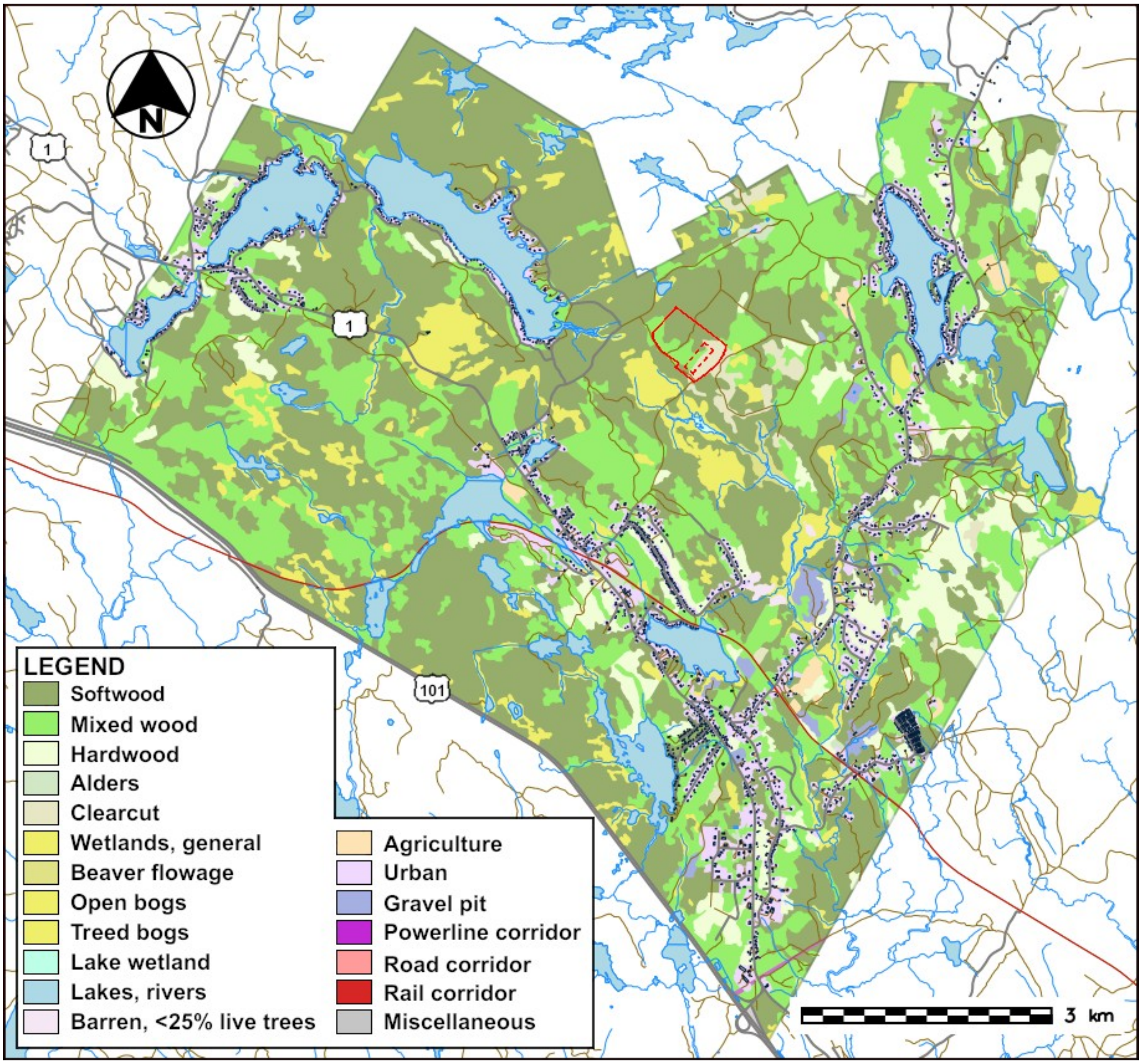

Figure 20: Present-day Uniacke SPS study area land cover and land use (per Geonova, 2024, based on air photos flown in 2013). The red lines show the approximate boundaries of the existing (dashed) and proposed (solid) extension of the Mount Uniacke Quarry (WSP, 2023).

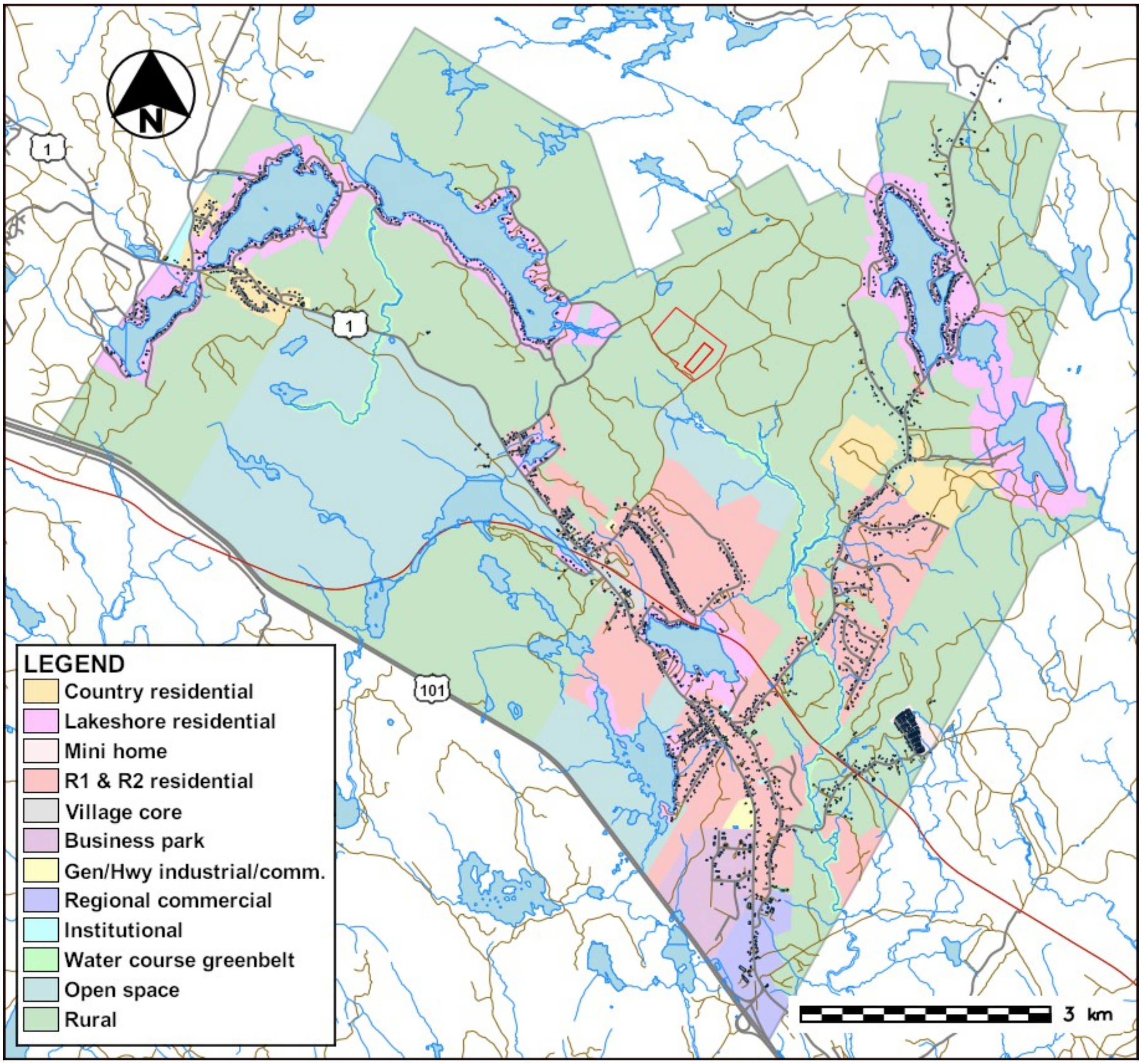

Figure 21: Latest zoning (MEH, 2023) within the Uniacke SPS study area. The red lines show the approximate boundaries of the existing (dashed) and proposed (solid) extension of the Mount Uniacke Quarry (WSP, 2023).

5.2 Topography and surface water hydrology

5.2.1 Topography

The map in Figure 22 shows the ground surface topography of the greater study area, which elevations range from 67.2 m to 232.5 m. The histogram in the legend shows the relative distribution of elevation values in the Figure 22 map area.

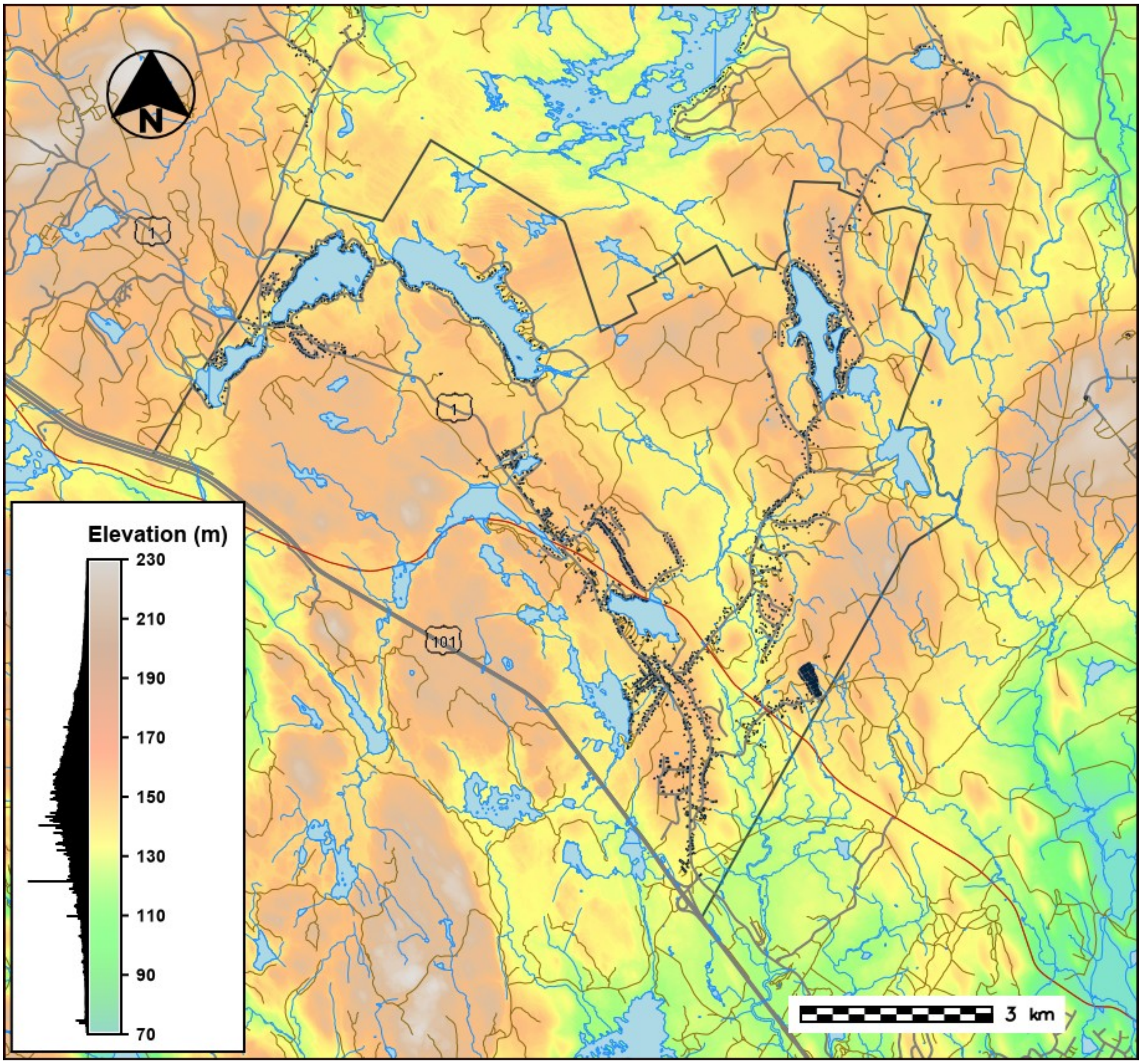

Figure 22: Greater Uniacke SPS study area ground surface elevations.

Within the Uniacke SPS study area, ground surface elevations range from 116.5 m to 217.0 m and average 157.0 m (standard deviation = 15.0 m). Correcting for elevation (calculating surface area along slopes), the Uniacke SPS study area includes a total estimated surface area of 81,206,801 m^2 (as opposed to a plan area of 80,298,791 m^2).

5.2.2 Surface water hydrology – study area watershed boundaries

The Uniacke SPS study area lies within four of Nova Scotia's primary surface watersheds and five secondary sub-watersheds as defined by NSE (2021) at 1:10,000 scale (Figure 23):

- secondary sub-watershed 1DE-1 of the St. Croix River primary watershed, which discharges to the Bay of Fundy via the St. Croix River then the Avon River,
- secondary sub-watersheds 1EH-2 and IEH-3 of the East/Indian primary watershed, with discharge into the Atlantic Ocean via the Northeast and Indian Rivers, respectively,
- secondary sub-watershed 1Ej-4 of the Sackville primary watershed, which also discharges into the Atlantic Ocean via the Sackville River, and
- secondary sub-watershed 1DG-1 of the Shubenacadie/Stewiacke primary watershed, with discharge into the Bay of Fundy via the Shubenacadie River.

Figure 23: Study area location (in red) relative to Nova Scotia's primary watersheds.

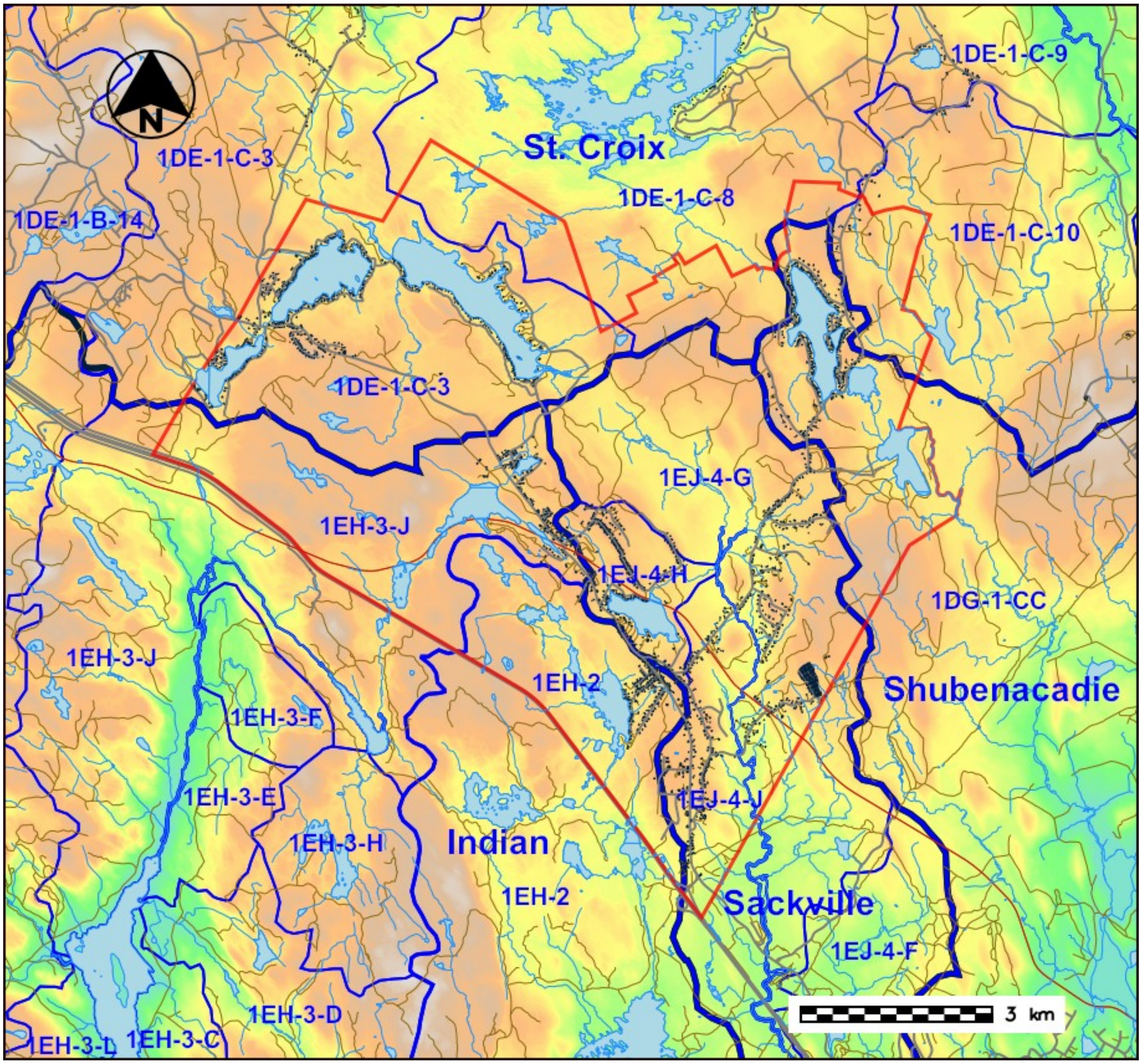

Figure 24: Surface watershed boundaries and their designations (NSE, 2021) within and around the Uniacke SPS study area. Primary watersheds are identified by name. Secondary sub-watersheds (eg. 1EH-2), tertiary sub-watersheds (eg. 1EH-3-J) and sub-tertiary sub-watersheds (eg. 1DE-1-D-3) are identified by their alpha-numeric designations.

Figure 24 shows the study area and local surface watersheds down to the sub-tertiary level. Approximately 33.64% of the Uniacke SPS study area is situated within and is drained by the St. Croix primary watershed, 30.65% of the study area is within and is drained by the Sackville primary watershed, 25.02% of the study area is within and is drained by the East/Indian primary watershed, and 10.69% of the study area is located within and is drained by the Shubenacadie/Stewiacke primary watershed.

5.3 Precipitation

Precipitation is all important to the recharge of groundwater of the Uniacke SPS study area because, due to its position at the very apex of four provincial primary watershed, except for subsurface flow possibly transcending more local basins, generally all of of the water contributing to the study area groundwater recharge will need to originate from precipitation. Study area groundwater recharge is discussed further in Section 9.5 of this report.

5.3.1 Current precipitation trends based on historic data

Precipitation at the Uniacke SPS study area falls as rain and snow, with frequent rainfall and snow melt events during winter. However, when considering longer-term groundwater recharge, all of the snow falling onto most recharge areas would also contribute to recharge as spring snow melt, so use of total annual precipitation should be adequate to estimate groundwater recharge.

Figure 25 and Table 3 summarize the 30-year climate normals for the period 1981 to 2010 (the latest 30—year normals available) from the Environment Canada (EC, 2014) Pockwock Lake climate station located approximately 8 km south-southwest of the study area’s southern-most boundary, roughly 14 km from the centre of the study area. They show the general “form” of the annual climate data for the area – that historically the highest average rainfall occurs in November – and a total average annual rainfall of 1,305 mm, and 1,513 mm total precipitation including snowfall.

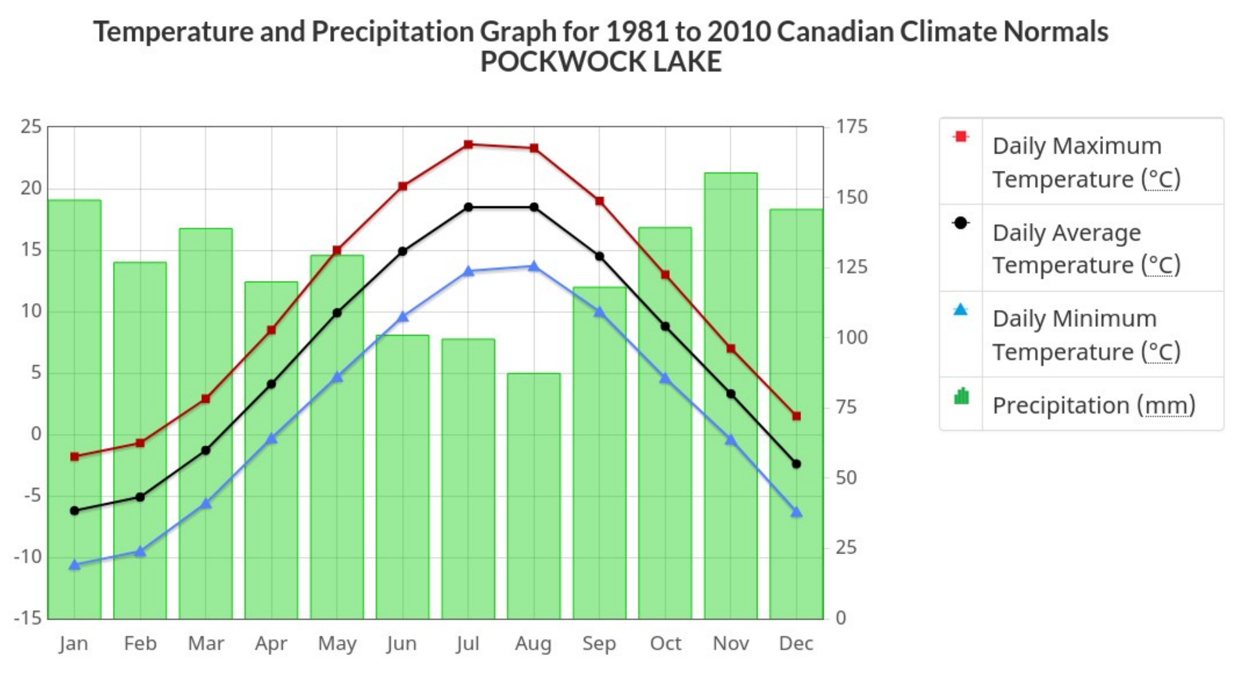

Figure 25: Total precipitation and temperature at Pockwock Lake (Environment Canada, 2020).

Table 3. 30-year mean (1981 to 2010) precipitation, Pockwock Lake, Nova Scotia.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Rainfall (mm)	94.2	79.2	101.1	109.2	128.6	100.9	99.5	87.3	118	139.2	142	105.6	1,304.7
Snowfall (cm)	54.4	46.8	36.1	10.5	0.7	0	0	0	0	0	16.5	39.6	204.7
Tot. precip. (mm)	149	126.8	138.9	119.9	129.3	100.9	99.5	87.3	118	139.2	158.7	145.7	1,513.2
Ave. snow depth (cm)			3	0	0	0	0	0	0	0	1	2	
Med. snow depth (cm)			0	0	0	0	0	0	0	0	0	0	
Extr. daily rainfall (mm)	67	72	63.2	76	75	53.4	74.6	48.8	133.2	91.6	73.8	72	
Date (yy/dd)	92/05	85/13	79/14	82/28	05/22	85/17	81/21	99/15	96/02	05/08	02/13	81/15	
Extr. daily snowfall (cm)	36	36	27	18.1	7	0	0	0	0	1	75	50.8	
Date (yy/dd)	87/31	02/04	93/18	97/01	95/06	79/01	79/01	79/01	79/01	97/23	04/13	79/09	
Extr. daily precip. (mm)	67	72	63.2	76	75	53.4	74.6	48.8	133.2	91.6	75	72	
Date (yy/dd)	92/05	85/13	79/14	82/28	05/22	85/17	81/21	99/15	96/02	05/08	04/13	81/15	
Extr. snow depth (cm)	44	60	53	15	0	0	0	0	0	0	44	39	
Date (yy/dd)	05/27	02/05	01/10	82/08	82/01	82/01	82/01	82/01	82/01	82/01	04/14	95/27	

However, the Pockwock Lake climate station is missing a large amount of data (Figure 25 and Table 3 represent only about 78% of the 30 years covered, so the climate station is not UN World Meteorological Organization (WHO) compliant) and the climate station is located adjacent to a paved road and to a power generating windmill which, although its construction date is unknown, can significantly affect both temperature and precipitation data readings.

The WHO compliant EC climate stations are located long distances apart, and there are no other WHO compliant climate stations near the site (the next closest climate stations are located at the Halifax International Airport about 26 km away, Shearwater 38 km away, and Kentville 58 km away, all of them in different micro-climate zones). So to help offset these data discrepancies and to accommodate Nova Scotia's ocean-affected climate peculiarities, a few years ago ewC developed a precipitation model[27] for Nova Scotia using GIS and total mean monthly and total mean annual precipitation 30 year normal data from the 57 EC (2014) climate stations (20 in Nova Scotia, 37 in New Brunswick) that are WMO compliant for the period 1981 to 2010.

Table 4 summarizes the total monthly and annual precipitation amounts from that model at the centre of the site. Based on the numbers in Tables 3 and 4, total annual precipitation at the site might be expected to be somewhere between 1,513 mm and 1,436 mm. A mean of these values that is weighted 75% toward the Pockwock data, or a total annual precipitation of approximately 1,494 mm, may be appropriate for the study area – for the 30-year period ending 2010.

Environment Canada has not published climate normals data for Pockwodk Lake for the 30-year period ending 2020. In fact, where they produced data for 49 Nova Scotia climate stations for the

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[27] The modelling was developed using spatial approximation analysis using climate station point data to floating-point raster format (10m x 10m resolution) by regularized spline interpolation with tension factor 30 and smoothing of 0.1 in GRASS GIS (2024). Measures were not needed to incorporate elevation-dependence, as local orographic effects are likely inherent to the climate station locations. However, anisotropy (ratio 2 to 1, azimuth 70 degrees) was applied to represent prevailing storm advance directions across Nova Scotia.

period ending 2010 (some of the WMO compliant, some of them not), they've published data (over 3 years late) for only 18 stations for the 30-year period ending 2020 (a 63.3% drop in available data). Likewise, where climate normals data for the 30-year period ending 2010 were published for 1,136 climate stations nationally, data for the 30-year period ending 2020 has so far been published for only 326 climate stations (a 71.3% drop in available climate data). As such, there is insufficient data available for the Maritimes from which to properly produce precipitation model for the period ending 2020.

Table 4. Mean total precipitation for the 30 year period 1981 to 2010 as defined from the ewC GIS precipitation distribution model.

Period	Total precipitation (mm)
January	142.1
February	111.1
March	126.9
April	116.0
May	125.2
June	92.7
July	90.4
August	87.4
September	112.8
October	128.4
November	156.4
December	146.2
Annual	1,435.8

5.3.2 Possible future precipitation related to climate change

The purpose for looking into possible future climate-related precipitation scenarios is to help determine what the future groundwater recharge situation might look like moving forward as new development increases the number of well water users within the Uniacke SPS study area.

Table 5 summarizes the climate change scenario data as projected by Richards and Daigle (2011). Their work appears to be the most widely used reference by others to prepare reports on water resources, flood prediction, and climate mitigation, which is why Table 5 is presented here.

The work by Richards and Daigle (2011) used the relatively very recent 1971 to 2000 climate normals period as their baseline, and is based on the IPCC's (Intergovernmental Panel on Climate Change) AR4[28] SRES[29] A2 and A1B CO_2 emissions and climate change scenarios, which

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[28] The IPCC's 4th Assessment Report, Working Group 1 Physical Science Basis, published 2007.

[29] Special Report on Emissions Scenarios, and IPCC report published in 2000 to describe greenhouse gas emissions scenarios in light of human activity and population size.

are roughly equivalent to the IPCC's AR5[30] RCP8.5[31] and RCP6.0 CO_2 emissions based warming scenarios, and to the IPCC's AR6[32] SSP5[33] and SSP3 to SSP2 climate change scenarios.

Table 5. Climate change scenario data as projected by Richards and Daigle (2011) for Shearwater (HRM) and as averaged for Nova Scotia (NS).

	1980's		2020's		2050's		2080's	
	HRM	**NS**	**HRM**	**NS**	**HRM**	**NS**	**HRM**	**NS**
Temperature – annual	6.7	6.4	7.7	7.5	8.9	8.7	10.1	9.9
Temperature – winter	-3.6	-4.1	-2.4	-2.9	-1.1	-1.5	0.3	-0.2
Temperature – spring	4.2	4.2	5.2	5.1	6.2	6.2	7.3	7.4
Temperature – summer	16.7	16.9	17.7	17.9	18.9	19.0	10.0	20.1
Temperature – autumn	9.3	8.8	10.4	9.8	11.5	11.0	12.7	12.2
Days with temp > 30°C	0.9	2.4	1.7	5.2	3.9	9.7	7.0	16.1
Days with temp < -10°C	3.4	4.5	2.3	3.6	1.3	2.2	0.7	1.4
Precipitation – annual (mm)	1,419.4	1,351.8	1,452.8	1,385.2	1,460.7	1,396.0	1,500.7	1,435.3
Precipitation – winter (mm)	388.4	382.1	403.6	398.4	411.3	407.7	431.6	428.1
Precipitation – spring (mm)	355.0	327.4	365.9	337.8	371.6	343.1	385.3	356.3
Precipitation – summer (mm)	312.1	277.4	317.6	282.0	314.9	280.1	315.5	280.4
Precipitation – autumn (mm)	363.8	365.0	366.7	368.1	364.3	367.0	370.6	374.2
Days with rain	138.5	131.6	146.1	142.4	148.8	146.5	152.8	150.3
Days with snow	45.8	44.8	46.7	53.4	39.0	45.3	32.9	38.5
Δ intensity short rainfall %	0	0	5	5	9	9	16	16
Water surplus (mm)	1,054.9	947.7	986.0	870.3	953.5	851.5	925.3	850.1
Water deficit (mm)	27.8	36.0	31.2	40.0	38.5	48.8	45.7	57.9

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30. The IPCC's 5th Assessment Report, Working Group 1 Physical Science Basis, published 2013.

31. Representative Concentration Pathway, which is a greenhouse concentration (not emissions) trajectory adopted by the IPCC with the goal of producing a more "scientific" approach to modelling future global warming, and which are represent levels of radiative forcing in W/m2. A short description of the four primary scenarios follows:

    - RCP2.6 is a very stringent pathway that assumes negative CO_2 emissions (zero net emissions plus successful sequestration) where emissions start decreasing in 2020 and to to zero by 2100, for a projected atmospheric CO_2 concentration of 400 ppm or less and a temperature increase of 0.3 to 1.7°C by 2100.
    - RCP4.5 is an intermediate pathway that also assumes CO_2 emissions (sequestration by trees) where emissions start decreasing in 2045, for a projected atmospheric CO_2 concentration of 570 ppm and a temperature increase of 1.1 to 2.2°C by 2100.
    - RCP6.0 is where CO_2 emissions start to decline by 2080, for a projected atmospheric CO2 concentration of about 720 ppm and a temperature increase of 1.4 to 3.1°C by 2100.
    - RCP8.5 is referred to by many as "business as usual", in which CO_2 emissions continue to increase for an atmospheric concentration of 1,300 ppm by 2100, with projected temperature increase of 2.6 to 4.8°C.

    The IPCC's mandate is clearly stated – it to study human-causes of global warming. Consequently, their RCP scenarios tend to ignore any natural sources of CO_2 (those are partially dealt with is separate reports), but instead assume that all changes in atmospheric CO_2 concentration are caused by human emissions.

32. The IPCC's 6th Assessment Report, Working Group 1 Physical Science Basis, published as draft in Aug. 2022.

33. Shared socioeconomic pathways, which represent changes in population, economic growth, education, urbanization, and the rate of technological development – a return to a less scientific approach to describing future global warming and possible climate change scenarios.

However, the IPCC's AR5 (2013) states that RCP8.5 scenarios are highly improbable, likely even impossible – as RCP8.5 assumes a six-fold growth in global coal consumption per capita, while the International Energy Agency and other energy forecasting groups collectively agree that coal consumption has already or will soon peak (Pielke Jr. and Ritchie, 2022). In AR6 (IPCC, 2021), the RCP6.0 scenario is considered implausible. Further, based data from on AR5 and the draft of IPCC AR6 (2021), Pielke Jr. et al (2021, 2022) have concluded with 95% confidence that an RCP3.4 equivalent (i.e. forcing of 3.4 W/m^2 by 2100 – an intermediary pathway between the "very stringent" RCP2.6 and less stringent mitigation efforts associated with RCP4.5) – should be considered as the most plausible projection of cumulative CO_2 emissions-based warming (with a 0.1% or 0.3% tolerance with historical accuracy).

Thus, the data in Table 5 (and other reports based on Richards and Daigle, 2011) should be viewed as incorrect and exaggerated, particularly in light of the very recent baseline used by Richards and Daigle. Yet, in follow-up reports, Daigle (2015) continues to use RCP8.5 and RCP6.0 and the same recent short-term baseline as the basis for his climate change temperature and precipitation projection calculations (as the AR5 and AR6 IPCC Summary Reports for Policy Makers also do, without giving any reasons for their departure from the Working Group 1 reports, as their basis upon which to claim a climate crisis). Pielke and Ritchie (2021) describe this as a misuse and abuse of climate pathways and scenarios, resulting in much of the climate research community being off-track from scientific coherence and correct policy-relevance.

Figure 26 emphasizes the significance of this. It is an updated version of IPCC AR5 Figure 11.25a that compares computer model projections with observations based on Christy and Spencer (2024), as updated by Hawkins (2019). Figure 27 is an updated version of IPCC AR5 Figure 11.25b that compares observations updated to include 2018 temperatures (Hawkins, 2019) to the 5-95% confidence range for all RCP scenarios, plus the most likely projections for the period 2015-2035 (as indicated by the red hatching), which IPCC have lowered, citing 'expert judgment' that the models are too sensitive to anthropogenic (CO_2) forcing (Curry, 2017).

Note that in Figures 26 and 27 the observed global temperatures for the past two decades are at the bottom of the 5–95% envelope of the model simulations. Overall, the trend in the model simulations is substantially (2 to 3 times) larger than the observed trend over that same period. The spike in global temperatures from the 2015 El Niño may have improved agreement between models and observations, but not by much, and temperatures returned to the lower 5-95% envelope after the El Niño. Curry (2017) concludes that the discrepancy between observations and model simulations appears to be caused by a combination of inadequate simulations of natural internal variability and oversensitivity of the models to increasing CO_2 concentrations.

In light of the modelled temperatures versus observed trends, and the recognition in AR5 and AR6 that RCP8.5 is an impossible scenarios and RCP6.0 is an implausible one, and the recent findings by Pielke et al (2021, 2022), it may be more appropriate to use RCP2.6 or RCP4.5 scenario-based temperature and precipitation projections upon which to estimate future

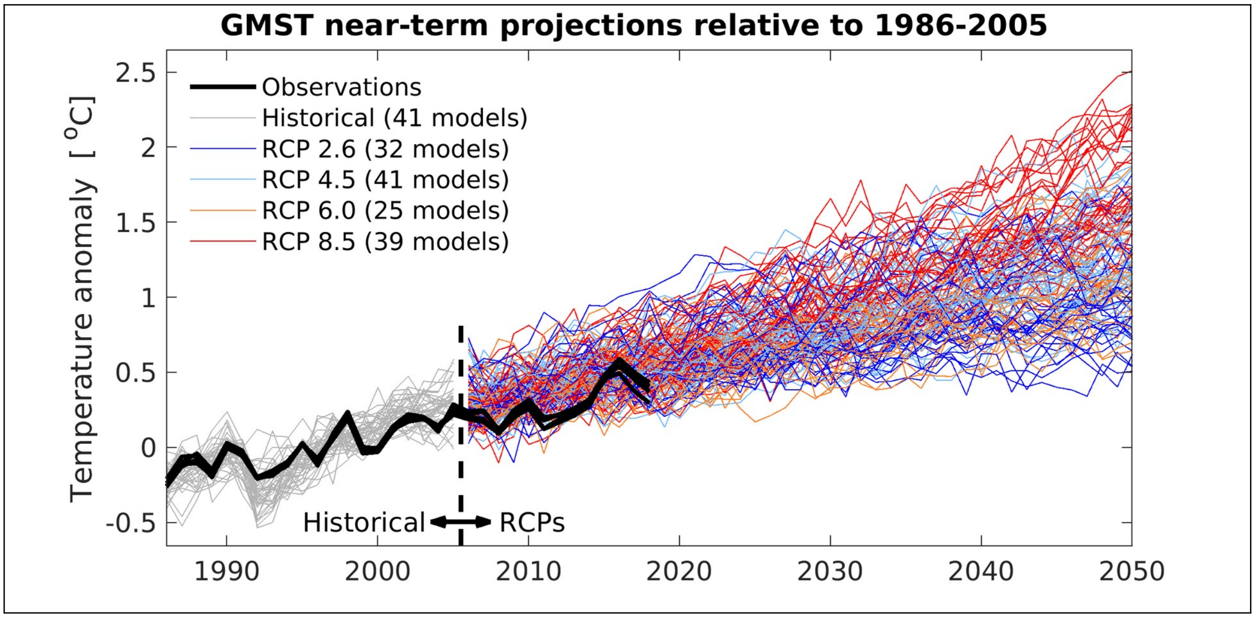

Figure 26: Updated version of IPCC AR5 Figure 11.25a, showing temperature observations and the CMIP5 model projections relative to 1986-2005 (from Hawkins, 2019). The black lines represent observational datasets (mostly from Christy and Spencer, 2024).

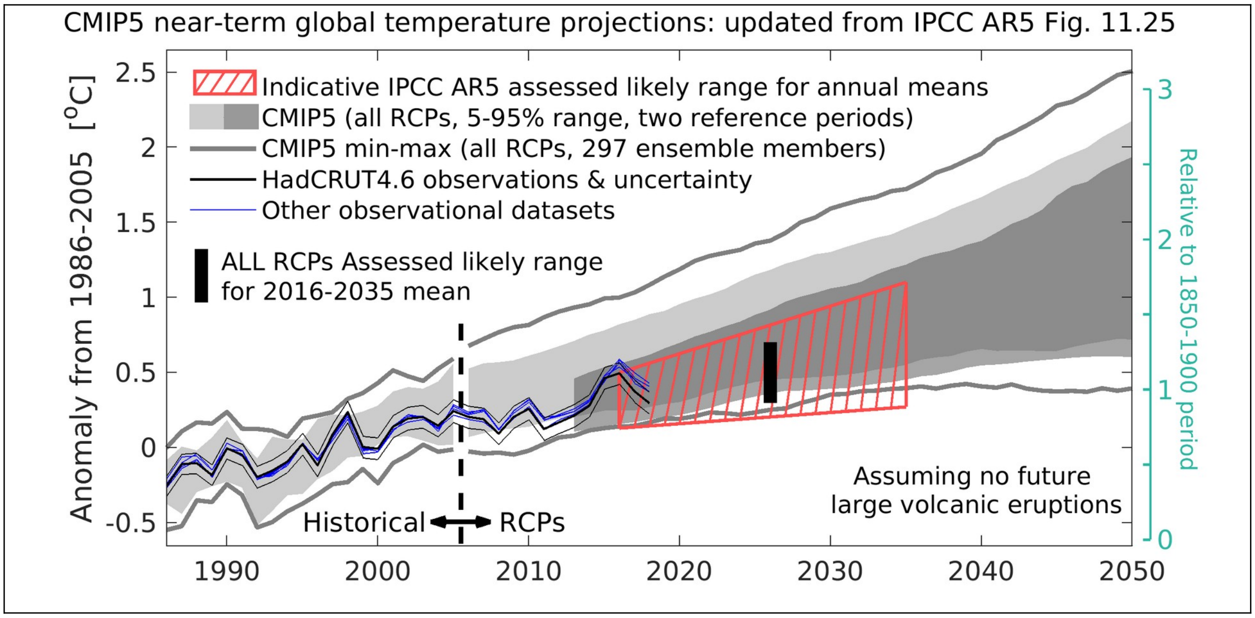

Figure 27: Updated version of IPCC AR5 Figure 11.25b with the HadCRUT4.6 global temperature time-series and uncertainty (black) (from Hawkins, 2019). The CMIP5 model projections are shown relative to 1986-2005 (light grey) and 2006-2012 (dark grey). The red hatching is the IPCC AR5 indicative likely range for global temperatures in the 2016-2035 period, with the black bar being the assessed 2016-2035 average. The blue lines represent other observational datasets. The green axis shows temperatures relative to 1850-1900.

groundwater recharge for the Uniacke SPS study area rather than those in Table 5. However, no such projections appear to be available in current published literature for Nova Scotia, and since calculating same is not in the scope of this study, defining trends from observed data.

Such work was done by ewC (2024) for central Nova Scotia, where in a review of raw daily and monthly data from numerous climate stations, it was resolved that long-term (150 years) of historic data compiled from the Truro and Debert climate stations might serve to explain possible future temperature and precipitation scenarios based on the past. Figure 28[34], which is from ewC (2023a), and other data from that study clearly illustrated the importance of looking at climate trends over much longer periods and baselines than was used by Richards and Daigle (2011). While defining possible future temperatures was not the primary intent of ewC (2024), nor is it of this report – defining total depths of precipitation available for groundwater recharge is, and based on the historic data plots reviewed for ewC (2024a) and in Figure 28, there appears to be a relationship between the temporally cyclic changes in temperatures over time and in precipitation depths. Further, warmer temperatures can increase evapotranspiration, thus reducing the availability of some of the rainfall and water from melting snowpacks within the overall water balance to serve as groundwater recharge for aquifers.

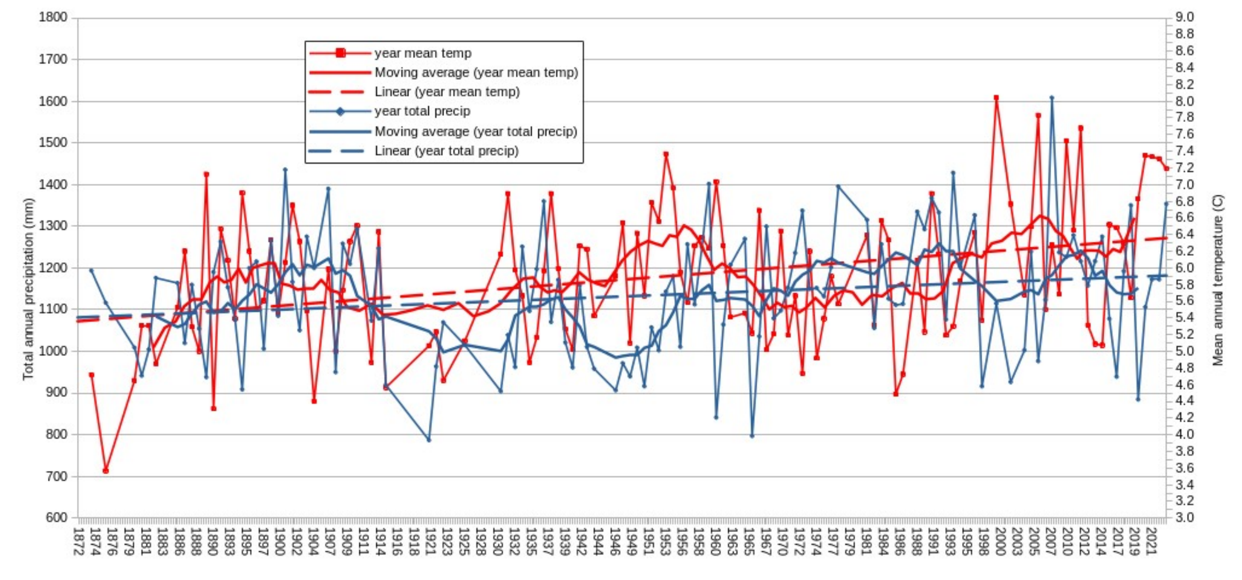

Figure 28: Historic mean annual temperatures and total annual precipitation at Truro from 1872 to 2022 (150 years), with period-centred 10-year moving averages of the data shown as solid thicker lines, and linear trend for the full period of record as dashed lines.

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[34] The plot is a compilation of data collected from three separate sets of weather measuring instruments that were moved progressively closer to more urban land use over the period 1872 to 2002 (and are thus likely to have experienced increasing urban island heating effects, which could not be corrected for in the available data) and from the Debert climate station from 2003 to 2022.

The annual mean temperatures and total annual precipitation trends in the above historic data are temporally quite variable, both in the short-term and long-term (i.e. Figure 28 clearly shows a 60 year cycle in temperature and a subdued/overprinted 11 or 22 year cycle in precipitation, likely related to Atlantic Ocean multi-decadal current oscillations), and observed data does not support the temperature and precipitation increases projected by Richards and Daigle (2011) using RCP8.5 and as in Table 5. In view that an RCP3.7 scenario (one that more closely reflects the past than the future based on IPCC computer models) is most likely, and assuming also that the past is likely to hold the key to forecasting the future, ewC (2024a) identified a relationship among the Figure 28 data and other historic data from which to project possible precipitation depths for that study's location, which notwithstanding spacial variability in absolute values, the trend may also be applicable to the Uniacke SPS study area.

Table 6 summarizes the predicted overall average total annual precipitation depths at the Uniacke SPS study area based on those (ewC, 2024a) temporal relationships.

Table 6. Present and projected future values for mean total annual precipitation depths (mm) at the Uniacke SPS study area to account for climate change based on the temporal relationships identified for central Nova Scotia by ewC (2024a).

1920's (today)	2050's	2080's	Early 2100's
1,499	1,516	1,532	1,549

6.0 Study area bedrock geology

The maps in Figures 29 and 30, and Figures 31 and 32, show the regional and local Uniacke SPS study area bedrock geology and lithostratigraphy, respectively.

The study area and environs are underlain by Cambrian to Early Ordovician age (540 to 470 Ma) metamorphosed sediments or the Goldenville and Halifax Groups, along with Middle to Upper Devonian age (395 to 360 Ma) granitic intrusives. As was noted in Section 3.3, together these bedrock units constitute the Meguma Supergroup.

As was noted in Section 3, the Meguma Terrane (Meguma Supergroup) is Canada's east-most tectonic terrane. It includes all of Nova Scotia south of the Avalon Terrane and the Minas Fault zone, which runs east-west from Chedabucto Bay to Cobequid Bay and the Minas Basin.

The Meguma Supergroup is comprised of four major bedrock groups: the older Goldenville Group, the largely conformably overlying younger Halifax Group, both of which are sedimentary sequences deposited in a mostly transgressive[35] marine environment, and the younger still Rockville Notch Group that unconformably overlies the Halifax Group. These have been intruded by numerous igneous plutons, with the South Mountain Batholith and Musquodoboit Batholith together comprising over one quarter of the Meguma Supergroup. Metasediments of the Goldenville Group and the Halifax Group and granodiorites of the eastern-most part of the South Mountain Batholith are present within the Uniacke SPS study area (Figure 30).

As was noted in Section 3, The Goldenville Group consists largely of Cambrian-Age (520 to 485 Ma) turbidite (submarine slide and avalanche) sands and related coarse sediments. The Early Ordovician age (485 to 470 Ma) Halifax Group, which sediments include finer-grained silts and muds, are thought to represent more distal and deeper marine deposition. The Lower Ordovician to Silurian age (470 to 420 Ma) Rockville Notch Group consists of a sequence of sedimentary and volcanic rocks that were deposited in what is believed to be a rift (White and Barr, 2017).

During the Acadian Orogeny (closure of the pre-Hercinian Ocean) as Gondwana (now Africa) and Laurasia (now North America) collided to form Pangea, these bedrock units were tightly folded against the Avalon Terrane and Laurasia and uplifted into a formidable mountain system. This now metamorphosed fold belt was then intruded by mostly Middle Devonian to Mississippian age (395 to 360 Ma) granitic plutons several kilometres below surface, followed by additional regional and localized deformation and rapid exhumation, the whole of which is referred to today as the Meguma Supergroup.

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[35] A marine transgression is a geologic event during which sea-level rises relative to the land and the shoreline moves toward higher ground, resulting in flooding. Flooded environments generally provide for better preservation of sediments and thus, of the geologic record. Marine regressions are the opposite. They are times during which sea-levels fall relative to the land, exposing former sea bottom. During those drier environments, erosion is prevalent and depositional processes (or their preservation) are reduced, thus leaving blanks in the geologic record.

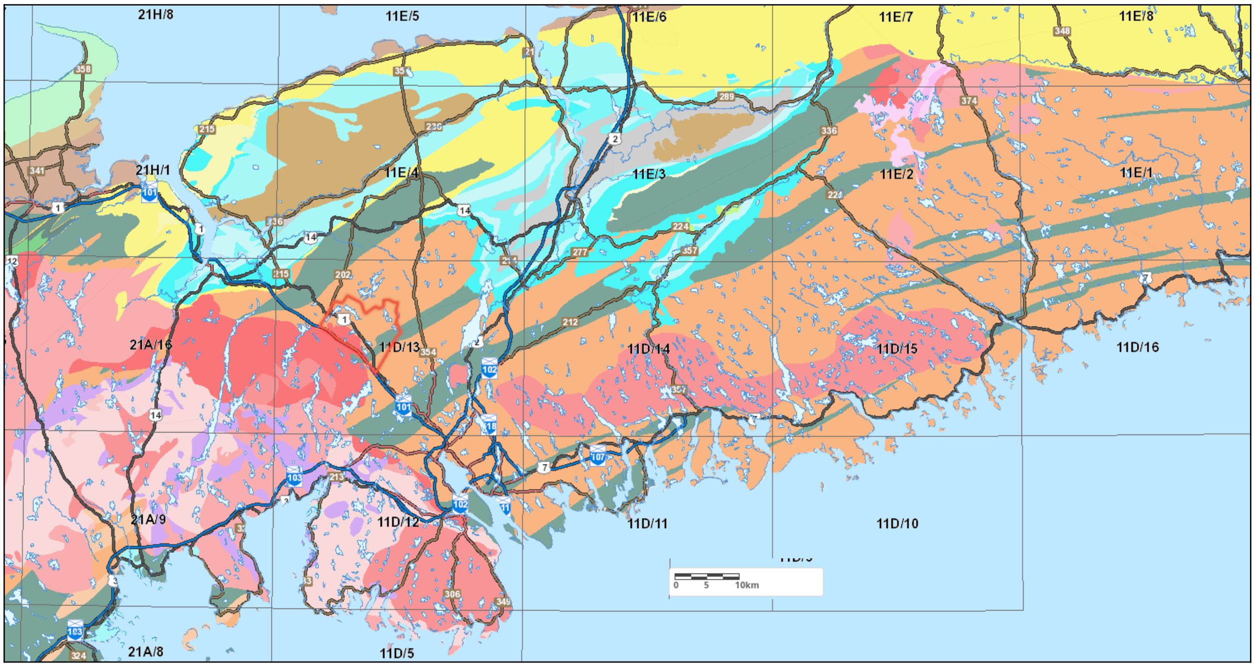

Figure 29: Uniacke SPS study area location (red boundary) relative to the Meguma Supergroup in the central part of Nova Scotia (Keppie, 2000). See Figure 31 for the Meguma Supergroup lithostratigraphy.

Table 7 summarizes the relative distribution of each of the Meguma Supergroup bedrock units present within the Figure 30 mapping area, and directly underlying the Uniacke SPS study area.

Table 7. Distribution of the Meguma Supergroup bedrock units present within the Figure 30 mapping area and directly underlying the Uniacke SPS study area.

Geologic unit		Percent of Figure 30 mapping area	Percent of Uniacke SPS study area
Granodiorite		26.51	7.91
Halifax Group	Glen Brook Formation	0.30	0.00
	Cunard Formation	6.13	6.30
Goldenville Group	Beaverbank Formation	4.29	9.30
	Taylors Head Formation	62.77	76.48
		100	100

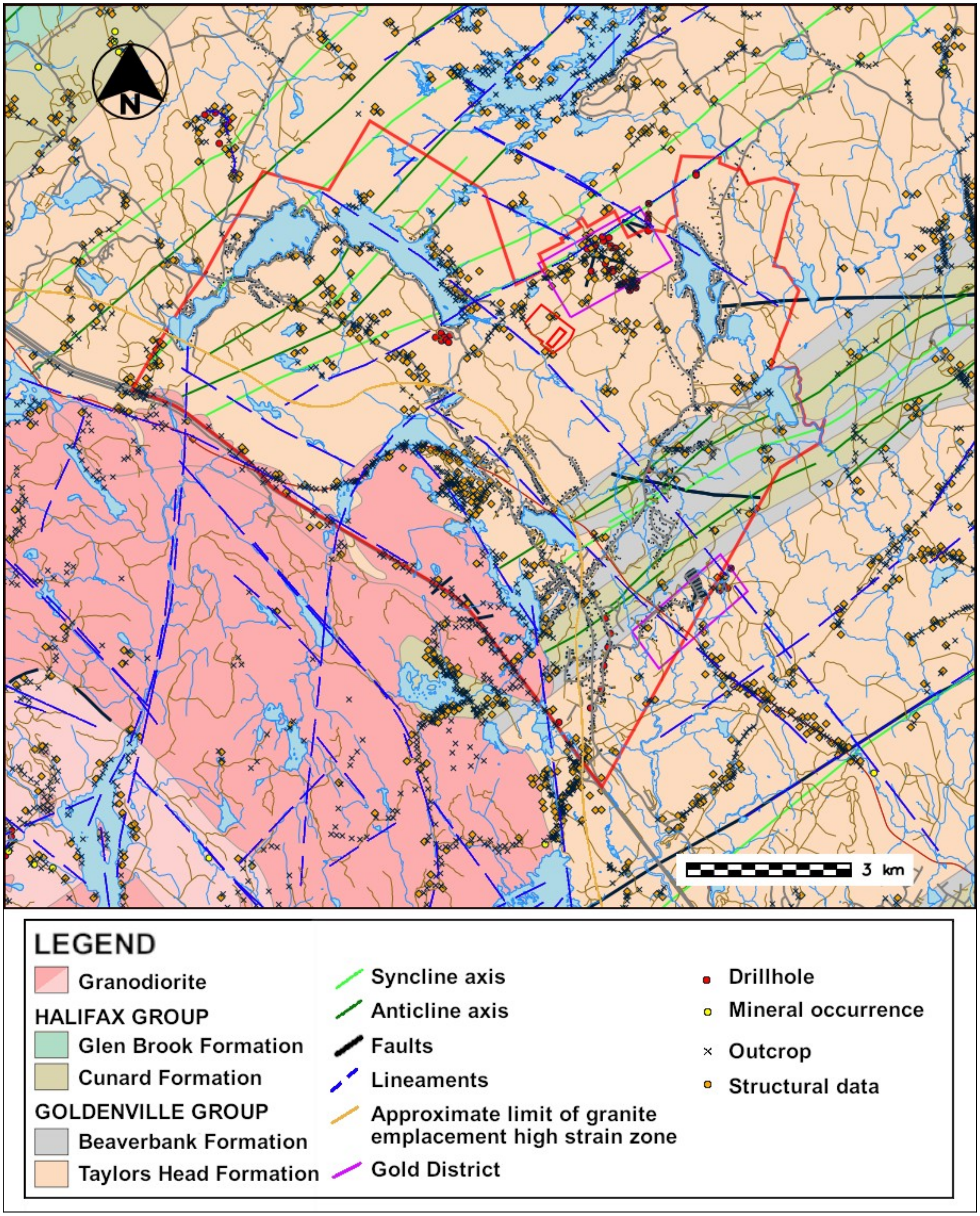

Figure 30: Uniacke SPS study area bedrock geology (Horne et al, 2009a, 2009b, 2009c, 2009d). The Uniacke SPS study area boundaries and the existing and proposed boundaries of the Northumberland Capital Corp. Uniacke Quarry are in red.

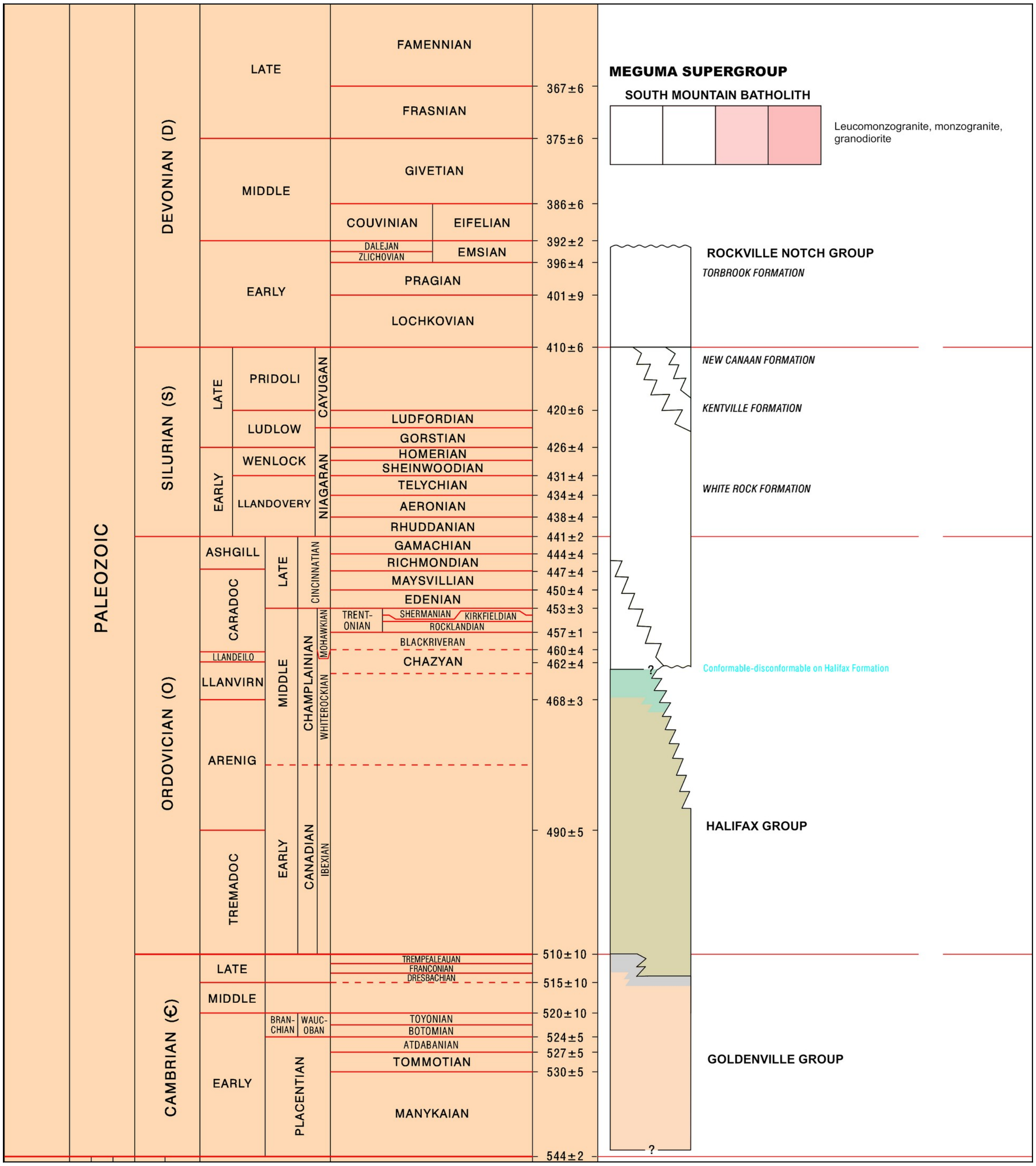

Figure 31: Local Cambrian to Devonian stratigraphy showing the bedrock units (coloured) present in the Uniacke SPS study area in Figure 30 (from Keppie, 2000; Pothier et al, 2015).

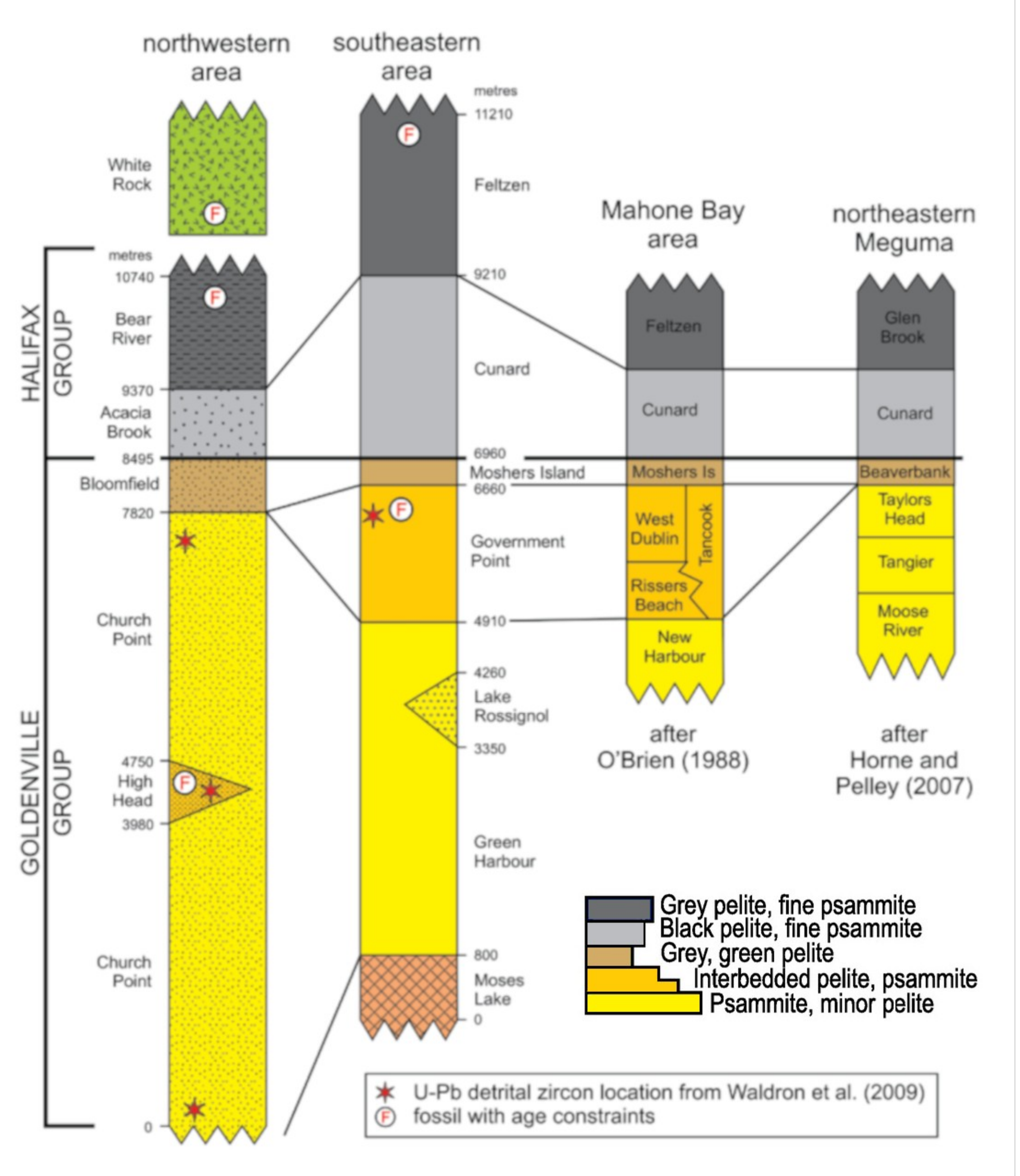

Figure 32: Schematic stratigraphic columns for the metasedimentary components of the Meguma Supergroup (modified from White, 2009 and Waldron et al, 2009).

6.1 Structure and metamorphism of the Meguma Supergroup

6.1.1 Folding

The main period of folding is thought by many to be ductile deformation of marine and island arc sediments related to the docking of the Meguma Terrane (and Avalon Terrane) with Laurasia between 420 and 400 Ma, before any granitic pluton emplacement took place. However, there is evidence of post-pluton folding from 378 to 366 Ma (Keppie et al (2002), in Culshaw and Lee, 2006) after sediment strengthening, which resulted in Goldenville Group saddle reef fold structure development (which host many if not most of Nova Scotia's gold deposits) and related auriferous quartz vein emplacement.

No matter the timing or number of episodes of folding, the direction of tectonic stresses causing folding resulted in the development of tight, vertical folds with a province-wide northeast axial trend, many of which can be traced over very long distances along strike. The folds in the metasediments have a 11 to 18 km wavelength that in not apparent in maps (Culshaw and Lee, 2006) that is overprinted by a 4 to 6 km fold frequency due to buckle shortening that is much more clearly evident in geologic maps.

6.1.2 Brittle deformation – faulting

In addition to sediment folding, the tectonic stresses related to the collision of Gondwana with Laurasia generated a number of well developed faults[36]. They have a distinctive northwest orientation in the east Meguma that typically show a sinistral (counterclockwise) strike-slip[37] separation (over 20 km for some, plus certain amounts of normal and/or reverse[38] displacement

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[36] Although described in a footnote to Section 3.2.3, the following is provided here for readers who may have skipped that section.

A fault is a planar fracture or discontinuity in rock across or along which there has been significant displacement as a result of rock-mass movements. Large faults result from the action of plate tectonic

forces, with the largest forming the boundaries between the plates, such as subduction zones or transform faults. The energy release associated with rapid movement on active faults is the cause of most earthquakes. Faults may also displace slowly.

A fault plane is the plane that represents the fracture surface of a fault. A fault trace or fault line is a place where the fault can be seen or mapped on the surface. A fault trace is also the line commonly plotted on geologic maps to represent a fault. A fault zone is a cluster of parallel faults. However, the term is also used for the zone of crushed rock along a single fault. Prolonged motion along closely spaced faults can blur the distinction, as the rock between the faults is converted to fault-bound lenses of rock that are then progressively crushed.

[37] Lateral, or horizontal displacement.

[38] Describes vertical or dip-slip displacement. In normal faults the block of rock above the inclined break line is displaced downward along the break; these are typical of extensional stresses. In reverse faults, faults the block of rock above the inclined break line is displaced upwards; this is typical of compression stresses and results in shortening of the crust. In both types of faults the section of rock that's below the fault line is referred to as the footwall, and the section of rock that's above the fault line is referred to as the hanging wall.

depending on location), and farther north, northeast thrust faults and shears along which motion was mostly dextral. The northwest striking faults define the overall structural fabric of the eastern Meguma and are responsible for the development of nearly all of the harbours along Nova Scotia’s Eastern Shore, whereas the northeast faults farther north are more difficult to define, with many buried by younger overlying sediment.

The northeast dextral strike-slip, thrust[39], and tension faults were active over long time spans. Some are related to the Gondwana/Laurasia collision (Boehner, 1981; Giles and Boehner, 1982), during it (Waldron et al, 2010; Keppie Sr, (undated); Javaid, 2011; Keppie Jr, 2013), and to later stresses during the Carboniferous (360 to 300 Ma) (Bachtadse et al, 2018), the Permian (~275 Ma) (Irving, 2005; Muttoni et al, 2003), and possibly into the Lower Cretaceous (145 to 100 Ma) (Stea and Pullan, 2001; Piper et al, 2005).

6.1.3 Metamorphism

The regional metamorphism[40] associated with tectonic compression during the Acadian Orogeny varies across the Meguma Terrane from amphibolite facies[41] (medium pressure and average to high temperature) in the extreme northeast and southwest areas of Nova Scotia, to mid- or lower-greenschist facies (low temperature and pressure) in central Nova Scotia (Compton et al, 2012).

The large volumes of granite and granodiorite (the South Mountain Batholith (SMB) encompasses nearly one third of the Meguma) that intruded deep below the surface into the tightly folded and regionally metamorphosed Meguma Supergroup strata resulted in the presence of well developed, well defined hornblende-hornfels facies (low pressure, moderately to very high temperature) contact metamorphic aureoles that range generally in width 0.5 to 2.5 km around plutons (Taylor and Schiller, 1966).

6.2 Goldenville Group lithostratigraphy

Upward to a dozen mappable formations (see Figure 32) are recognized in the Goldenville Group (White, 2010; Pothier et al, 2014). The Goldenville Group is dominated by thickly bedded to massive grey to greenish grey, generally poorly sorted quartzose and feldspathic psammite (metasandstone) with chlorite-rich matrix, interbedded with minor grey to black pelitic rocks

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[39] A reverse fault in which the fault plane is nearly horizontal. Thrust faults can result in significant crustal shorting and vertical stacking of strata in cases were multiple, sequential thrust faults are present.

[40] As noted in an earlier footnote to Section 3, metamorphism is a process of mineral assemblage and texture variation that results from the physical-chemical changes in solid rocks as they are subjected to pressure (regional or dynamic metamorphism) and/or temperature (contact metamorphism). Metamorphism comprises recrystallization, deformation, and mineralogical alteration.

[41] A metamorphic facies is a set of mineral assemblages formed under similar pressures and temperatures, which certain minerals can be linked to certain tectonic settings, times, and places in the geologic record (see Figures 18 and 19 in Section 3 of this report.

(metasiltstone, slate, argillite) (Moose River, Moses Lake, Church Point, Green Harbour, Tangier, New Harbour, Taylors Head, Tancook Formations), and grades upwards into thinly bedded psammite and metasiltstone, and silty slate (Government Point, Beaverbank, Moshers Island[42], Bloomfield Formations). Gold-bearing quartz veins occur at many localities within the lower-most Goldenville Group formations (Williams et al, 2018).

The maximum measured thickness of the Goldenville Group is about 5,400 m, with the base not exposed. The stratigraphically lowermost exposed unit in the Goldenville Group, in the Yarmouth to Digby area, is 3 km in stratigraphic thickness below the High Head member. This metasandstone unit yielded 555 Ma detrital zircon, giving an earliest Upper Neo-proterozoic depositional age for that exposed part of the Goldenville Group (White et al, 2007).

The 520 to 502 Ma. Taylors Head Formation and the 502 to 497 Ma. Beaverbank Formation, are the two Goldenville Group bedrock stratigraphic units that are present within the Figure 30 map area and within the Uniacke SPS study area.

The Taylors Head Formation is characterized by grey, medium- to thick-bedded, very fine- to medium-grained metasandstone that is locally interlayered with green, cleaved metasiltstone, and rare black slate. It typically weathers to a grey-beige colour. Calc-silicate nodules are common.

The Beaverbank Formation is characterized by greenish-grey to black, well-laminated metasiltstone to slate, with minor, very thin- to thin-bedded fine-grained metasandstone. It contains abundant manganiferous nodules, laminations and coticules. It is most easily recognized in the field by its greenish-purple iridescence in fresh bedding-parallel breaks. It weathers to a slightly darker colour than the Taylors Head Formation.

The Goldenville Group is overlain conformably by the Halifax Group, although some have suggested that the two are in part contemporaneous. It is intruded by Upper Paleozoic granitic plutons. Where the Halifax Formation is absent, the Goldenville is unconformably overlain by the Lower Carboniferous Horton and Windsor groups and by the Upper Triassic Wolfville Formation of the Fundy Group.

Horne et al (2009a, 2009b, 2009c, 2009d) (Figure 30) do not specify which formation is present within and immediately within the Uniacke SPS study area. However, from Smith et al (2005), Horne and Pelley (2007), Compton et al (2012), Waldron et al (2015) and White and Vaccaro (2020), and through a familiarization with the geology of the area from outcrops and float that were observed along the south shore of Long Lake northeast of the Uniacke SPS study area, and the geology of the South Uniacke area which was mapped in detail by Gagné (1988), Gagné and Wait (1988), and from water well drill cuttings collected at Long Lake South Uniacke confirm

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[42] The Beaverbank and Moshers Island Formations have been earlier ascribed by some to the Halifax Group (White et al, 2007; White, 2010), the have more recently been ascribed to the Goldenville Group (White et al, 2014; Pothier et al, 2014).

that the bedrock unit present within the Uniacke SPS study area is indeed the Taylors Head Formation.

6.3 Halifax Group lithostratigraphy

The Halifax Group includes at least eight mappable formations and their lateral equivalents (Cunard, Acadia, North Alton, Acadia Brook, Bear River, Lumsden Dam, Feltzen, Bluestone, Glen Brook, Elderkin Brook, Hellgate Falls Formations (Pothier et al, 2015)). The group is dominated by greyish-green to black pelite and, locally, red slate, and minor fine- and very fine-grained metasandstone; it is generally thinly bedded and strongly sheared. An abundance of graphite and sulphide minerals within some of the Halifax Group formations (the Cunard Formation and its equivalents, in particular) suggest it was deposited under anaerobic sea-floor conditions during a period of basin-wide stagnation (Waldron, 1987, 1992).

The Halifax Group thickness varies from about 3,600 m in the type area (Halifax) to about 500 m in southwest Nova Scotia. It conformably overlies the Goldenville Group, and as with the rocks of the Goldenville Group, it has been intruded by Upper Paleozoic granitic plutons. It is unconformably overlain by the Rockville Notch Group, which is present in the Yarmouth-Digby area and near Kentville. Elsewhere, it is unconformably overlain by the Lower Carboniferous Horton and Windsor Groups and the Upper Triassic Wolfville Formation of the Fundy Group.

The 497 to 485 Ma. Cunard Formation and conformably overlying Glen Brook Formation (upper age not defined along Nova Scotia's Eastern and Southern Shores) are the two Halifax Group bedrock units present within the Figure 30 map area, but with only the Cunard Formation being shown to be present within the Uniacke SPS study area.

The Cunard Formation is characterized by finely bedded black slate with thinly bedded metasiltsone/metasandstone layers, and medium-bedded, fine-grained, cross-laminated metasandstone. Sulphide minerals (pyrite and pyrrhotite, some with arsenic inclusions) are common and prone to generating acid rock drainage. It is characterized by its medium to dark brown weathering, frequently with iron staining, and by its black colour when freshly broken, frequently with well formed cubic pyrite crystals ranging from table salt size to 1 cm.

The Glen Brook Formation consists of mainly thinly bedded (centimetre-scale), green to grey, colour-banded, laminated and cross-laminated metasiltstone and slate (Horne and Pelley, 2007). Thin bedding and colour variation results in high variability at the outcrop scale, but this variability characterizes the unit, and the unit is uniform at the regional scale. Locally there are dark grey intervals that contain abundant marble-sized concretions. A few isolated thick metasandstone beds occur. This unit generally lacks sulphide and the aeromagnetic response is low. The contact with the underlying Cunard Formation where exposed to the east is abrupt but gradational (Horne, 1993).

6.4 The South Mountain Batholith (SMB) granodiorite

Approximately 8% of the Uniacke SPS study area is underlain by the eastern-most part of the SMB, which extends from the west-central to southern-lower part of the study area to Digby. The sections below briefly describe what plutons and batholiths are, how the SMB evolved, and details the general petrographic (mineralogical composition), chemical, and radiometric characteristics of the SMP igneous rocks within the Uniacke SPS study area.

6.4.1 A quick primer on the geology of plutonic rocks

The SMB is a complex of plutonic igneous[43] rocks that have solidified from a melts or partial melts (some plutons originate as not quite liquid, plastic masses) at great depth. Plutonic rocks force their way upward through older surrounding rock as a function of materials present in the plutons being less dense than the country rock they rise through15. As such, they float up, over long periods of geologic time, through country rock, usually as diapirs – much like the lighter density fluid in lava lamps rises through the more dense fluid.

Because they cool deep underground, plutonic rocks do so slowly, over tens of thousands of years or longer, which allows individual crystals within them to grow large by chemical fractionation to form separate minerals as temperatures change, and by coalescing. Thus, plutonic rocks are generally coarse-grained rocks, with the material at the centre of plutons, which cool more slowly, having larger crystals, and material at the edges of plutons cooling more quickly having smaller crystals (by contrast, in volcanic rocks, which cool at surface, crystals are evident usually only under a microscope).

The folded metasedimentary material that formed the Meguma Terrane mountain chain that existed during Pangea time hosted these plutonic rocks at their roots to form the SMB, the whole of which was later denuded and exposed by erosion[44]. A large body of this type of rock is called a pluton. The term *"batholith"* is used to define a collection of such plutons that may cover areas from several tens to hundreds of kilometres.

There are many major types of plutonic rocks, the classifications and names of which depends on the mix of minerals present in the rock[45]. To begin, there are four primary classes of igneous

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[43] Igneous rock is one of the three main rock types – the others being sedimentary and metamorphic. Igneous rocks form through the cooling and solidification of molten earth material (magma or lava), that originates at or from just above the earth's mantle. Igneous rocks often form at the roots of mountains, and are significant in that they make up 90-95% of the top (16 km) of the earth's crust by volume.

[44] The material that was eroded from the Pangea Meguma mountain range today makes up the greater than 10 km thickness of sediments in the Maritimes Sedimentary Basin and Nova Scotia's offshore continental shelf.

[45] It is important to know the difference and to distinguish a mineral from a rock. A mineral is a material having a specific chemical composition and crystalline structure at room temperature. For example, while graphite and diamond are both composed of pure carbon, they are minerals because their crystalline structures are very different, which is why one is very soft and the other very hard. Rocks, on the other hand, are ...cont'd on page 64

rocks based on mineral composition: ultramafic, mafic intermediate, and felsic. Ultramafic and mafic[46] rocks contain more magnesium and ferric rich minerals, with lower silica content (generally 45-55%). Felsic[47] and intermediate rocks are composed of more aluminum-silicate minerals and have a higher silica mineral content (70-85%) that are also rich in other elements like oxygen, potassium and sodium, and usually more quartz is also present. Except for minor intrusive sills and dykes, the SMB and other related plutons and batholiths in Nova Scotia are chiefly composed of felsic rocks.

A number of rock classification schemes are available from which to further classify and name igneous rocks. Most make use of ternary diagrams, which is what MacDonald (2001), Ham (1997) and Kontak et al (1999) and many others have used to classify the rocks of the SMB. Figure 33 is one such diagram, which the International Union of Geological Sciences (IUGS) proposes[48] and is now the generally accepted scheme (also used by MacDonald (2001), White et al (2014), and others for classifying plutonic rocks by their modal composition.

The classification diagram in Figure 33 is for felsic plutonic rocks with less than 90 vol-% mafic minerals[49], which includes some mafics at the extreme range, and which is based on the relative percent distribution by volume of quartz (Q) and alkali-feldspars (A), plagioclase feldspars (P) and feldspathoids[50], or foids for short (F). The QAPF diagram in Figure 33 incorporates two ternary diagrams[51] that encompass all of the rocks of the SMB plutons, and less major sills, dykes, and pegmatites[52].

...cont'd from page 63 made of of an assemblage of minerals, be they grains of one mineral, or grains or crystals of many different minerals. Different rocks types are classified by origin, and then by the assemblage of minerals they are made of.

[46] Mafic rocks are generally found in dark shades of green or greenish-black in colour. They are low density due to the low content of silica present in them, and form mostly as part of the sea bed. Due to their low viscosity, when extruding to surface, the lava erupted is usually very runny. Basalt is a well-known example of a mafic rock, such as erupts in Hawaii or is present on the Upper Triassic age (220-205 Ma.) North Mountain of Nova Scotia.

[47] Felsic rocks are generally found in lighter shades of grey, pink, orange. The felsic lava is usually denser and due in part to its chemical composition, is generally found at 650-750˚ C when it extrudes to surface, thus causing explosive volcanic eruptions (Mount St. Helens on the west coast is one example).

[48] The IUGS recommends the QAPFM classification whenever a rock's mineral composition (as opposed to the chemical composition) can be determined.

[49] Rocks that contain over 90 vol-% mafic minerals are called ultramafic and classified in an independent scheme.

[50] Feldspathoids are a group of tectosilicate minerals that resemble feldspars, but have a different structure and much lower silica content.

[51] It is made of two ternary diagrams with the corners Q, A, P and F, A, P, adjoined to each other along their A-P edge. The corners represent cases in which only one felsic component is present, effectively 100% of either quartz, alkali-feldspar, plagioclase or foid. Because foids and quartz are mutually exclusive in an igneous rock, the QAPF classification is always based on a maximum of 3 components, either QAP or APF, and the compositions of the rocks are plotted in either the upper or lower triangle.

[52] Pegmatites are extreme igneous rocks that form during the final stage of a magma's crystallization They are extreme because the contain exceptionally large crystals and sometimes contain minerals that are rarely found in a pluton's related other major types of rocks.

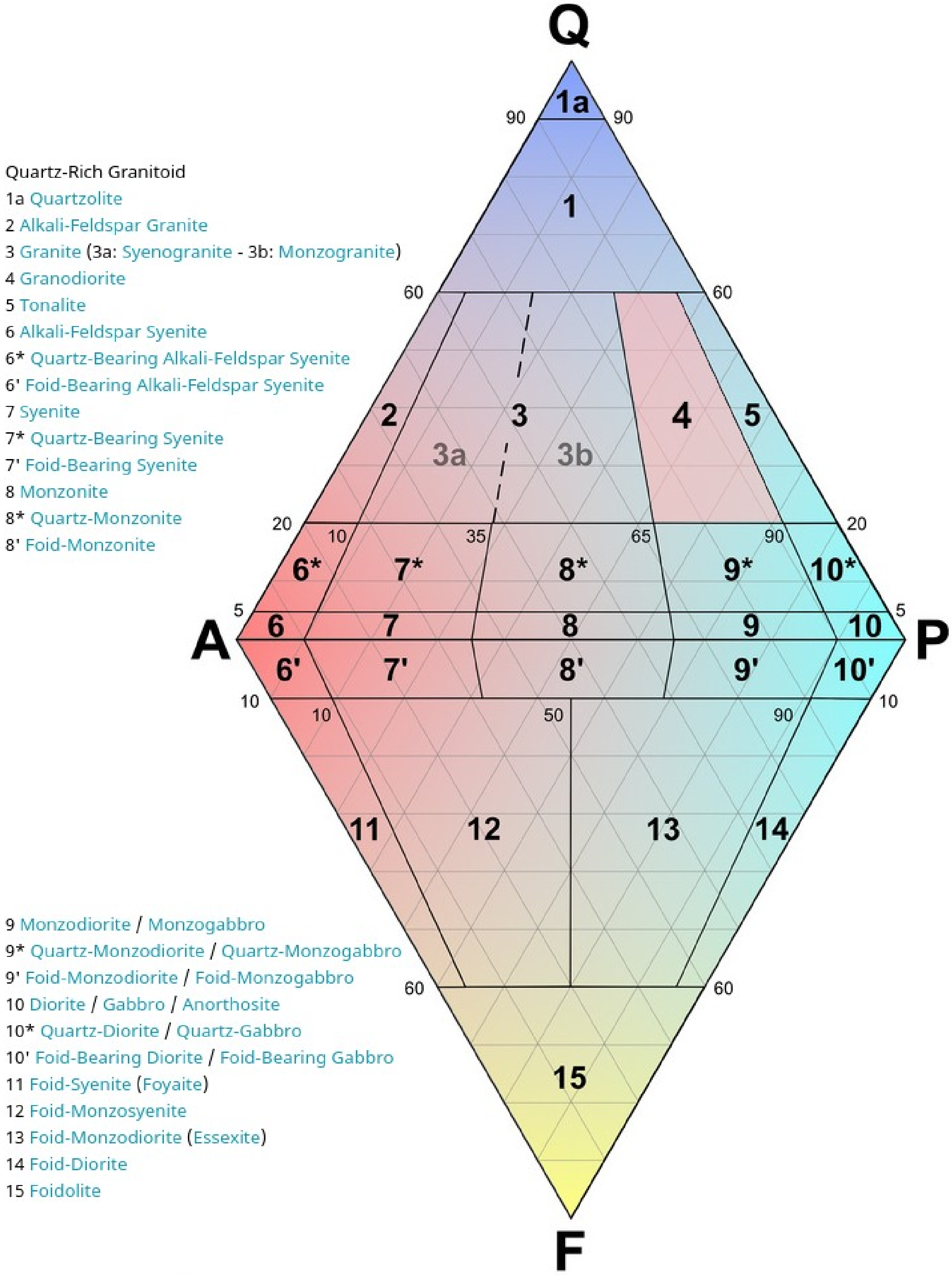

Figure 33: QAPF classification diagram describing rocks of the SMB shown in Figure 30. Granodiorite (4) is shaded pink.

The plutonic rocks that underlie the Uniacke SPS study area fall compositionally within zone 4 in Figure 33.

6.4.2 General description and genesis of the SMP

The SMB is one of the largest granitoid complexes in the Appalachian orogen, representing over 7,000 km2 of the bedrock geology in southern Nova Scotia. It is made up of two penecontemporaneous suites of plutons (MacDonald et al, 1994; MacDonald, 2001); an earlier granodioritic to monzogranitic suite (stage 1 plutons), which are present in the Figure 30 mapping area and underlying the Uniacke SPS study area, and a slightly later monzogranitic to leucogranitic suite (stage 2 plutons) that were emplaced at around 380–370 Ma. during the Acadian Orogeny (Reynolds et al., 1981; Keppie and Dallmeyer, 1987; Clarke et al, 1993).

Gravity models reveal the SMB plutons have flat or gently dipping floors at approximately 7.0 km depth and aspect ratios greater than 6:1. They are underlain by deeper (over 10 km) elongate northeast–southwest-trending roots that may indicate magma feeder zones (Benn et al, 1999). Benn et al (1999) report that from maps and Schmidt projections of the magnetic fabric data, in the Stage 1 plutons foliation[53] poles define a northwest–southeast girdle with two point maxima showing predominantly steeply and shallowly dipping orientations, and the magnetic lineations have a strong northeast–southwest preferred orientation that is parallel to the regional fold axes in the country rocks and perpendicular to regional Acadian shortening. There is evidence of this in the Figure 30 mapping area.

The magnetic lineations are also perpendicular to late aplitic[54] and pegmatitic[55] dykes in the batholith, and are therefore parallel to the late increments of stretching of the solidifying plutons. Benn et al (1999) interpret the magnetic fabric pattern in the Stage 1 SMB plutons to be a signature of the Acadian tectonic strain that affected them during late stages of crystallization.

In the stage 2 plutons, Benn et al (1999) indicate that there is a predominantly horizontal magnetic foliation, which is consistent with the shallowly dipping foliation and layering they observed in outcrop. They suggest that the Stage 2 plutons are characterized by mostly horizontal magmatic structures, which supports the interpretation of a sheet structure in the batholith.

The widespread preservation of the horizontal fabrics in the Stage 2 plutons suggests they underwent less tectonic strain while crystallizing than did the Stage 1 plutons. Also, the very narrow deformation aureole within the country rocks around SMP Stage 2 plutons suggests lateral spreading of country rock by the plutons was not the main space creation mechanism during emplacement; rather, space was mostly created by vertical displacements (stoping and assimilation) of country rocks. The presence of highly altered Cunard Formation rocks along Highway 102 at Bayer’s Lake Industrial Park is an example of that.

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[53] Foliation is the parallel arrangement of certain mineral grains that gives the rock a striped appearance. Foliation forms when pressure squeezes the flat or elongate minerals within a rock so they become aligned.

[54] Having a fine- to medium-grained sugary texture.

[55] A texture in which mineral grains are exceptionally large.

6.4.3 Local pluton bedrock petrology and radiometric characteristics

MacDonald et al (1994) describe the SMB that underlies the Uniacke SPS study area as a light to medium grey, predominantly medium- to coarse-grained with minor fine-grained granodiorite with an equigranular or slightly magacrystic[56] texture, that contains 15-25% biotite, traces of muscovite and cordierite, and in which metasedimentary country rock zenoliths[57] are abundant. Horne et al (2009b, 2009c) give a similar description, but describe the SMB present beneath the study area as a medium- to dark-grey rock granodiorite in which the quartz has a bluish colour.

While the SMB has been studied in detail at many locations (Benn et al, 1999; MacDonald, 2001, and many others), there does not appear to be much economic interest in the SMB in the immediate Mount Uniacke area. Consequently, literature searches have yield little petrographic information pertinent to local groundwater resources potential and quality, except for Poulston et al (1991), who identified elevated values for sulphur within the granodiorite, which contribution they attributed to partial melting of the country metasediments (likely from the Halifax Group) and their assimilation-fractional crystallization. They found 30 to 60% of the sulphur in the granodiorites to be present as pyrrhotite, with the remainder as sulphur substituted into biotite.

Wells in the SMB are known to produce water with elevated uranium values in places. Figures 34 and 35 show the regional and local equivalent uranium (eU) distribution (NSDNR, 2006) from airborne radiometric surveys[58] flown from 1976 to 1990 by the Geologic Survey of Canada at 250 x 250 m resolution. Because of the linear compression of the original data from 16 to 8 bit, the values for eU from NSDNR (2006b) are only relative across all of Nova Scotia and range 0 to 255 for the entire province. In Figure 34 (presented here as a reference for readers to the area of Figure 35 for the Uniacke SPS study area), eU values range from a low of 25 (coinciding largely with rocks of the Goldenville Group) to a range of 150 to 250 from the SMB (highest values coinciding with monzogranite and leucomonzogranite), the Kinsac Pluton north of Fall River, and the Musquodoboit Batholith southeast of the Kinsac Pluton, and with values of around 180 associated in many places with strata of the Halifax Group (largely the Cunard Formation).

Values within the 150 range are considered quite high and are often associated with uranium in well water – radiometric maps such as in Figures 34 and 35 are the basis from which Nova Scotia as developed its risk maps for uranium in groundwater (O’Reilly et al, 2009) and radon

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[56] Where some grains or crystals are considerably larger than the encircling matrix.

[57] A xenolith is a rock fragment, usually of earlier melts or country rock, that are entrained during magma ascent. These can vary in size from a few cm to about ¼ metre.

[58] Using a sodium iodide detector, which provides a measurement of the three most abundant naturally occurring radioactive elements, potassium, uranium and thorium. Uranium is measured indirectly from

gamma ray photons emitted by daughter products in their decay chains, and is monitored by means of gamma ray photons at approximately 1.46 MeV from 214Bi. Corrections have been applied to account for dead time, ambient temperature changes, background radiation, spectral scattering and deviations of terrain clearance from the planned survey altitude.

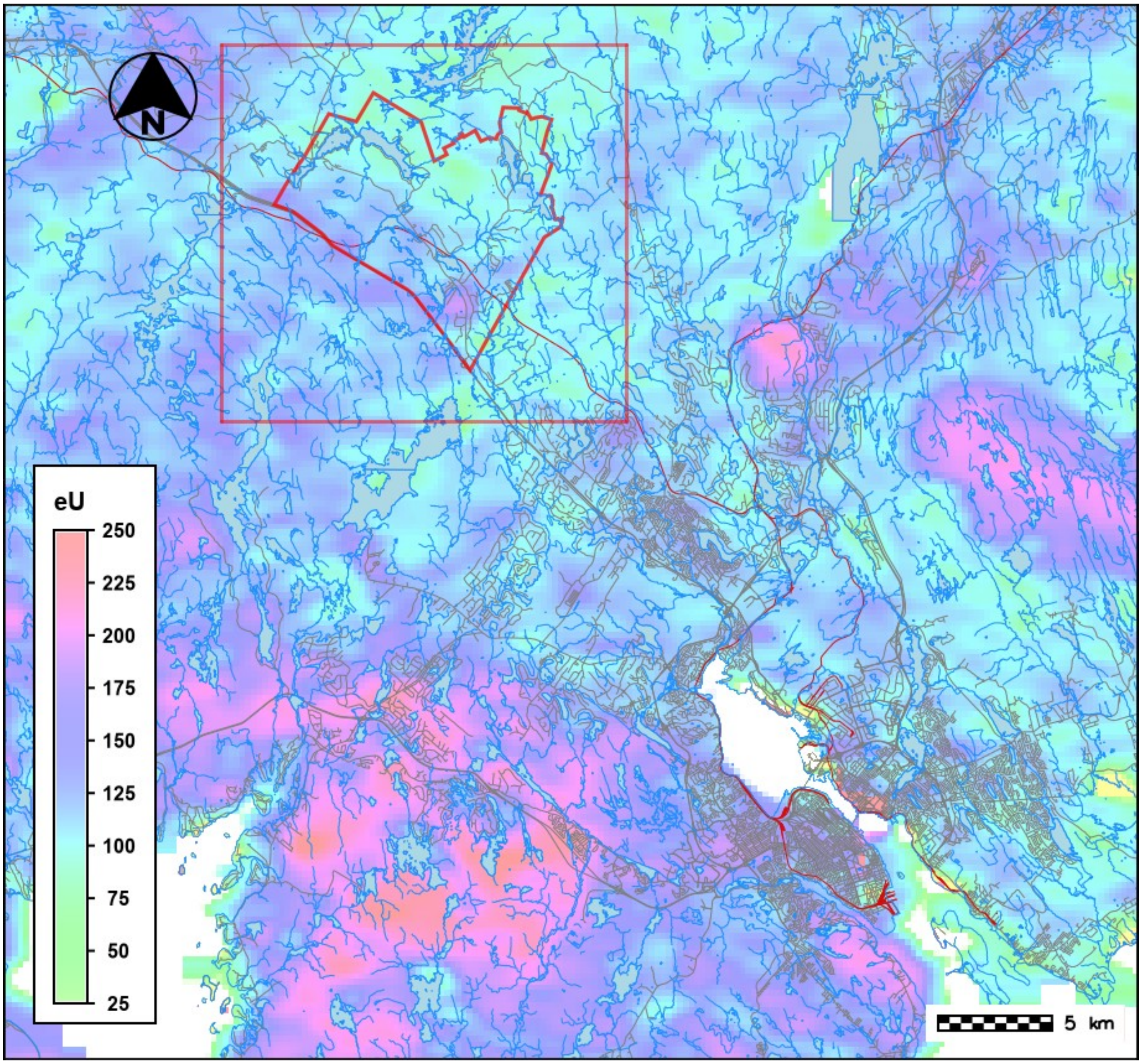

Figure 34: Relative eU distribution within the Halifax to Mount Uniacke area, presented for reference when viewing Figure 35 (red square).

(O'Reilly et al, 2013), and although no risk maps have been produced, in extreme cases also possibly radon's progeny lead-210 (^{210}Pb), which was found to be causing well water supply quality issues at Laurie Park (ewC, 2021b) located downgradient of their well's recharge area within Cunard Formation.

In Figure 35, values range from a low of 25 within the Goldenville Group, to 150 within the SMB granodiorite, but with the highest values present within the western-most part of the Cunard Formation within the Uniacke SPS study area – along and west of Etter Rd. between South Uniacke Rd. and East Uniacke Rd.

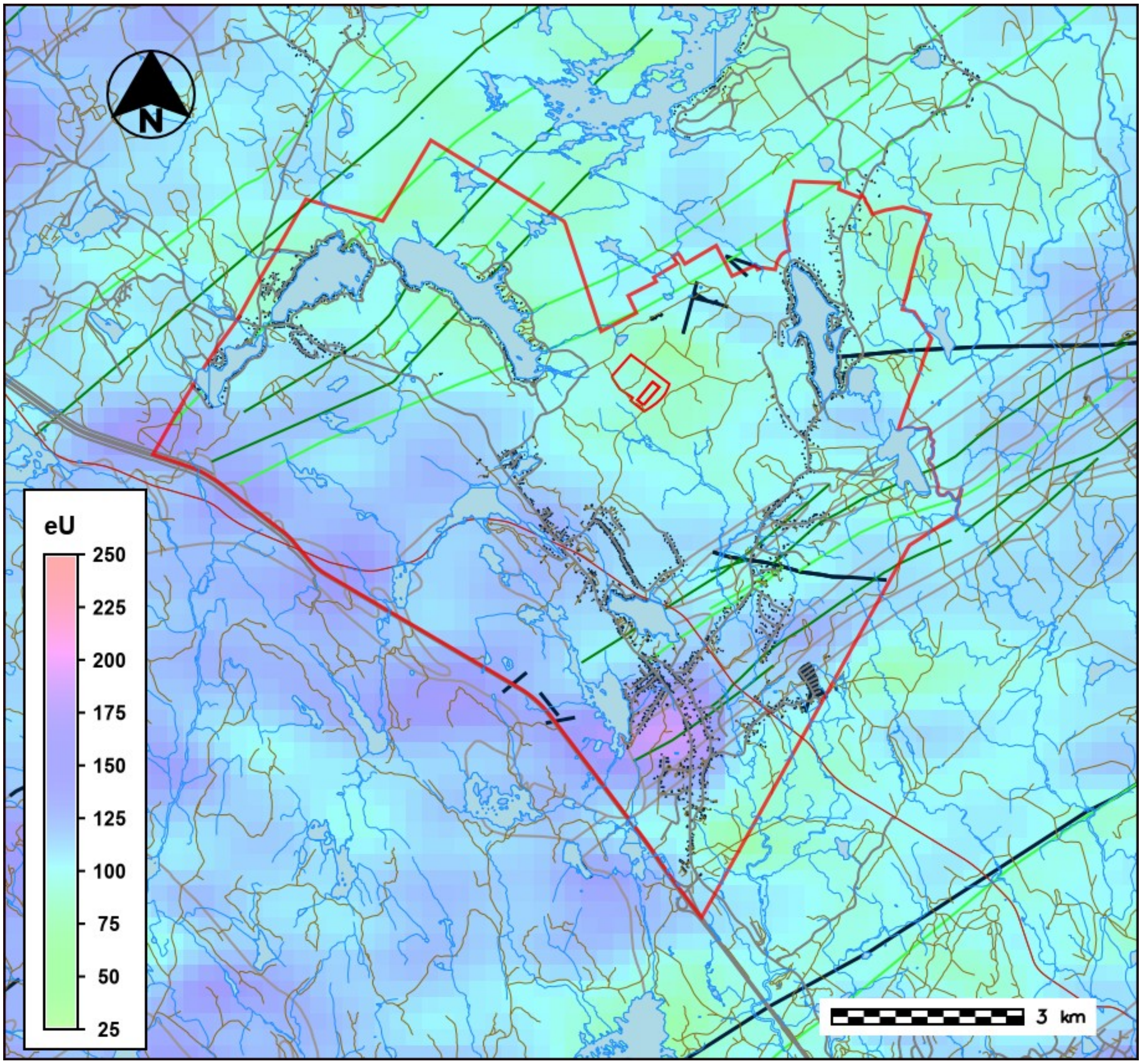

Figure 35: Relative eU distribution within the Figure 30 mapping area. Bedrock unit boundaries from Figure 30 are shown as grey lines, anticline and syncline axis as dark and light green lines, published mapped bedrock faults as thicker black lines. The Uniacke SPS study area boundaries are in red, as are the Mount Uniacke existing and proposed quarry. The legend is per Figure 34 (i.e. only the lower range of it applies to this figure).

6.5 Area structural geology

As was noted in Section 3 and in later parts of this report, the tectonic activity and collision of Gondwana with Laurasia during the Acadian Orogeny caused the Meguma Terrane sediments to become compressed, tightly folded, metamorphosed, and fractured. The orientation of the meta-sedimentary strata bedding fold anticline/syncline axis, and the resulting complexity of the related faults that are critical to the Uniacke SPS study area wells being able to produce any water[59], are entirely a result of those tectonic collisions.

Mapping by Faribault (1901, 1902) focused mostly of bedrock stratigraphy, and Horne et al (2009a, 2009b, 2009c, 2000d) mapped only a few faults within the Figure 30 map area (see details later), but they do show lineaments as observed from air photos and from DEM, which may be fault-related. Also, Horne et al (2009a, 2009b, 2009c, 2000d) have provided 953 strike and dip[60] values for various structural features within the Figure 30 mapping area, taken mostly along roads and stream and lake shores. These include values for bedding, some for overturned bedding, cataclastic zones[61], dykes, bedrock cleavage[62], joints[63], mineral lineations or boudinage[64] axis and stretching lineations, quartz veins, shear zones, slickensides[65], and fold axial plane orientations, as well as a number of glacial striae[66] orientations. The data that is relevant to this

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[59] The tectonic squeezing and metamorphism of strata has essentially removed all primary (sedimentary grain interstitial) permeability – thus wells in the Meguma depend entirely on secondary (fracture flow) permeability.

[60] Strike and dip refer to the orientation of a geologic feature, such as bedding, or fault planes. The strike line represents the azimuth of the intersection of that feature with a horizontal line (in simple terms, the wet mark that the water surface in a lake would leave on a sloping bedding surface). Dip gives the steepest angle of decent of the tilted feature being measured. All strike/dip values used here are defined using the right-hand (North American) rule (in which the dip direction is 90º clockwise of the strike direction).

[61] A type of fault rock that has been wholly or partly formed by the progressive fracturing and comminution of existing rocks, a process known as cataclasis. Cataclasis involves the granulation, crushing, or milling of the original rock, then rigid-body rotation and translation of mineral grains or aggregates before re-lithification (cementing back together, by mineralization from fluids or by compression) of the broken rock material.

[62] Cleavage in structural geology (not to be confused with mineral crystal cleavage) describes a planar rock phenomena that occurs as a result of the stresses applied during tectonic deformation and metamorphism – which result in a realignment or the rock fabric (crystal or sedimentary grain orientation) – the type and degree of which is controlled by rock type, stress levels and orientations (can be from multiple, sequential directions). Therefore, cleavage typically shows a measurable geometric relationship with the axial plane of folds that develop during deformation, and is referred to as axial planar foliations. Foliations are symmetrically arranged usually with respect to the bedding fold axial plane, again depending on the overall composition, bedding distribution of lithology, and resulting competency of a rock.

[63] A joint is a break (fracture) of natural origin in a layer or body of rock that lacks visible or measurable movement parallel to the surface (plane) of the fracture. Although joints can occur singly, they more often appear as joint sets and systems. A joint set is a family of parallel, evenly spaced joints that can be identified through mapping and analysis of their orientations, spacing, and physical properties. A joint system consists of two or more intersecting joint sets. Joints typically form in response to geologic stresses, usually related to tectonic deformations or orogenic events (i.e. the collision of Gondwana with Laurasia). Joints may also form as a result of stresses created within a melt as its volume decreases during cooling, or around the pluton as it displaces country rock.

[64] A geological term for structures formed by extension, where a rigid tabular body such as hornfels, is stretched and deformed amidst less competent surroundings. The competent bed begins to break up, forming sausage-shaped boudins.

[65] A slickenside is a smoothly polished surface, usually containing striations, that are caused by the frictional movement of between rocks along a fault, with the striation orientation defining direction of motion.

[66] Glacial striae are scour marks left in outcrop surfaces by rocks embedded in glacial ice moving over those outcrops. Similar to the scratches left by sandpaper, but at a much larger scale.

discussion on structural geology includes:

- Bedding: 378 bedding orientation measurements, of which 356 are for bedding which tops are known[67] (19 of them for overturned bedding), and only 22 strike/dip measurements for which bedding tops unknown.
- Cleavage: 215 measurements, plus 39 other stretching lineation measurements, all with about the same outcrop location distribution as for the above.
- Joints: 198 measurements, again with about the same outcrop distribution as above.
- Veins and dykes: 10 dyke measurements, all in the SMB (southwest corner) of the Figure 30 area, and 47 vein orientation measurements, presumably of quartz veins within parted bedding planes and/or bedrock joints, with roughly even distribution within the central portion of the Figure 30 area (14 of them within the Uniacke SPS study area).
- Fault and shear zone related features: these include orientation measurements of 11 cataclastic zones, 11 shear zones, and 14 observed slickensides.

The above structural data was extracted from the digital version of the geology map's GIS attributes table and analyzed using the OpenStereo application (Grohmann and Campanha, 2010; Endlein, 2017) to create the Schmidt (equal area) stereonet[68] plots and rose diagrams in Figure 36, for analysis and illustration of the general geological structural trends at and around the site.

Determination of the contour intervals in the Figure 36 stereonets was done using the Robin and Jowett (1986) method, which is based on relative pole distribution. Great circles are not shown because their shear numbers for all but the veins data would obscure the plots.

The following four sections describe each of the bedrock structural features – bedrock bedding

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[67] It is important to recognize the depositional tops of bedding when making structural measurements, as folds with overturned bedding may indicate more severe structural bedrock deformation. Bedding tops are normally identified from depositional structural features, such as preserved sedimentary wave ripple patterns, soft sediment deformation (by gravity slumping, bioturbation caused by burrowing bottom dwelling animals, etc.).

[68] A stereonet is a graphical tool that allows the projection of three-dimensional information onto a two-dimensional plane. Stereonets involve the projection of lines and planes inside a transparent sphere, with an extended plane (or line) passing through its centre at 90 degrees to the plane. A plane will cut the sphere forming a line (great circle) on the sphere's surface, whereas a line will generate a point (or pole).

Two alternative projections are commonly used, the upper and lower hemisphere respectively, which use depends on the discipline of interpretation. When the sphere is viewed from above, these are referred to as stereographic projections, or stereonets; as the lines and planes extend beyond the sphere, intersections in the upper and lower hemispheres are visible. These can be plotted on the 2D circular form that represents the sphere and the planes and lines within it.

The points in Figure 36 (and their contoured Fisher Distribution) are lower hemisphere (stereonet) projections of the lines that were drawn perpendicular to the structural planes as defined by the strike and dip field measurements from Horne et al (2009a, 2009b, 2009c, 2009d).

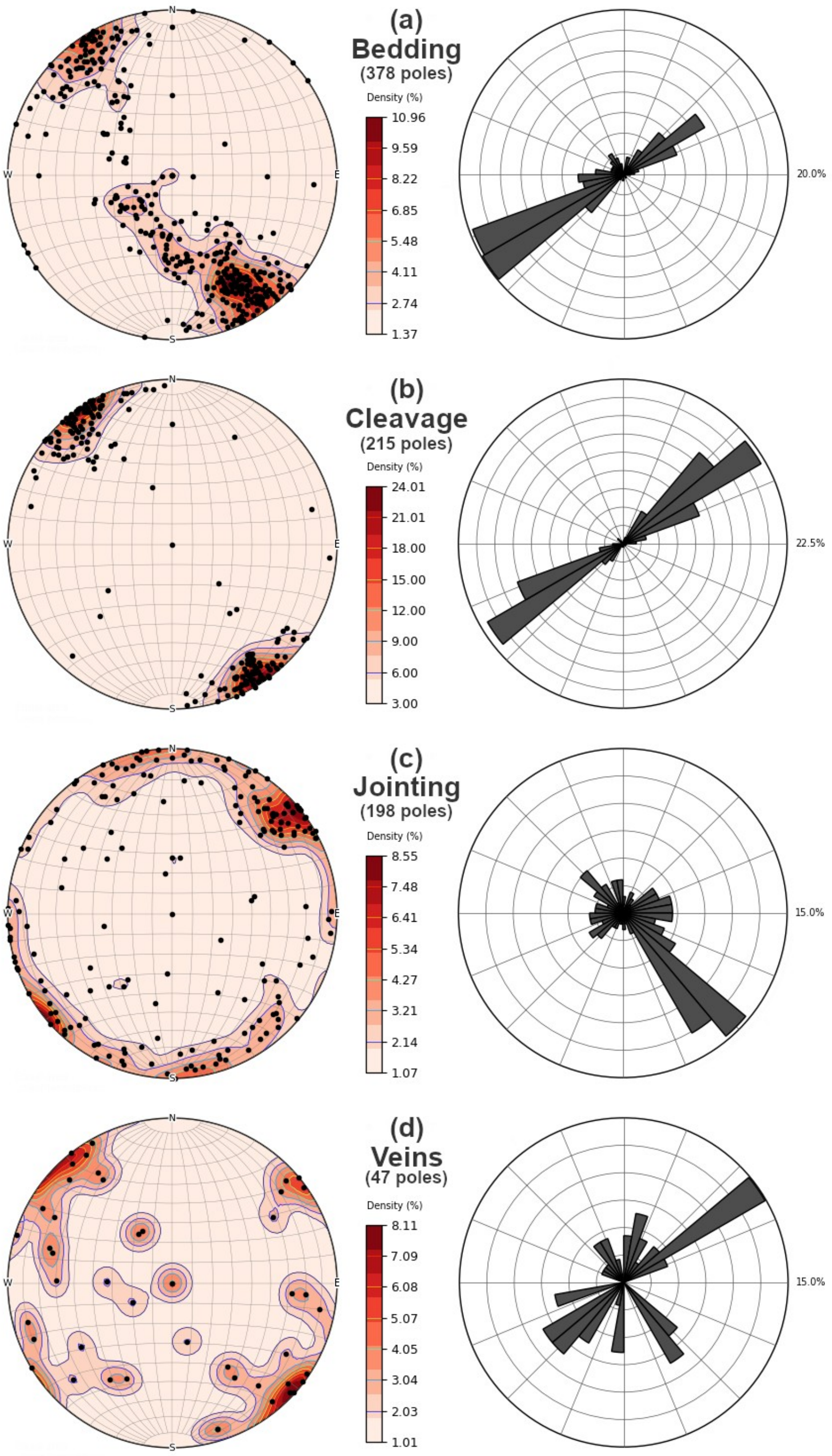

Figure 36: Schmidt stereonet projections of strike/dip planar data and rose diagrams of strike data for structural features in Figure 30 area.

and cleavage, bedrock joints, veins, and bedrock faults – that are relevant to local and possibly regional aquifer performance and thus, possible well potentials within the Uniacke SPS study area, based on published data. Section 6.5.4 on bedrock faults also takes things beyond the published work and looks at lineaments, based on LiDAR DEM-based shaded relief, that may be indicative of faults within the immediate study region.

6.5.1 Bedrock bedding and cleavage

The bedding orientations represented by Figure 36 (a) show a marked northeast (overall arithmetic mean azimuth of 68.8º) strike. Horne et al (2009a, 2009b, 2009c, 2009d) measured a few horizontal dips within the Figure 30 mapping area, but the bulk (0.15 to 0.85 percentile) of the dips range from 34º to 84º through vertical, with greater numbers of northwesterly dips (mean 59º) measured than southeasterly dips (mean 69º), and numerous overturned beds.

Horne et al (2009a, 2009b, 2009c, 2009d) have identified major and minor fold axial plane orientations at 10 locations within the Figure 30 map area. One is horizontal, and dips for the others range from 7º to 82º. The anticline and syncline fold axis at Cockscomb Lake are shown to plunge 20º to 30º north and the Mount Uniacke anticline is shown to plunge 12º north.

The gold at many of Nova Scotia's gold districts is hosted in domed[69] anticlinal folds, which tend to create more dilation between bedding planes into which hydrothermal fluids may flow and precipitate dissolved matter. Such doming certainly exists at the nearby South Uniacke Gold Distict (Gagné, 1988; Gagné and Wait, 1988). While Horne et al give no details about doming at the Mount Uniacke Gold District, Faribault (1901) confirms the presence of doming there too.

Within thick/massively bedded Goldenville Group bedrock units, cleavage can be and is often confused with bedding, particularly where outcrop exposures are poor and few. Figure 36 (b) shows a similarly marked northeasterly 57º strike orientation that parallels bedding strike orientations, but with generally 80º to vertical dips with roughly equal distributions north and south for primary bedrock cleavage.

6.5.2 Bedrock joints

A total of 198 joint orientation measurements are available within the Figure 30 mapping area. The number of measurements is somewhat sparse in the northern parts of the study area, with their distribution being focused mostly along roads (predominantly along Brushy Hill Rd. just outside the study area), along Highway 101, at a few lake shores, and in clusters at outcrop cuts along the railway.

Among these measurements, Figure 36 (c) shows one distinct major joint set within the Figure

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[69] Doming results when folds oriented in one direction are subjected to secondary stresses and are again folded along their axis such that bedding takes on a dome-shape.

30 mapping area, which strike range from 130º to 150º (northwest) with mostly westerly dips that range from 60º to vertical with the bulk around 80º, but also with near-vertical easterly dips.

Two secondary joint sets are also apparent from Figure 36 (c) – one that strikes east-west with roughly equal numbers of northerly and southerly dips that range from 80º to near vertical, and another joint set that strikes approximately 65º (northeast) which dips range from about 70º to vertical that are distributed about equally to the north and south. This latter joint set is more apparent in areas of the Meguma farther to the south (ewC, 2021a).

6.5.3 Veins

There are only 47 vein (likely quartz) strike/dip measurements available within the Figure 30 mapping area. All but four of those measurements are north and east of Highway 101, which inside the study area are clustered west of and around the southern part of Cockscomb Lake, in the Mount Uniacke Gold District, and at the eastern part of the study area along the Uniacke anticline/syncline, as well as outside of the study area to the south along the railway, and in the northwest within the Lakelands and the Hillsvale areas, as well as in the Ardoise area.

Figure 36 (d) shows that the bulk of the veins within the Figure 30 mapping area are bedding-parallel with roughly equal but slightly greater northerly dips that range from about 65º to near vertical. These include a number of much more horizontal (likely anticline-top dilation area) veins. A second vein set strikes northwest, parallel to the major joint set, with dip directions and frequency that roughly match this joint set. They are likely joint-fill veins, suggesting some dilation along the study area's primary joint set.

There are no measured veins parallel to the east-west joint set, which suggests that join set may be related to compression (i.e. not sufficient aperture size opening within that joint set to have allowed hydrothermal fluid flow). The last vein set is roughly parallel to the 65º (northeast) joint set, which deps cannot be easily deciphered from the Figure 36 (d) stereonet, but which raw data suggest includes a combination of more horizontal southerly dips and steeper northerly dips.

6.5.4 Bedrock faults

The relevance to this assignment of knowing where bedrock faults (and related joints) may be located and understanding their distribution and frequency, is that faults and joints form the pathways through which groundwater may flow within metamorphosed bedrock that otherwise has little to no primary permeability.

Horne et al (2009a, 2009b, 2009c, 2009d) provide relatively little fault or bedrock fracture information on the area. They show only three bedrock faults within the Figure 30 mapping area (an unnamed east-west fault at Cockscomb Lake, an unnamed east-west to west-northwest fault located about mid-way between South Uniacke and East Uniacke, and the western extension of the east-northeast striking Shubenacadie Grand Lake thrust fault south just outside of the study area), but several northeast and northwest striking lineaments (blue dashed lines in Figure 30) as defined from shaded relief (small scale images).

They report two cataclast zones along the Shubenacadie Grand Lake Anticline and thrust fault, four cataclast zones along the Mount Uniacke Anticline and Syncline trend northeast off-site and southwest on-site to the bottom (south end) of Cockscomb Lake, as well as five cataclast zones between Lily and Pigott Lakes and at Cameron Lake northwest of the study area in vicinity of the Rawdon Mine Anticline and Syncline complex, which appears to be an extension of the fault mapped by ewC (2023a) just north of the study area and farther to the northeast. Horne et al (2009a, 2009b, 2009c, 2009d) also report ten shears measured at bedrock outcrops, five of which area located within the granodiorite in the southwest part of Figure 30, but with five located within Meguma metasediments:

- one at UTM 432797E/4971493N (strike/dip 345º/75ºN) at/near the contact of the Goldenville Group and granodiorite at the west end of Uniacke Lake, which may or may not be associated with pluton emplacement,
- two just outside the study area in the Lakelands area at UTM 238741E/4975012N and 428837E/4975088 (both with strike/dip 075º/82ºS),
- one on the northeast shore mid-way up Cockscomb Lake at UTM 433586E/4975368N (strike/dip 138º/84ºW), and
- one just outside the study area near Hillsvale, UTM 429932E/4977111N (strike/dip 032º63ºE).

They also report slickensides present associated with these shears. However, except for the east-west fault located mid-way between East and South Uniacke, along which they clearly show dextral strike-slip motion (possible vertical motion unknown, if any) Horne et al (2009a, 2009b, 2009c, 2009d) give no information on the nature or sense of motion along the faults.

However, in his greater, larger-scale mapping, Faribault (1901) did identify five relatively extensive fault sets (one is a relatively wide shear zone) in the Mount Uniacke Gold District, along which he identified about 80 m of strike-slip sinistral motion and some normal vertical displacement, plus at least five more faults (mapped by Gagné and Wait (1988)over only short exposure distances along western vein extensions within that Gold District. Well yields show clear evidence of faults also farther west (ewC, 2021a). Faribault (1902) also mapped three faults within the Mount Uniacke Gold District; one striking northeast along which he shows greater than 30 m of dextral strike-slip motion, and two northwest striking faults that intersect with the northeast fault, along which both apparent dextral and sinistral motion are shown (likely associated with vertical motion of the triangular rock block that is bound by the three faults).

6.5.5 Taking local structural considerations beyond the published work

The lineaments that may be indicative of faults that Horne et al (2009a, 2009b, 2009c, 2009d) have identified and are shown in Figure 30 would have been identified using relatively small-scale (1:50,000 scale or smaller) shaded relief images, and the number sun locations above the horizon from which those shaded relief images were produced is not given, thus possibly limiting their ability to identify lineaments in detail. So for this assignment, the latest 2018, 2019 and 2020 flown LiDAR DEM data (Geonova, 2024a) was used to generate shaded relief images with the sun located 30º above the horizon and casting shadows over DEM from eight azimuth directions (45 decrees apart), and analyzed using both PCA images and raw shaded relief images while zooming in and out on-screen at scales ranging from 1:70,000 scale up to 1:10,000 scale and greater as necessary within the Figure 30 mapping area to help resolve certain local details.

Figure 37 shows the traces of the 869 lineaments identified: cluster density indicates the number of shaded relief images from which lineament traces were visible.

The lineaments identified range in length from 260 m to 7,969 m and average 1,710 m (length distribution: 25th percentile = 886 m, median = 1,309 m, 75th percentile = 2,125 m). The rose diagram in Figure 38 shows the azimuth frequency, at 5° intervals, for the 869 lineaments that were identified within the Figure 37 assessment area.

A drumlin field (more details on drumlins are given in Section 7 of this report) extends along the eastern part of the study area, northwest just outside the study area, with some drumlins within the study area – drumlins obscure bedrock topographic features, thus making it difficult to define bedrock lineaments in those areas. However, the tills appear quite thin with exposed bedrock (bedding can be discerned from shaded relief images) elsewhere, thus making it possible to define bedrock lineaments over 65% of the Figure 37 mapping area.

The level of interpretation possible from the lineament analysis was limited by the technical scope and study area boundaries of this assignment. However, due to the importance of bedrock faults on groundwater flow, an explanation of the newly defined local (and regional) structural geology setting defined from the findings made from this lineament analysis is warranted.

Figures 37 and 38 show three primary and four secondary lineament or possible fault sets: (1) a primary east-northeasterly set, (2) a primary west-northwest set, (3) a primary northwest set, and (a) a secondary westerly to west-northwest set, (b) a secondary east to east-northeast set, (c) a north-northwest set, and (d) a north-northeast set.

Figure 39 was created to help readers understand what all of this means – done using lineaments from Figure 37, augmented by: 1) the topographic trends clearly apparent from the PCA image also generated for this analysis, 2) earlier work by Horne et al (2009a, 2009b, 2009c, 2009d), Faribault (1901, 1902) and Gagné and Wait (1988), and 3) from a more regional review of the shaded relief images (sun cast in only one direction) as provided by the Geonova (2024d).

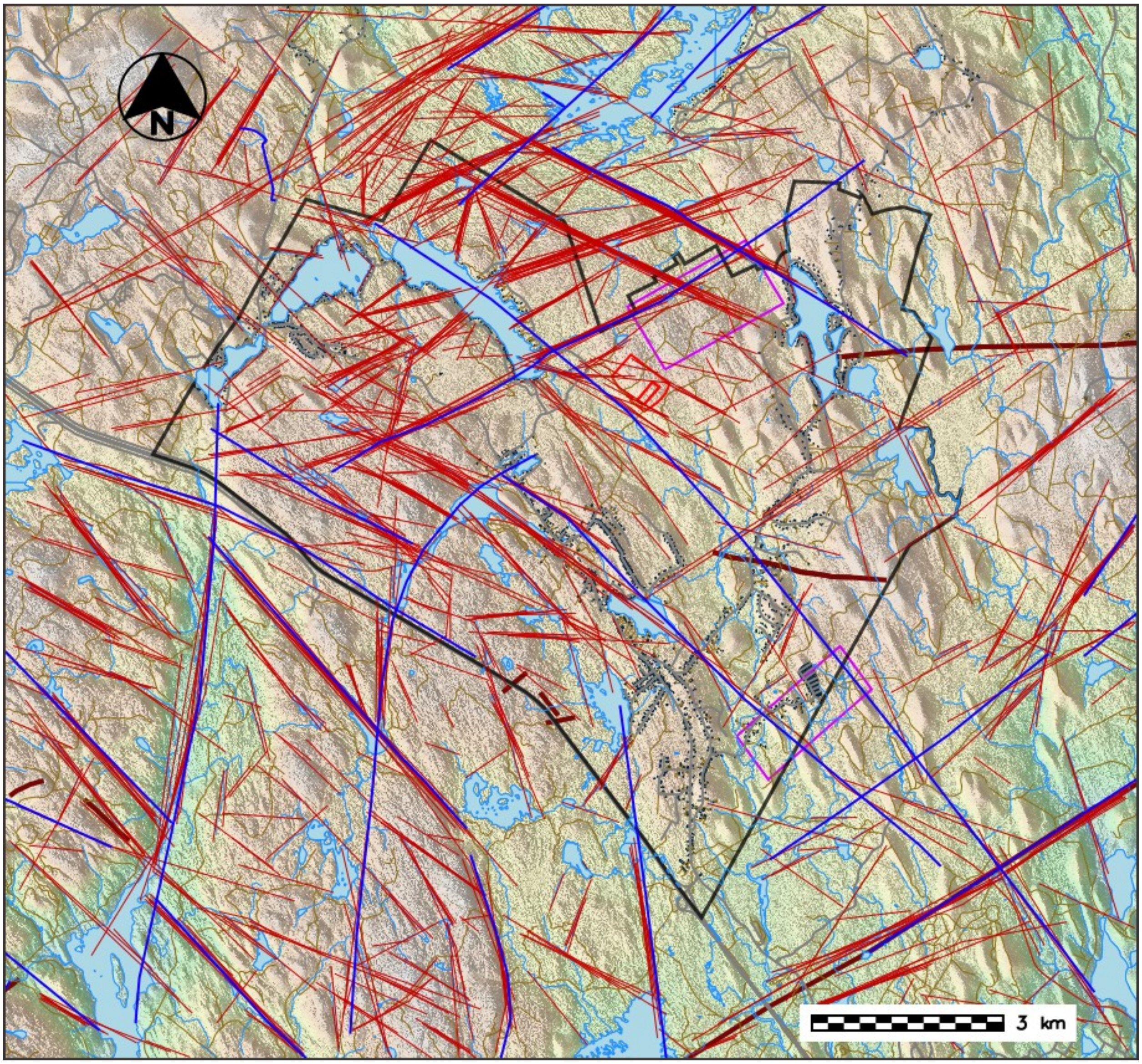

Figure 37: Lineaments (in red) as identified from shaded relief lineament analysis carried out for this assignment. Elevation legend same as for Figure 22. The shaded relief image that's overlain onto the topography (coloured) layer was generated with the sun due west and 30º above the horizon. The study area boundaries are in black, the historic mining district boundaries are magenta, and the bedrock fault and lineaments per Horne et al (2009a, 2009b, 2009c, 2009d) are in dark brown and blue, respectively.

Figure 39 shows a primary northeast fault set in the north part of the mapping area that appears as a western extension of a major regional fault system that has not been published locally, and which parallels the Shubenacadie-Grand Lake Fault in the southeastern corner Figure 39.

What Figure 39 shows specifically in the north is two locally sub-parallel fault pairs – the faults in the southern pair are spaced roughly 750 m apart, with the southern fault within that pair

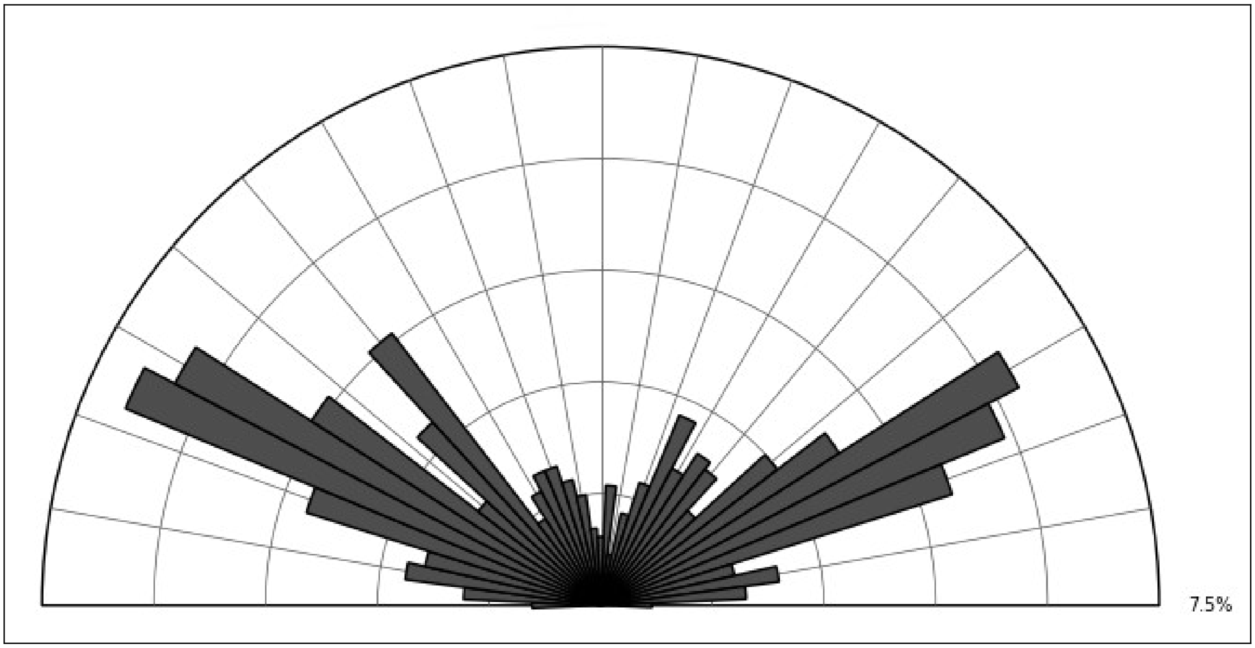

Figure 38: Rose diagram for lineaments in Figure 37.

situated immediately north of Long Lake – and the other, sub-parallel northeasterly pair that is located roughly 2.2 km (in the west) to 2.8 km (in the east) north of that southern fault-pair.

Based on bedding visible in the shaded relief images generated for this assessment and from the bedding measurements by Horne et al (2009a, 2009b, 2009c, 2009d), there is apparent drag folding, which is frequently associated with large displacements along strike-slip bedrock faults. There also appears to be some block rotation between two parallel fault pair-sets, wherein folded beds that would have originally had a northeast strikes now (based on Horne et al (2009a, 2009b, 2009c, 2009d) measurements and from shaded relief images) strike north-south to northwest.

The drag folding between the parallel fault sets suggests 600 m or more of dextral displacement between the southern fault pair, and notwithstanding block rotation, 1,200 m or more of dextral displacement also between the southern and northern fault pairs. Apparent fold shortening and buckling also suggests that there may have northwest stresses responsible for perhaps some trusting immediately to the north of Long Lake and at places farther north within Figure 39.

Matching the major fault topographic lineaments from this assignment with smaller regional shade relief images from Geonova (2024d) allowed tying the current new findings to the larger, more regional geological structural picture as provided by others in published geologic maps.

As such, from regional shaded relief (Geonova, 2024d) it was possible to extend the newly found northernmost fault-pair identified in Figure 39 from north of File Mile Lake and perhaps as far west as the north part of Panuk Lake (which is itself a regional fault (MacDonald et al, 1994; MacDonald, 2001)) within the SMB, northeast for approximately 56 km past Long Lake, past

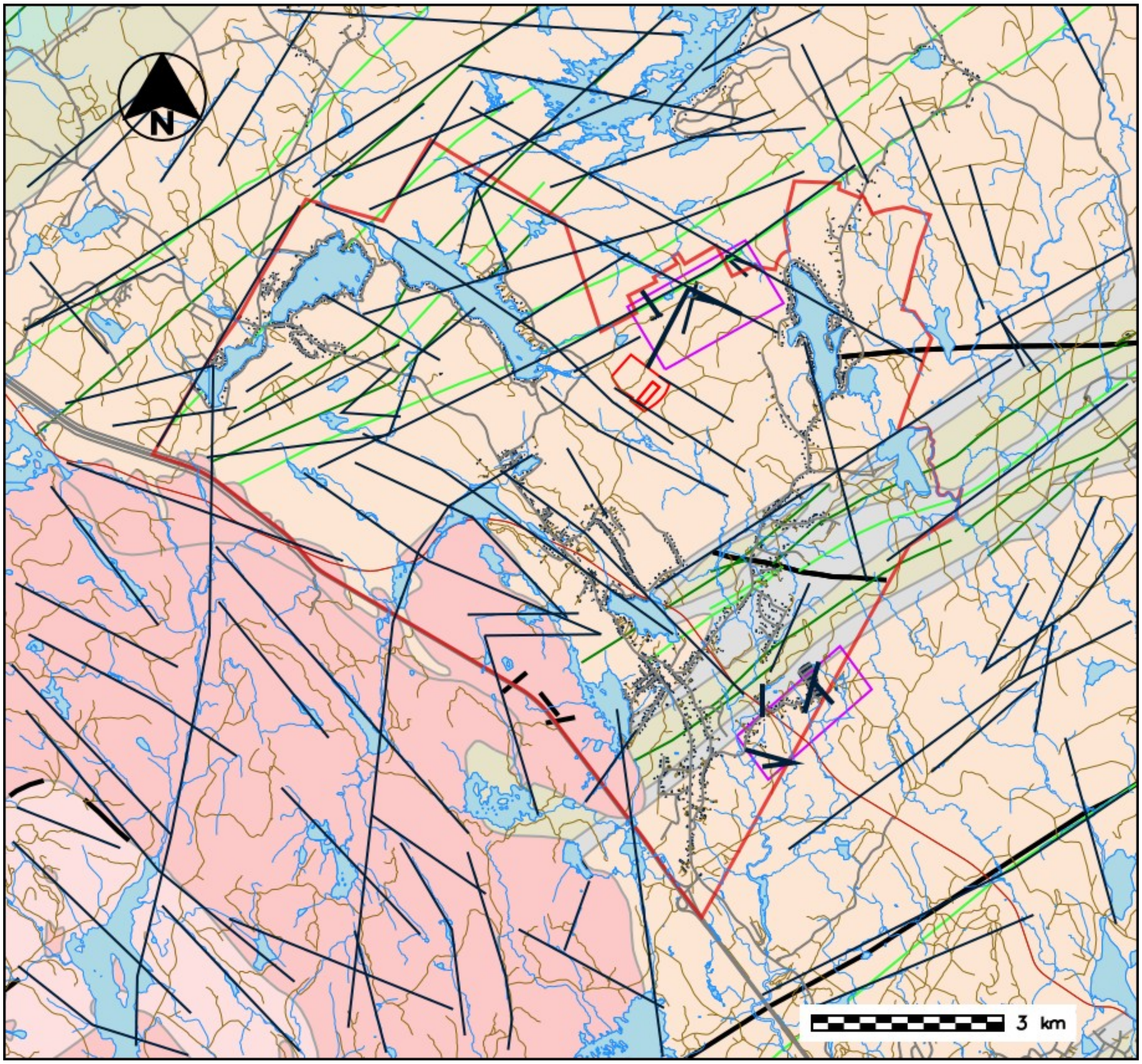

Figure 39: Site area bedrock geology with the lineament-based faults (thinner solid black lines) interpreted from this assignment's shaded relief lineament analysis and mapped faults (thicker solid black lines) as presented by Horne et al (2009a, 2009b, 2009c, 2009d), Faribault (1901, 1092) and Gagné and Wait (1988). The legend colours for the geologic units and anticlines and synclines shown are per Figure 30. Note that northern-most fold axis as shown by Horne et al may not make sense in light of the new fault interpretations presented here.

West Indian Road to a location about 6 km north of the community of Indian Brook. That would make the northern fault-pair as defined from the current analysis a western extension of the Roulston Corner Fault – a thrust fault that Horne et al (2001) had only assumed to the Hebert River and which they and Giles and Boehner (1982) show to join up with the Rawdon Fault about 80 km from Panuk Lake and just east of Highway 2 and south of Hilden.

The southern fault-pair immediately north of Long Lake can be traced in regional shaded relief (Geonova, 2024d) from Five Mile Lake in the SMB, for about 36 km northeast past Long Lake to a point located at Highway 14 about 4 km south of Upper Nine Mile River. This east extension of the southern fault-pair, which within Figure 39 clearly appears related to the Roulston Corner Fault, as noted above is not shown in any of the currently available published geological maps.

The faults represented by this primary northeast lineament set are parallel to other major northeast thrusts and shears that produce the structural fabric of the north Meguma Terrane and which have been mapped by Giles and Boehner (1982), Horne et al (2001), and Waldron et al (2010) to the north of and at the site (i.e. the Roulston Corner Fault, and the Rawdon Fault north of it), and by Giles and Boehner (1982) and Horne et al (2001) to the south of the site (i.e. the Milford Station Fault, and south of it extending from Shubenacadie Grand Lake to just north of Lewis Lake, the Grand Lake Shear (Horne et al, 2009a, 2009b, 2009c, 2009d). These are all thrust and/or strike-slip faults along which there has been dextral motion.

The northeast faults that are interpreted form this shaded relief lineament analysis that in Figure 39 are to the south of Long Lake – one that crosses through the middle of Cockscolm Lake, the other that crosses through the southern end of Cockscolm Lake – are also likely to be associated with the tectonic stresses that are responsible for the two more northerly major northeast striking fault sets discussed above.

The secondary (west-northwest) fault set interpreted from the lineament analysis are either associated with the more regional structural fabric that is present along nearly all of the eastern part of the Meguma and the Eastern Shore of Nova Scotia (the site and Figure 39 mapping area appear to be situated at what may be the junction, or the divide, of these two structural regimes), or the northwest faults may be conjugate faults (adjustment faults that occur to rheologically maintain spatial volume) to the northeast striking faults, which appears to be the case with the third northerly striking faults or fault-sets.

In summary, the Uniacke SPS study area appears to be geologically situated between two major northeast striking faults with dextral strike-slip motion, with the northern part of the study area being integrated within the northern-most northeast fault, with the west-northwest and northwest striking fault sets likely being synthetic adjustment faults to these latter two. The relative severity of faulting within the study area has the potential to produce significant, albeit extremely variable, fracture flow capability within the Uniacke SPS area.

6.6 Local economic geology

Searches were carried out of the designated land use database (Geonova, 2024b), the Nova Scotia mineral occurrence database (MacRae et al, 2024), the abandoned mine openings database (Hennick and Poole, 2024), drillhole database (O’Neill and Poole, 2023) and literature searches were done the Geological Survey of Canada “GeoScan” and the NS Natural Resources Energy and Mines Branch "NovaScan" library databases in efforts to identify any past and/or current mineral interests within the Figure 30 area. Those searches identified the following:

- Recorded mineral occurrences:
    - Gold at the South Uniacke and Mount Uniacke Gold Districts (both past gold producers), which are situated in southern part of the Uniacke SPS study area in the central part of tertiary sub-watershed 1EJ-4-G, and in the northeastern part of the Uniacke SPS study area bordering (at the upstream-most parts of) sub-watersheds 1EJ-4-G and 1DE-1-C-8, respectively.
    - The Hillsvale Vein System located about 1.2 km northwest of the northern-most border of the Uniacke SPS study area, where gold was the commodity of interest, with arsenopyrite and pyrite mineralization within quartz veins. A total of 6 exploratory drill holes were drilled in the vicinity of this occurrence.
    - The Ardoise gold (former gold producer with pyrite and arsenopyrite mineralization in quartz veins) and the Ardoise Hill ochre (ochre, limonite, iron-oxide mineralization) prospects located approximately 3.5 km northwest of the northwestern border of the study area, where at least one shallow (less than 4 m) shaft and upwards to eight pits were dug.
    - The Pockwock Lake gold occurrence, located at the northern end of Pockwock Lake about 1.5 km from the southernmost point of the Uniacke SPS study area, which was worked via pits.
    - The South Uniacke manganese occurrence (pyrolusite mineralization) located approximately 4.2 km outside the southeastern border of the study area.
    - The Sandy Brook gold occurrence, the Christie Lake wolframite, copper, molybdenum and zinc occurrence, and the Kehoe Hill uranium prospect, each located 7 km, 10 km and over 11 km due west of the southernmost corner of the Uniacke SPS study area, where native gold; wolframite, scheelite, chalcopyrite, and molybdenite; and torbernite, autunite and stillmanite were the minerals of interest.
- Mines – which from the above, only the South Uniacke Gold District and the Mount Uniacke Gold District have been developed within the Uniacke SPS study area. More details are provided below.

Much of the following is from Faribault (1901, 1902) and Malcolm (1929) as summarized by Parsons et al (2012) and MANS (2019).

6.6.1 South Uniacke Gold District

Compared to some other Gold Districts, little information exists on the mining history at South Uniacke. This may be because South Uniacke ranked only 20th (Parsons et al, 2012) out of about 40 Gold Districts in terms of total recorded gold produced.

South Uniacke, which is classed as a vein-rich gold deposit type (Kerr, 2020), is a small side fold on the Holmes Settlement fold.

Gold was first discovered in the area in 1887, and almost continuous production was recorded from the following year until 1900 (Johnston, 1979). During the first 2 years, 298 tons of ore produced from the Hard Lead yielded 3,200 ounces of gold (10.7 oz/ton milled) and in the subsequent 4 years a total of 7,073 ounces of gold was recovered from 788 tons of crushed ore.

Prior to 1900, modest production was also derived from the Slate Lead. Sporadic production continued until 1905. In 1922, a new shallow shaft was started, followed by additional spurts of activity with the sinking of more shallow shafts and dewatering of older ones in 1928, 1937 and 1947 and the drilling of 5 diamond drill holes in 1942. There has been no production since then.

From 1888 to 1948 the South Uniacke District is reported to have produced 20,762 troy ounces of gold from a reported 11,070 tonnes (Parsons et al, 2012) to 11,722 tonnes (Kennedy and Nicholson, 2006) of crushed ore, with an average grade of 55.05 g/tonne[70], (1.77 troy ounces/tonne) (Pelley et al, 2007) from over 50 pits and shafts.

A geologic site plan by Faribault (1902) shows the three major gold leads[71] (the Hard and Slate Leads were the major two, the Middle Lead having had some work done along it) located roughly under the first two southern-most rows of mobile homes at Valley Gate Park, plus two more working leads (the Copper and North leads) located farther north.

A 123 m deep shaft was sunk at the far east end of the Hard Lead, from which a 30° incline was worked to a vertical depth of 220 m. An additional seven shafts were sunk along the Hard lead, ranging from 122 to 6 m deep, becoming shallower westward, except for one shaft west of the northeast fault noted earlier, which was sunk to a depth of 45 m.

The Slate Lead had ten shafts along it that ranged in depth from 24 to 92 m, with six deeper than 61 m. The Slate lead appears to have been worked to a maximum vertical depth of around 114 m.

The Middle Lead is shown to have been worked mostly as near-surface, shallow trenches.

Most of the significant mining work was limited to areas east of the railway and more specifically, from about 200 west of the Davis Drive meets South Uniacke Road and eastward. For example, the “shafts” farthest south of Valley Gate Park were 15 m deep and near surface trenches only. The “shaft” immediately east of the railway and one at the north edge of the site were each also reported (Hennick and Poole, 2024) to be only about 15 m deep; but they

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[70] To give some perspective, successful historical NS gold mines often had just one or two ounces of gold per ton, but others, such as at Oldham, have yielded over 100 ounces per ton and producing 85,178 ounces of gold. Today, output at successful gold mines is measured in grams per ton, not ounces.

[71] By comparison, at least 40 leads were worked at the Oldham Gold District, including some mining shafts and a significant number of surface trenches.

appeared (Gagné and Wait, 1988) to be pits only and all others near the railway and on-site were worked as near-surface, shallow trenches.

The Faribault (1902) plan shows three crushers – two were about 200 and 250 m east of Valley Gate Park, each having 3 and 5 stamps, respectively, and a main crusher with 10 stamps located about 200 m southwest of the South Uniacke Road at Davis Drive. The Faribault plan shows only one tailing pond immediately northwest of the main crusher. However, tailing ponds were likely also present at the other two crushers east of Valley Gate Park.

The area is shown to have included one store just to the south of where Valley Gate Park is now, a school north of South Uniacke Road about 370 m west of Davis Drive, and another store with post office and a station building at the east side of the railway just west of South Uniacke Road.

Notwithstanding reports of later work, except for what appears to be later trenching on both sides of the railway, nothing suggests that any more significant mining work took place beyond the area shown by Faribault (1902).

As was typical of the day at other NS Gold Districts, mining at South Uniacke was done by focusing mostly on gold-rich quartz veins. Refining the ore involved crushing it with mercury in battery boxes (stamps), then discharging the resulting pulp onto secondary copper plates coated with mercury to recover any gold that escaped amalgamation in the crusher boxes. Then the gold-mercury amalgam was retorted to produce sponge gold and mercury for reuse.

During this process, very fine particles of mercury were generated and were usually lost into mill tailings (as much as 14 grams or more of mercury per ton of ore processed (Parsons and Percival, 2005)) along with the crushed quartz and associated sulphide minerals (mostly pyrite, pyrrhotite, and arsenopyrite). Also, some mercury was lost to atmosphere during the retort process, leaving a trail of mercury condensate on the ground surface downwind of the mills.

6.6.2 Mount Uniacke Gold District

Gold was discovered at Mount Uniacke in 1865, which led to a rapid increase in prospecting and mining in this district. By the end of 1867, the number of homes in the area grew to over 200 residences and three stamp mills had been built for processing ore, whereby production increased from 72 ounces of gold in 1866 to 1,622 ounces in 1867. The peak annual production of the district (3,247 troy oz. of Au) was reached in 1868, after which production nearly stopped due to skepticism surrounding fraudulent speculative stock sales (crushers, which were never used, were built to sell mining stocks) – between 1869 and 1874 only 14 ounces were reported.

However, after 1874, production resumed, was up and down, and was carried on almost continuously until 1941. From 1867 to 1941, approximately 27,740 ounces of gold were produced from 54,256 tonnes of crushed rock. As such, the Mount Uniacke Gold District ranked 15th (Parsons et al, 2012) out of about 37 mines in terms total recorded gold produced for Nova

Scotia gold mining areas having produced over 1,000 troy ounces of gold (for perspective, the top Mining District in Nova Scotia, at Goldenville, produced 210,153 troy ounces of gold from a reported 540,617 tonnes of crushed ore).

In total, mining was done following over 100 leads (gold-bearing quartz veins) (Faribault, 1901; Smith and Goodwin, 2009) from 8 shallow trenches, 25 open cuts (most shallow, but three of which were 24, 45 and 50 m deep), and 158 shafts that ranged in depth from 4.5 m to 120 m deep (40 were 4.5-10 m deep; 50 were 10-20 m deep; 25 were 20-30 m deep; 22 were 30-50 m deep; 8 were 50-80 m deep; and one was 120 m deep) (Hennick and Poole, 2024).

As was the norm of the day at other Nova Scotia Gold Districts, mining at Mount Uniacke was done by focusing mostly on gold-rich quartz veins. Refining the ore involved crushing it with mercury in battery boxes (stamps), then discharging the resulting pulp onto secondary copper plates coated with mercury to recover any gold that escaped amalgamation from the crusher boxes. Then the gold-mercury amalgam was retorted (burned off and evaporated) to produce sponge gold for later refinement by melting, and mercury condensate for reuse.

At the Mount Uniacke Gold District, mill foundations can be found throughout this district (Parsons et al, 2012), which operating stamp mills were reported to range in size from 5 to 30 stamps (Faribault 1901; Malcolm 1929). Faribault (1901) and Smith and Goodwin (2009) show the locations for four. The largest volumes of tailings were discharged into a wetland downslope of the former P.C.F. Gold Mining Crusher (Parsons et al, 2012) located at approximately UTM 436628E/,4975410N, and another wetland downslope of Foster's Crusher along Mill Pond, located at approximately UTM 436290E/4975178N (Faribault, 1901; Smith and Goodwin, 2009), both of which are located within the St. Croix river sub-watershed 1DE-1-C-8 and within the northern part of the Uniacke SPS study area.

6.6.3 Environmental considerations re. local mineral occurrences and mining

None of the off-study area mineral occurrences noted above are expected to present any environmental concerns within the Uniacke SPS study area due to the small nature of those operations and to their distances from the study area boundaries. However, the gold mining and refining operations at South Uniacke, and mostly those at Mount Uniacke, are expected to have left certain unfavourable environmental legacies.

At South Uniacke, all of the more significant mining operations and related mine dumps (waste rock material that was deemed at the time to not contain gold value and which was not crushed) took place east of the faults shown at Valley Gate Park. Thus, those past activities are unlikely to be a cause for any direct concern regarding groundwater quality for water supply wells drilled most anywhere north and west of the Valley Gate Mobile Home Park, and related tailings dumps are expected to have impacted only a very small part of the Sackville River where a small tributary to it appears to originate at one of the tailings ponds.

Things appear to be different at Mount Uniacke, however, where both underground and above ground operations were generally much more intensive, and the total volumes of tailings and the areas into which they were dumped were also much larger, which are all located directly within the boundaries of the Uniacke SPS study area.

Elemental mercury may have been spilled at both the South Uniacke and Mount Uniacke stamp mills, and during the mercury amalgam process of extracting gold from ore, very fine particles of elemental mercury were generated and were usually lost into mill tailings. Parsons and Percival (2005) have reported that in general as much as 14 grams or more of mercury per ton of ore processed could be lost this way, along with the crushed quartz and associated sulphide minerals (mostly pyrite, pyrrhotite, and arsenopyrite, could be).

Also, some mercury was lost to atmosphere during the retort process, leaving trail of mercury condensate on the ground surface in aureoles downwind of the retort mills. At South Uniacke, in light of the stamp mill locations and prevailing wind directions, this would have been limited mostly to areas east of the mobile home park. However, at Mount Uniacke, where the stamp mills were more widely spaced and distributed, mercury condensate falling onto the ground is expected to have affected much larger areas of that mining district.

This said, elemental mercury is not directly soluble in water, and as such any elemental mercury that may have been spilled at or accumulated on the ground surface as condensate downwind of the South Uniacke mining operations stamp mills, and mercury condensate accumulating at Mount Uniacke, is not likely to be a direct concern for groundwater. However, organic mercury complexes may be water soluble, and mercury bound to sediment may have been transported along steams away from tailing areas and reacted with organics created by wetland plant decay.

At South Uniacke, the tailing areas at all three crushers discharged via 2nd and 3rd order head-water streams of the 5thto-7th order sub-basins east and south of the mobile home park. As such, any tailing discharge would have been into the Sackville River very close to but within the Uniacke SPS study area boundary. At Mount Uniacke, all three crushers discharged via 5th order streams flowing north into Mud Lake, which although located in sub-tertiary 1DE-1-C- 8, is downgradient approximately 1.86 km west-southwest of the site and situated within one of Long Lake’s farthest southerly sub-basins. Mud Lake drains via a stream that flows west-northwesterly and discharges in the cove south of Acker Narrows and west of Mill Cove at Long Lake.

No published data were found regarding direct environmental concerns from past ore processing at South Uniacke. But at Mount Uniacke, concentrations of arsenic as high as 45,832 mg/kg (average 4,418 mg/kg) buried beneath 10-20 cm of organics and vegetation are reported by Drage (2015), and from depths averaging around 0.5 m and up to 1.2 m (Parsons et al, 2012) in the Mount Uniacke tailings ponds. This compares to an overall maximum of 312,300 mg/kg (average maximum of 129,828 mg/kg) and a maximum average of 75,669 mg/kg (mean average of 19,485 mg/kg) for reported by values from all the NS gold districts studied by Drage (2015).

Arsenic may be transported in the dissolved phase in surface waters with low pH. However, Parsons et al (2012) have reported values for pH in the trailings below Mill Pond to range from 6.2 to 6.9, which is well within the range for Nova Scotia surface waters, and also above where most metals are likely to be (or kept) dissolved in waters that are exposed to air.

At Mount Uniacke, the spread of organic mercury should be expected to be more widespread – EPS (1978, via Parsons et al (2012)) are reported to have observed tailings sediment on the tailings ponds floodplain all the way to Mud Lake, located about 1.75 km from the crusher at Mill Pond. The mercury values obtained from those same tailings by Parsons et al (2012) ranged from 1,100 μg/kg to a maximum of 130,000 μg/kg (norms below 20,000 μg/kg, generally) from tailings depths of 0.2 to 2.5 m (Parsons et al, 2012).

Additionally and to summarize, while the tectonic and related structural events that took place millions of years ago has no doubt locally caused the bedrock in the South Uniacke area to become naturally mineralized (pyrite, pyrrhotite, arsenopyrite, and some gold) in the eastern-most parts of that Gold District, they are expected to be somewhat localized. The issues specifically regarding possible naturally elevated arsenic and other metals in groundwater is discussed further in Section 8.1 of this report.

6.6.4 Present and possible future local mineral work

Gold exploration may continue to be a matter of interest at the former South Uniacke and Mount Uniacke Gold Districts. That’s because since the past focus on mining was mostly on quartz veins, the older prospecting and mining methods used has resulted in a lot of the ore in Nova Scotia’s historic Gold Districts having been left behind. However, due to the development of new exploration and mining techniques, and to changes in gold economics, many of the old mining sites have seen a resurgent interest by gold exploration and mining companies.

A search of the NovaScan database suggests that work completed in 2007 by Acadian Mining Corp. (Pelley et al (2007), in 2019 by Kiltz (2021), and in 2022 by MacKinnon and MacDonald (2024) may have been the last of any exploration done at South Uniacke.

There was considerable interest in the Mount Uniacke area from 2016 to 2021, with 1156219 B.C. Limited (affiliated with Meguma Gold Corp. submitting numerous assessment report via Mercator Geological Services Ltd. (Power, 2018, follow-up reports in 2021). They operated many continuous claims from Mount Uniacke eastward (often done to prevent others staking claims while tying areas on-strike to claims that are being worked), which since then appear to have been dropped. The latest work at Mount Uniacke was in 2022 by MacKinnon (2024) as follow-up to earlier 2016 and 2017 work (MacKinnon and Grant, 2019a, 2019b).

This said, assessment reports submitted to NS Natural Resources generally take two to three years before they become public via NovaScan, so other more recent work may have been done in the former South Uniacke and Mount Uniacke Gold District area. However, based on the current claim holders, those appear to be small and/or independent prospectors. In light of the huge environmental costs involved, particularly in areas where there is new or potentially new urban development, smaller operators are often dissuaded from pursuing exploration projects.

Figure 40 shows the currently held claims, and Table 8 summarizes the information on the claims that are currently held and shown in Figure 40 within the Uniacke SPS study area.

Table 8. Summary information on current exploration claim holders in the Uniacke SPS study area.

Claim	Claim holder			Claim				Claim NTS map/tract/claim identification
No.	No.	ID	Mailing address	Age	Term	Expiry	Status	
Mount Uniacke Gold District area								
50503	564793	ExplORE Resources Ltd.	43244 Cabot Trail, RR# 1 Englishtown B0C1H0	16	7	2025-01-21	active	11D13C45-H, J 11D13C46-G, H, J, K to Q 11D13C51-A
55501	564789	21Alpha Resources Inc.	49 Queen Street, PO Box 794, Chester B0J1J0	2	1	2025-01-30	active	11D13C45-G, K
55503	564789	21Alpha Resources Inc.		2	1	2025-01-30	active	11D13C45-G, K
55504	564476	John Shurko		2	1	2025-01-30	active	11D13C51-B
55560	565865	Marnik Ooms	178 Partridge Ln., Mount Uniacke B0N 1Z0	2	1	2025-01-31	active	11D13C44-J, K
56556	566147	Taco Zandstra	55 Beaumont Dr., L. Sackville B4C 1V5	1	1	2026-09-09	active	11D13C28-N, O 11D13C45-C, D
56656	564793	ExplORE Resources Ltd.	43244 Cabot Trail, RR# 1 Englishtown B0C1H0	1	1	2026-11-20	active	11D13C45-A, B, F, L, O, P, Q 11D13C46-A to D 11D13C47-D, E, M, N 11D13C50-D to G, K to P 11D13C51-C to K 11D13C52-A
South Uniacke Gold District area								
52895	201219	Perry MacKinnon	43244 Cabot Trail, Skir Dhu B0C1H0	7	3	2025-12-13	active	11D13B98-J, K, P, Q
56176	200840	Ken Hiltz	401 Moose Horn Drive, PO Box 907, South Brookfield B0T1X0	2	1	2025-12-18	active	11E4B53-C
56679	200840			1	1	2026-12-03	active	11D13B94-Q 11D13B95-N, O 11D13B98-B to H, L 11D13B99-A

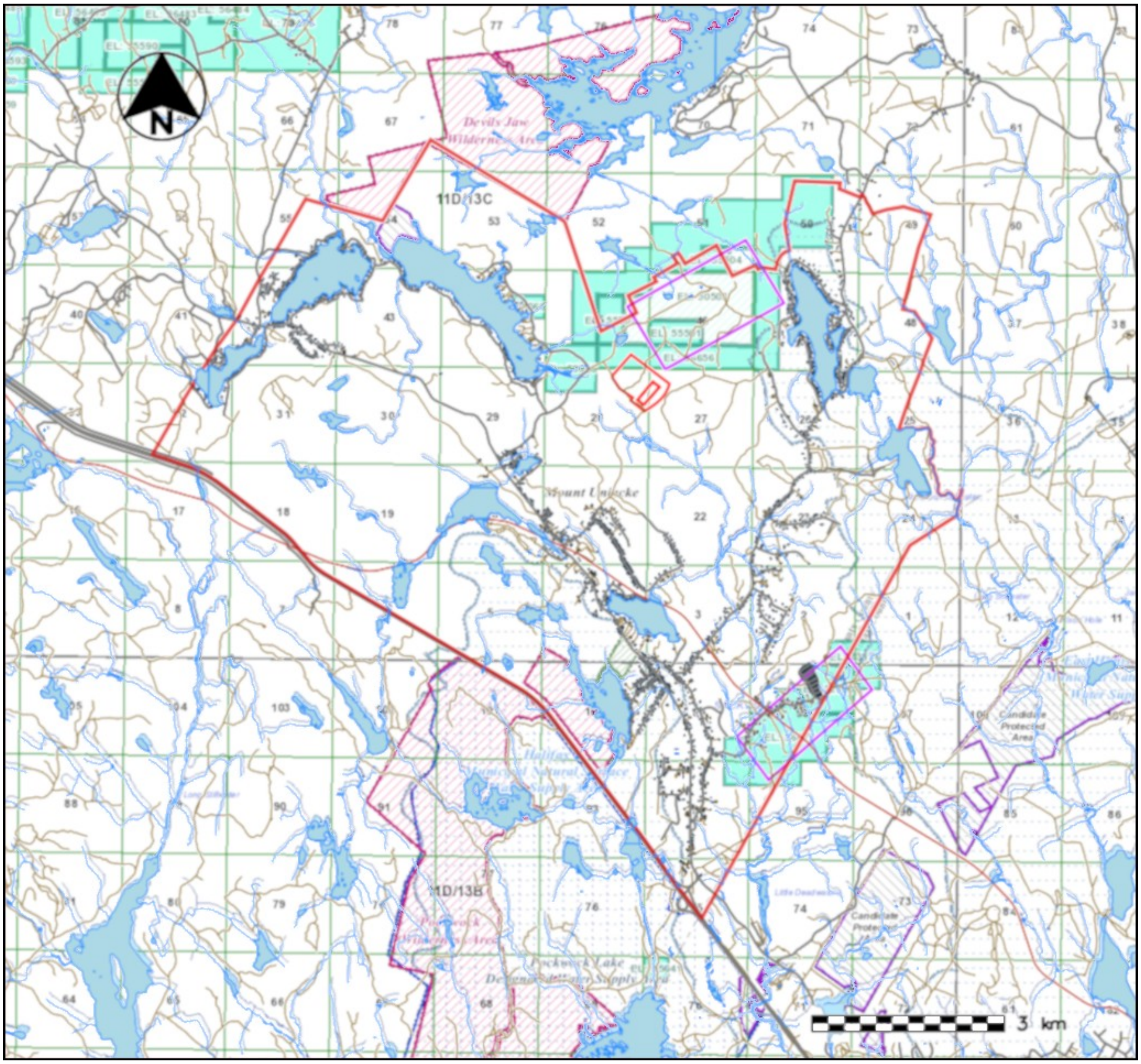

Figure 40: Current (as of 27 Dec. 2024) exploration claims (light aqua) within the Uniacke SPS study area. Purple hatched areas are no-claim areas. Red lines define the Uniacke SPS study area and the proposed expanded Mount Uniacke quarry boundaries, the mauve lines define the former South Uniacke and Mount Uniacke Gold District boundaries.

6.6.5 Mount Uniacke Quarry

Northumberland Capital Corp. Inc. proposes to significantly expand the Mount Uniacke quarry, with the real potential for severe deleterious effects to existing and future wells that could result in a possible new well construction (and thus new development) exclusion zone of over 450 hectares (an estimated 300 to 350 new lots sized based on avoiding possible well interference –

see Section 9.7 of this report).

The sections of the Environmental Assessment Registration report prepared by WSP (2023) describing the area geology and the hydrogeology and groundwater resources at and around the existing and the proposed expanded quarry are very incomplete to non existent. In the VEC assessment section of their report, the groundwater VEC Section 6.3 is just as incomplete – the proposed mitigation measures are inadequate, the blasting setback of 500 m for wells is incorrect (800 m is what NSE generally recommend, which we view to be a minimum distance in some circumstances), and WSP indicated using that incorrecte 500 m setback only “when possible”.

Large amounts of blasting are no doubt being done in the existing quarry, and larger amounts of blasting are expected to be carried out in the expanded quarry. The impacts of quarry-style and scale blasting on water supply wells are frequently irreversible.

7.0 Study area Quaternary geology

7.1 Background

The Quaternary Period (about 2.6 Ma to today) includes the Pleistocene Epoch (the period of latest glaciation, which began about 2.6 Ma and ended 18,000 to 12,000 years ago), and the Holocene Epoch (the period following the last glacial melt, to today).

The major features of the landscape of Nova Scotia – the overall relief, the distribution of highland, upland and lowland areas – are all the product of its long tectonic history. The land minor features – the final rounding of the land surface, the alignment of surface lineations, surficial deposits and sea-level changes – are the product of glacial activity that involved ice flows up to 1 km thick over Nova Scotia during the Quaternary Period.

The last phase of glaciation, which ended about 10,000 years ago, left behind during the Holocene an unconsolidated mantle of sediment. On it, drainage patterns were reestablished and soils were developed.

Much of the following discussion is from Stea and Mott (1990) and Davis (1998). Deep-ocean-sediment core samples provide evidence that there were more than sixteen glaciations during the Quaternary. They generally each lasted about 100,000 years, separated by 10,000 to 20,000 year-long warming periods, which progressed slowly until huge ice sheets covered most of Canada. But on-land Nova Scotia, evidence for only the last two (the Illinoian and the Wisconsin glacial advances) is preserved.

Illinoian (190,000 to 130,000 year old) and/or pre-Illinoian glacial deposits are preserved as iron-cemented conglomerate (Prest, 1898) and till in parts of southern and central Nova Scotia, but besides being only vaguely touched upon by Stea et al (1992), are otherwise unmapped. However, buried Sangamonian (130,000 to 115,000 year old) fluvial deposits that were laid down during the interglacial period between the Illinoian and Wisconsin glacial advances are known to have been preserved at McCabe Lake (ewC, 2023b), possibly in the Fall River area (ewC, 2024b), and unknowingly mapped by Matheson (1999, in ewC, 2024d).

The Wisconsin glaciation started about 75,000 years ago (although northern Cape Breton Island ice-free conditions may have persisted until 50,000 years ago) and ended 12,000 to 10,000 years ago. Each major glacial advance, by its nature, tends to destroy evidence of previous glaciations. The glacial deposits and features in Nova Scotia are therefore almost all of Wisconsin age.

The main events of the Wisconsin glaciation have been interpreted from their deposits and striation patterns which indicate ice-flow patterns. The Wisconsin glaciation occurred in four phases (see Figure 41), with each leaving new deposits stacked over older ones where the older deposits were preserved, or onto bedrock where they were not. These stacked till sheets and

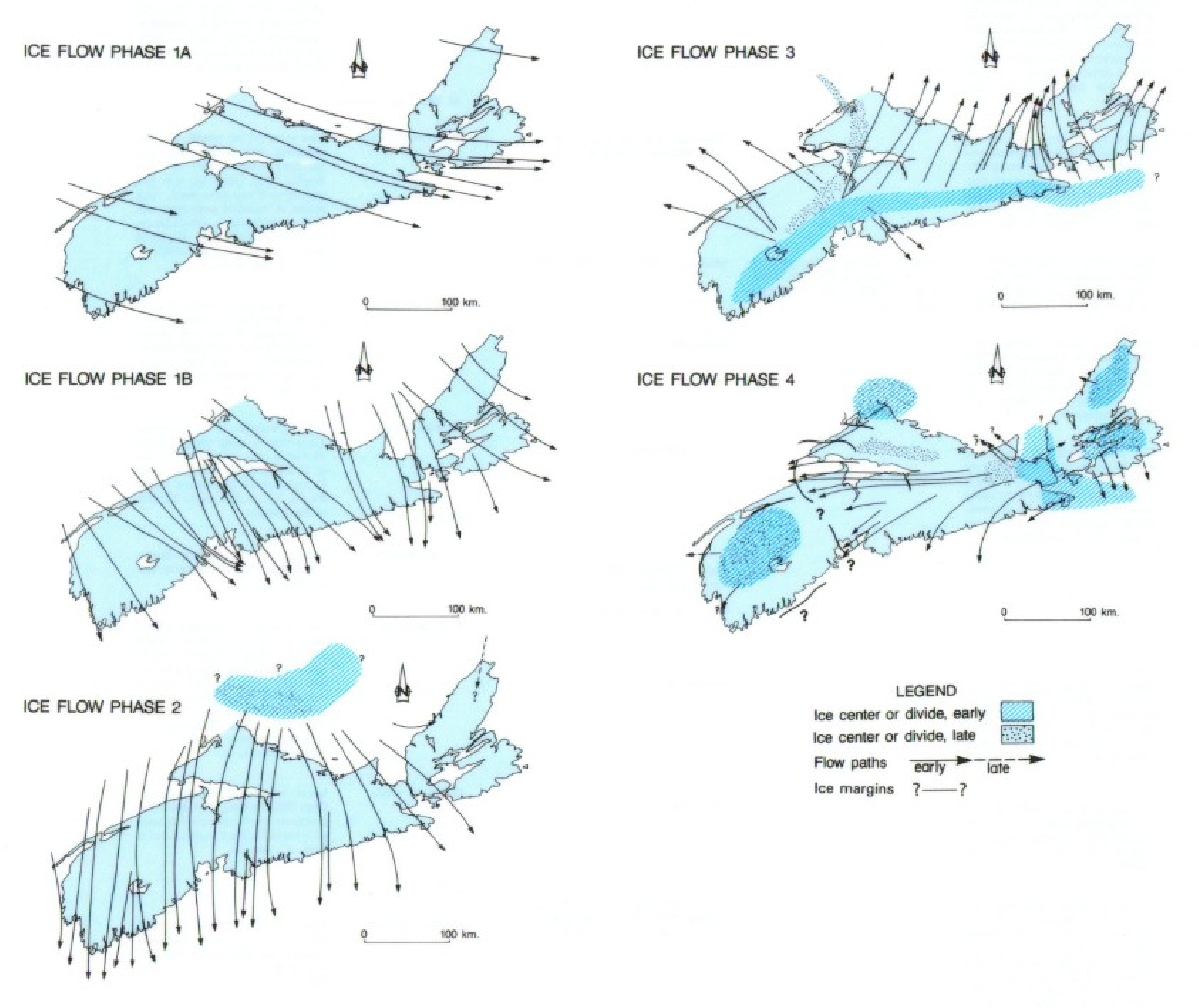

Figure 41: Ice flow patterns deduced from striation and drumlin directional data (copied from Stea et al, 1992).

superimposed striations helped to interpret the changes in ice flow.

The Phase 1 striations, erratics, and till fabric suggest that the earliest and most extensive ice flow in Nova Scotia was eastward, then southeastward. The majority of the drumlin fields in Nova Scotia were formed during this phase and modified during Phase 2.

Phase 2 ice flow was southward and south-westward from from the Escuminac Ice Centre in the Prince Edward Island region, and established much of the drumlin topography and alignment of the geomorphological features in Nova Scotia.

Phase 3 included development of thick ice and an ice divide in southern Nova Scotia, with northward and southward ice flow.

Phase 4 saw mostly westward ice flow from remnant ice caps from Phase 3, which formed over the Chignecto Peninsula, and where eskers and striations cut across features formed by earlier ice flows.

None of the advances in the late Wisconsin were as strong as those before, and they became progressively weaker, until the ice caps finally disappeared from Nova Scotia some 10,000 to 12,000 years ago.

7.2 Pleistocene ground cover

The Wisconsin glacial advance and and depositional events left behind surficial deposits both regionally and locally, that consist of: drumlins, ground moraine (sheet till veneer or blanket), and Holocene alluvial and lacustrine and related organic deposits. Figure 42 shows their distribution at and around the Uniacke SPS study area, and Table 9 summarizes the areal distribution of the surficial geology units and lithology within that mapping area and within the Uniacke SPS study area boundaries.

Table 9. Area distribution of the surficial geology unit/lithology types in the Figure 42 mapping area and within the Uniacke SPS study area.

Unit/lithology type	Figure 42		Uniacke SPS study area	
	m^2	percent	m^2	percent
Organic Deposits	5,220,310	1.77	2,111,370	2.63
Beaver River Till (stony ground moraine)	101,432,048	34.43	36,187,368	45.07
Lawrencetown & Rawdon Till (silty ground moraine)	68,489,488	23.25	18,653,891	23.23
Silty Drumlin	27,085,544	9.19	11,988,319	14.93
Bedrock	88,335,457	29.98	10,562,835	13.15
Lakes	4,062,753	1.38	795,009	0.99
Totals	294,625,600	100.00	80,298,791	100.00

7.2.1 Glacial tills

The Figure 42 mapping area includes three tills; the older Lawrencetown Till, the younger Beaver River Till, and the younger still Rawdon Till. The Uniacke SPS study area contains only two of these tills; the Lawrencetown and the Beaver River Tills.

Stea and Fowler (1981) and Stea et al (1992) describe the Lawrencetown Till as a reddish brown, moderately compact, noncalcarious, fissile and massive, silty ground moraine till that is derived from both local (80%) and distant (10-70 km transport distance) sources. Stea and Fowler (1981) describe the Rawdon Till as an olive gray, also compact, fissile silty till that contains both Horton Group and Meguma rocks, as well as reworked Lawrencetown Till material. There is frequently Fe-Mn oxide staining on fissility planes of both tills, along with horizontal fluvial inclusions. These tills display a bimodal clast fabric, with matrix clays dominated by kaolinite.

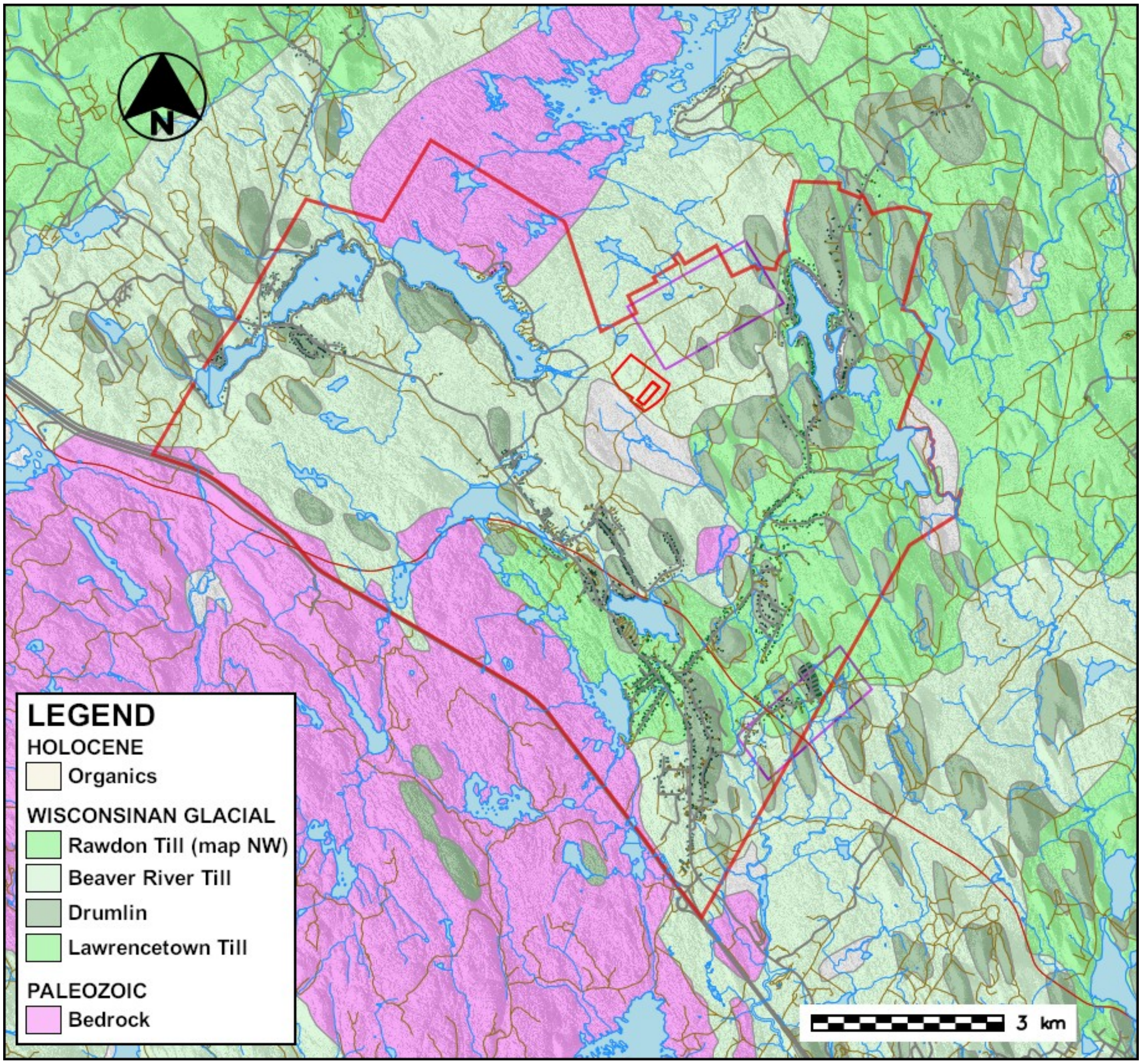

Figure 42: Quaternary (surficial) geology (from Stea et al, 2006).

The Lawrencetown Till is said to have developed in areas that are underlain by Carboniferous bedrock and as such, is likely to have been imported from at least 10-15 km away by glaciers.

As noted above, the Lawrencetown Till can contain up to 80% locally derived clasts, whereas the drumlin facies generally contains 10-30% allochthonous (not indigenous) components that may have been transported as far as 10-70 km. These may include basalt (from the North Mountain), leucogranite (from the Cobequids and reworked Trassic Fundy Group rocks), and sandstone, shale, and conglomerate (from the Triassic and Carboniferous fundy and Windsor Groups).

The Lawrencetown and Rawdon tills generally produce flat to rolling topography with few surface boulders, and are typically thick (3 to 30 m, but average 2 and 2.5 m, respectively) enough to mask bedrock undulations. Both tills originate from material released from the base of an ice sheet by melting, from ice sheet that were centred in the province. These tills generally provide the best agricultural land in the province, both having moderate drainage and stoniness, with moderate to good buffering capacity for acid rain because of frequently transported calcareous bedrock components.

The Beaver River Till (Utting, 2011), which Stea et al (1992) refer to as Quartzite Till, is generally found stratigraphically above (is younger than) the Lawrencetown till. Utting describes it as a diamicton[72] with sandy matrix and locally derived clasts. Stea and Fowler (1981) and Stea et al (1992) go further to describe it as a light bluish grey, loose, with angular clasts that are largely cobble sized, and generally has a sandy matrix, but which may be siltier matrix when present in metamorphosed terrane.

The Beaver River Till, which can range in thickness from ranging from 1-20 m in places, and 0.5-5 m in others that include exposed bedrock, is derived from local bedrock sources and forms flat to rolling topography with many surface boulders. As with the Lawrencetown till, the quartzite till material was released from the base of an ice sheets by melting; and were also deposited by ice sheets centred over Nova Scotia. This till presents moderate limitations to crop use that include stoniness, rapid drainage, erodibility, and poor buffering capacity for acid rain. Factors that affect its use for construction include shallowness, stoniness, and generally the presence of a high water table within it.

7.2.2 Drumlins

Drumlins are streamlined, elongate landforms with their long axes parallel to ice flow direction and steeper faces up-glacier. There are no modern examples of drumlins being formed, but they are thought to have generated as material released from the base of an ice sheet by melting, reworking, and moulding by ice action, often where there are large changes in the bedrock topography.

Stea and Fowler (1981), Stea et al (1992) and Utting 2011) all seem to suggest that the drumlins within the Figure 42 mapping area are a facies of the Lawrencetown Till. Stea and Fowler (1981) and Stea et al (1992) describe the local Lawrencetown drumlin facies as being sandier or siltier than their surrounding tills, depending on location, and generally containing a higher percentage of distant source material, including red clay. They state also that the Lawrencetown drumlins are often co-deposited with multiple tills.

Utting (2011) further describes the local drumlins as being composed of up to three tills: a core of Hartlen Till (which is not present in the area as a moraine or till blanket, but is observed only at coastal sections of Nova Scotia) that locally is overlain by either Lawrencetown Till or by

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[72] A non-sorted or poorly sorted conglomerate material containing a large range of particle sizes.

Beaver River Till. The Hartlen Till is a medium bluish grey to greyish-brown, compact, non-calcareous, fissile and massive diamicton with dark grey, compacted, clayey silt matrix that is dominated by illite. It is predominantly locally derived and contains lesser (6-15%) distally derived clasts.

Drumlin thickness is affected by the surface relief of the landforms they are sitting on. In some instances depth to bedrock (determined from water well data) exceeds the surface relief, thus suggesting that material filled a preglacial topographic low or paleovalley. Locally, these thicknesses may exceed 30 m.

7.2.3 Glaciofluvial deposits

Stea et al (1992, 2006) show no glaciofluvial deposits in the Figure 42 mapping area. However, the Herbert River located not far outside and north of the Figure 42 map area follows the same general course as did ancient glacial streams. Also, many of the local surficial aquifer units that Kennedy (2014) mapped throughout mainland Nova Scotia, which have been considered to be of late Wisconsin age (last ice sheet meltwater deposits), have been found by ewC (2023b, 2024b, 2024d) to be Sangamonian interglacial fluvial deposits that are buried deep beneath Wisconsin tills and drumlins. As such, should water wells drilled in the Uniacke SPS study area find buried fluvial channel deposits, particularly if they are beneath drumlins, those may be associated with ancient bedrock valleys and their potential Sangamonian origin should not be discounted.

7.3 Holocene deposits

7.3.1 Deeper soil horizons

There is little to no readily available published information on the alluvial, lacustrine, or organic deposits present within the Figure 42 mapping area. However, they constitute only a very small percentage of the post-glacial deposits in the greater and the Uniacke SPS study area.

The organic deposits, which develop by infilling of ponds or river courses by vegetation, are said in surrounding areas to comprise sphagnum moss, peat, gyttja, and clay. They form in bogs, fens and swamps, with the swamps generally forming along river valleys. The bogs locally may range in thickness from 1 m at the edges, to 5 m in the centre. The swamps are reported to be typically less than 2 m deep.

Any alluvial deposits that may be present within the greater study area would have been laid down by small streams and rivers after the retreat of the last glaciers. They are comprised of gravel, sand, and mud, and are typically bedded, with coarser deposit fractions at base, and finer fractions at the top. Stream channels generally consist of gravelly sand with their floodplains containing sand and silt.

Alluvial deposits are generally flat or gently sloping across stream and river valley floodplains and sloping alluvial fans. They form thin veneers that are generally under 1 m in thickness in small streams, but may be up to 20 m thick in large floodplains outside of the study area.

7.3.2 Soil A and B (shallower) horizons

The A and B soil horizons include the top and subsoil layer immediately below surface – generally the layers that are cultivated – as opposed to C horizon soils described above, which except for water-based organic deposits, typically contain little to no organic matter.

The A and B horizons, along with the C horizon, can affect precipitation infiltration into the soil and thus, both groundwater recharge rates, and quality, but only with very local effect.

The Uniacke SPS study area is underlain by two soils: the Elmsdale Series soil, which is present across the southeast half of the Uniacke SPS study area and distributed essentially as is the silty till that is present in Figure 42 (Cann et al, 1954), and the Halifax Series soil, which is distributed across the rest (northwestern part) of the Uniacke SPS study area. In the mapping by Cann et al (1954) no difference or distinction is shown in soil time relative to drumlins.

The Elmsdale Series soil is described as a light brown sandy loam over yellowish red sandy loam. It has as parent material reddish brown clay loam till, which is derived from shale and sandstones, and contains hard slate and quartzite cobbles. It is very stony with rapid draining.

The Halifax Series soil is described as a light brown sandy loam over yellowish brown brown sandy loam that is fairly stony. It has as parent material reddish brown sandy loam till derived principally from granite. This soil has good to excessive drainage.

8.0 General and detailed study area hydrogeology

Commercial and domestic groundwater supplies may be obtained from dug wells constructed in till or other surficial deposits, or from wells that are drilled through surficial materials into the bedrock beneath. Dug wells and drilled wells will each have different water quality and yield characteristics. While the manner in which dug and drilled wells are constructed may have some influence, this is due mostly to the physical and chemical makeup of the materials into which they are constructed – or the matrix through which groundwater flows from recharge to wells.

Those readers who have patiently gone over the groundwater basics and historic and local geology parts of this report should now be armed with the knowledge needed to better grasp the nature of the groundwater flow matrices within the Uniacke SPS study area – to move directly into the details of the Uniacke SPS study area hydrogeology – to more fully understand its varied groundwater recharge and flow characteristics, existing well yield capabilities – and more importantly in terms of producng policy for future community grown within the study area, to better understand its future groundwater supply potentials, limitations, and potential concerns.

8.1 Available local aquifer units

The aquifer units, or hydrostratigraphic units[73] (HUs) that are available for individual wells within the Uniacke SPS study area include:

- the three Quaternary surficial HUs – the sandy Beaver River Till HUs, the silty Lawrencetown Till HUs, and the drumlin HUs – for dug wells, which thicknesses are expected to be adequate across all but about 14% of the study area, through which all groundwater flow will be mostly if not all via primary permeability, and
- the four bedrock HUs – the igneous (granodiorite) HU, and the three metamorphosed bedrock HUs: the Goldenville Group’s Taylors Head Formation HU and Beaverbank Formation HU, and the Halifax Group’s Cunard Formation HU – through which all groundwater flow will be via secondary (fracture flow) permeability.

Each of these seven HUs will present specific groundwater quality characteristics, as well as different flow characteristics, and depending on the local intensity and direction of bedrock fractures, possibly very different groundwater flow characteristics within individual bedrock HUs, as each bedrock formation is likely to respond differently to the folding, fracturing and faulting tectonic stresses they have been subjected to.

Section 8.2 describes the availability, nature and quality of the well and other hydrogeological data within and immediately around the Uniacke SPS study area used to characterize the study

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[73] A Hydrostratigraphic Unit (or HU) is defined as a part of a body of rock or a soil unit that forms a distinct hydrologic unit with respect to the nature of the flow and of the chemistry of groundwater.

area's HUs. Sections 8.3 and 8.4 give general and detailed descriptions of these HUs in terms of their general degree of confinement, groundwater flow characteristics, well yields, and quality.

8.2 Available data quality, location accuracy, and selection

Figure 43 shows the point locations of the publicly available data sources used for this study. These data include the most recent well log database files (NSE, 2019; Kennedy and Fisher, 2022, current to 31 Dec. 2020), the latest well water quality (NSDNR, 2024b), and pumping test (Drage, 2018; Kennedy, 2022, current to Nov. 2021) spreadsheet and GIS data files.

The yellow and orange dots in Figure 43 represent a total of 1,547 wells within that mapping area (including those in the HRM) – six are reported to be dug wells[74] (located in the Ardoise, Lakelands and Hillsvale areas; the rest are drilled bedrock wells.

Of the 1,541 drilled wells that are reported to be present (or plot) within the Figure 43 mapping area (Kennedy and Fisher, 2022), 17 are reported to have been drilled for commercial and/or industrial use, one is reported to have been drilled for irrigation purposes, 7 are reported to be public (non-municipal use) wells, and one is reported to be a municipal well (at the Beaver Bank Villa in HRM). Water use descriptions are not given for 91 of the 1,541 drilled wells within the Figure 43 mapping area – the rest of the wells are reported to have been drilled for domestic use.

The NS well log database (Kennedy and Fisher, 2022) contains records for 962 drilled bedrock wells that plot within boundaries of the Uniacke SPS study area. Of these, 9 are reported to be commercial and/or industrial wells, one is reported to have been drilled for irrigation purposes, 7 are reported to be public (non-municipal) wells, and 64 have no water use reported, with the remainder of the wells reported to have been drilled for domestic purposes.

It is important to note regarding the above publicly available data and its general use that the Nova Scotia well log database is poorly georeferenced[75] for wells that were constructed prior to mid-2016. As such, many of the wells discussed in the upper two paragraphs may not be within the boundaries stated, which can present difficulties in carrying out proper hydrogeological

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[74] Dug wells appear to be seriously underrepresented in the Nova Scotia well log database due to the more recent need to register them, and an apparent lack of reporting of more recently constructed dug wells.

[75] Drillers did not start to use GPS devices (accurate to about 10 m) to locate wells until after mid-2006. Before that, well locations were identified (often guessed at) to within about 1 km using using map books. Within the available well log database files, the locations for wells drilled before 2006 are defined as the 1 km UTM centroid in which they are thought to have been drilled, or as the centroid of the community they are reported to be in, and in some cases, at the centroid of building lots where drillers reported civic addresses or property identification (PID) numbers. While most well logs include well owner names, many have no address, so the only way to locate those wells is by title search (beyond the scope of this study). Therefore, where in GIS many wells plot in the same location (i.e. the same 1 km UTM centroid), those wells are shown in Figure 43 as a series of stacked dots that are offset (by 5 m) to the northeast.

Of note: with the advent of smart phones with GPS, many drillers use those to report well locations, but most phone GPS are accurate to only about 30 m.

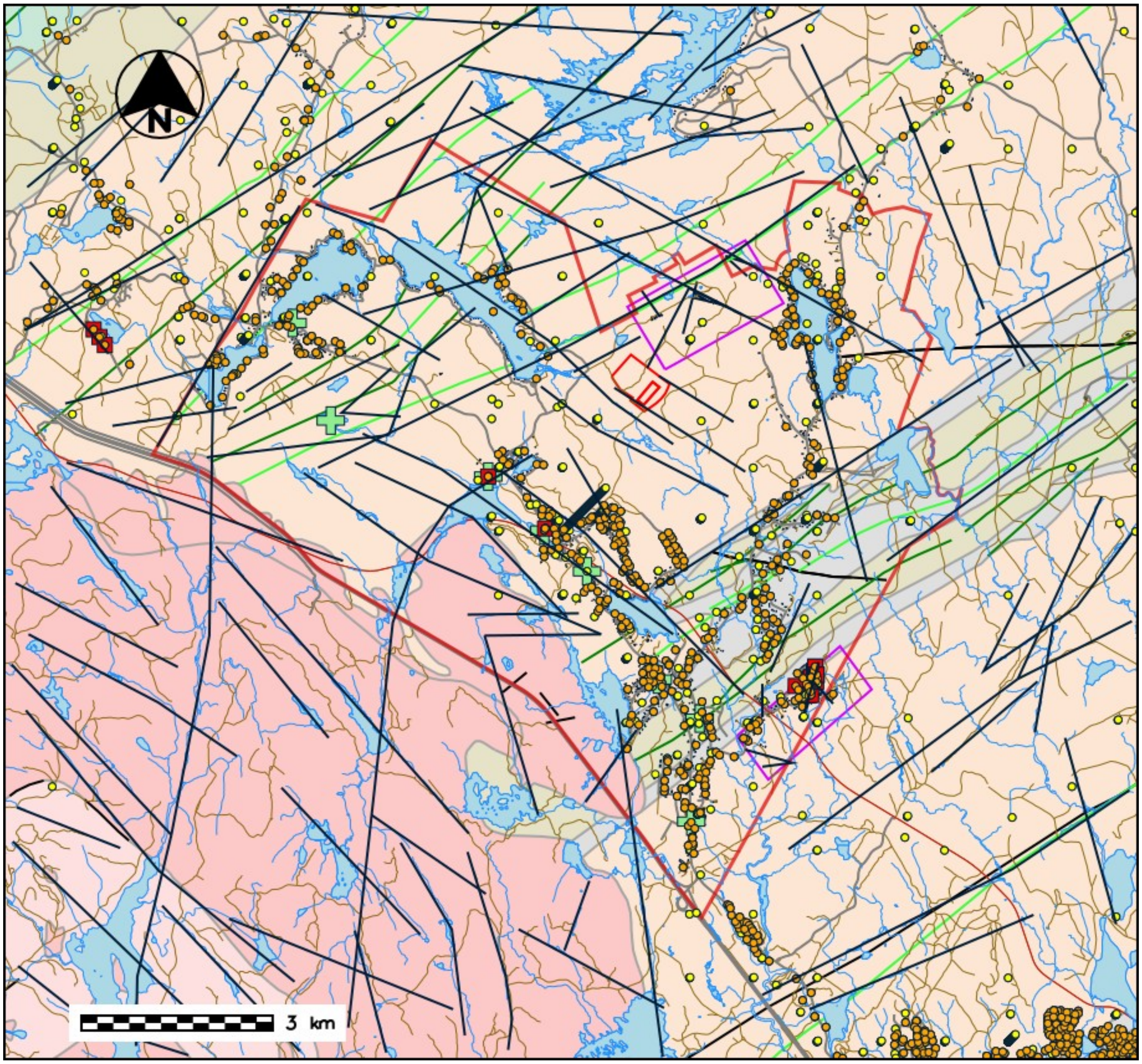

Figure 43: Sources and locations of groundwater data used for this study. The orange dots represent wells with reported UTM coordinates of 100 m or better accuracy. The yellow dots represent wells with lesser reported UTM coordinate accuracy; those that are stacked vertically have generally unknown locations and are arbitrarily given coordinates that plot at the centres of 1 km UTM grid. The red squares represent wells with pumping test data, and the green crosses represent wells with publicly available water quality data. The geology legend is as in Figure 30, with the faults (black lines) from Figure 39. The Uniacke SPS study area and proposed expanded Mount Uniacke quarry boundaries are red, with the former Gold District boundaries in mauve.

assessments, particularly where several wells that plot at one location within the database may have been constructed within an area with different types of closely spaced geology – thus requiring that certain data be removed to avoid biasing interpretations across geologic units.

Based on the general width of the narrower geologic units as shown in Figure 30 and on the known accuracy of their boundary locations as determined from geophysical data (King, 2006a, 2006b) and local detailed on-the-ground mapping (Gagné and Wait, 1988; ewC, 2007, 2914, 2018, 2023b), a well data location accuracy threshold of about **125 m** is considered to represent the maximum georeferencing error practical for this study.

As such, in order to meet that data location accuracy threshold, of the 1,541 and 962 wells that based on database-reported location coordinates plot within the Figure 43 and Uniacke SPS study areas, the number of wells which database information can be used to reliably interpolate and map such characteristics as bedrock, well and casing depths, and well yields, must be limited to only 783 and 483 data points[76], respectively (about 50% of available wells). That said, all of the above-noted Nova Scotia well log database information may be used for making general statistical evaluations, with the caveat that such evaluations will contain certain levels of error.

Table 10 summarizes the database information according to georeferencing accuracy.

Table 10. Summary of the Nova Scotia well log database georeferencing accuracy for wells plotting (based on reported coordinates) within the Figure 43 mapping and the Uniacke SPS study areas.

Reported UTM coordinate level accuracy (m)	Wells plotting within the Figure 43 mapping area			Wells plotting within the Uniacke SPS study area		
	Number of well records	Cumulative number of well records	Cumulative % of total well records	Number of well records	Cumulative number of well records	Cumulative % of total well records
10	2	2	0.13	2	2	0.21
10 to 15	318	320	20.77	198	200	20.79
15 to 30	1	321	20.83	1	201	20.89
30 to 40	41	362	23.49	33	234	24.32
40 to 50	93	455	29.53	77	311	32.33
50 to 75	137	592	38.42	63	374	38.88
75 to 100	154	746	48.41	84	458	47.61
100 to 125	36	**783**	**50.75**	25	**483**	**50.21**
125 to 150	16	798	51.78	8	491	51.04
150 to 200	10	808	52.43	4	495	51.46
200 to 400	26	834	54.12	23	518	53.85
400 to 641	30	864	56.07	22	540	56.13
641 to 707	498	1362	88.38	322	862	89.60
707 to 1130	154	1516	98.38	81	943	98.02
1130 to 7829	25	1541	100.00	19	962	100.00

Among the wells with better than 125 m location accuracy within the Figure 43 mapping area, 632 plot as having been drilled into the Taylors Head Formation, 87 plot as having been drilled

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[76] These are wells which locations would have been obtained using GPS instruments (reported to be accurate to within 15 m) or estimated using civic address or PID. However, no distinction is made in the well log database on whether those coordinates were taken by dedicated GPS instruments, or by cell phone,

into the Beaverbank Formation, 61 plot as having been drilled into the Cunard Formation, one plots as having been drilled into the Glen Brook Formation, and two plot as having been drilled into Granodiorite. Within the Uniacke SPS study area, 391 plot as having been drilled into the Taylors Head Formation, 61 plot as having been drilled into the Beaverbank Formation, 29 plot as having been drilled into the Cunard Formation, and two plot as having been drilled into granodiorite. None plot as having been drilled into either the Glen Brook Formation, as it is not shown to be present below the Uniacke SPS study area.

Within the Figure 43 mapping area, there is publicly available pumping test data for 13 wells within the Uniacke SPS study area, for 3 wells outside the study area, plus unpublished pumping test data (ewC, 2014, 2018) for 3 more wells outside the study area[77]. There is publicly available water quality data for water samples collected from 14 wells located within the study area. The locations for all wells with pumping test data and with water quality data are known with adequate accuracy for use.

8.3 Characteristics of the Quaternary HUs

Due to the small number of dug wells in the database for the Figure 43 area, there is insufficient data available to properly characterize the surficial HUs of the greater study area. Therefore, the discussion below on the surficial HUs must be limited to general knowledge of the area topography, land use, surficial geologic unit distribution, and the effects that those aquifer materials might impose upon the regional, nearby, and on-site groundwater recharge and deeper medium hydrogeology and hydrogeochemistry.

There are three primary Quaternary HUs within and immediately around the Uniacke SPS study area: the Lawrencetown Till HU, the Drumlin HUs, and the Beaver River Till HU. Those areas that are shown in Figure 32 to be generally devoid of Quaternary deposits in fact typically do contain then layers of overburden. But except in rare locations, those layers are likely to be too thin to be considered able to store and/or transmit any large amounts of groundwater to be tapped by dug wells. However, those areas can and usually do influence groundwater recharge.

Till generally has low permeability and thus, any wells constructed in this till HUs may be expected to provide sustained yield rates that are just large enough to meet average single residential needs in low density developed areas. However, due to the generally sandier nature of the tills overlying more competent rock in granitic terrains (not to be confused with geologic Terranes) or areas that are underlain by greywacke (i.e., the Taylors Head Formation), wells dug into the local tills might be expected to have slightly higher yields, although this may be offset somewhat by the presence of thinner tills generally present over these kinds of bedrock terrains.

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[77] Besides data produced for water withdrawal approval purposes, there is no regulatory requirement for pumping test data in unpublished reports to be submitted to the province, unless that is done as a courtesy by those having the reports prepared. Consequently, there may be lots more pumping test data available for some areas that simply cannot be found.

Dug wells are known to produce generally good quality water. However, since tills and drumlins are usually unconfined, wells that are constructed in them are typically prone to contamination from surface sources (thus the greater setbacks required from septic systems compared to drilled wells). This is due in part to the nature of the construction of dug wells, and to shorter groundwater travel times, and thus shorter natural soil filtration distances, available for the shallow groundwater entering dug wells.

Also, due to the short groundwater travel distances to dug wells, and thus shorter aquifer residence times (less time to dissolve minerals), water from dug wells will typically have lower pH, and in many cases can be exceptionally soft and have low total dissolved solids (TDS) concentrations. This low pH and low dissolved minerals can often result in water from dug wells being aggressive and corrosive to plumbing systems.

Depending on local topographic relief, the nature and permeability of surficial materials, and the availability of local recharge, the depth to the surface of the groundwater table may be expected to vary significantly within the Uniacke SPS study area Quaternary HUs deposits. In many cases, particularly where till permeability is low, the piezometric (water table) follows general ground surface elevation (more on this in Section 8.5), with deeper piezometric levels expected in areas of higher elevation. In many cases in Nova Scotia, groundwater elevations in dug wells can fluctuate between 1 and 2 m seasonally. The larger fluctuations may cause problems with dug wells going dry during the summer, particularly where bedrock and/or well depths are shallow.

8.3.1 Evaluation of local Quaternary HU characteristics based on available data

Figure 44 shows estimated bedrock surface elevations[78] within and around the Uniacke SPS study area, and Figure 45, which is derived from Figures 22 and 44, shows estimated overburden (soil) thickness[79], which in the Uniacke SPS study area were calculated to range from less than

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[78] Figure 44 was created by first plotting the depths to bedrock reported in the NS well log database (Kennedy and Fisher, 2022) for wells with 125 m or better location accuracy, plus 29 of 61 drillholes from the NS exploration drillhole database (O'Neill et al, 2023) which location accuracies were confirmed (all better than 30 m), then subtracting those values from the Lidar DEM elevations at the data point locations (at 1 m resolution) to obtain buried bedrock surface elevation point values. Those bedrock surface elevation values were then patched to a map representing 0.5% of the surface elevations (17,664 data points), at 5m x 5m resolution, within the areas shown as bedrock (little to no soil cover) in Figure 42. This data was then interpolated using the v.surf.rst module in GRASS GIS to produce a 5m x 5m resolution bedrock surface elevation raster map by spatial approximation analysis using point data to floating-point raster format by regularized spline interpolation with data distance scale-based tension and smoothing of 0.1. Anisotropy with a ratio of 5 to 1 and azimuth 310º was used in the bedrock surface elevation modelling to represent two of the three primary lineament structural features as shown in Figures 36 to 38 and the likely northwest to southeast prevailing scraping/erosional direction by the Wisconsin glacial ice. However, not having applied anisotropy to also reflect the northeast striking lineament structural features, and the relatively wide spacing of the water well and drillhole bedrock depth data points used, possible narrow ancient bedrock valleys may still have been missed within some parts of the Figure 44 mapping area.

[79] Figure 45 was created in GRASS GIS (2024) by subtracting the Figure 44 bedrock surface elevation map from the surface elevations shown in Figure 22 (at 5m x 5m resolution from moving neighbour average of 1 m data), to generate an overburden thickness map able to account for varying till and drumlin

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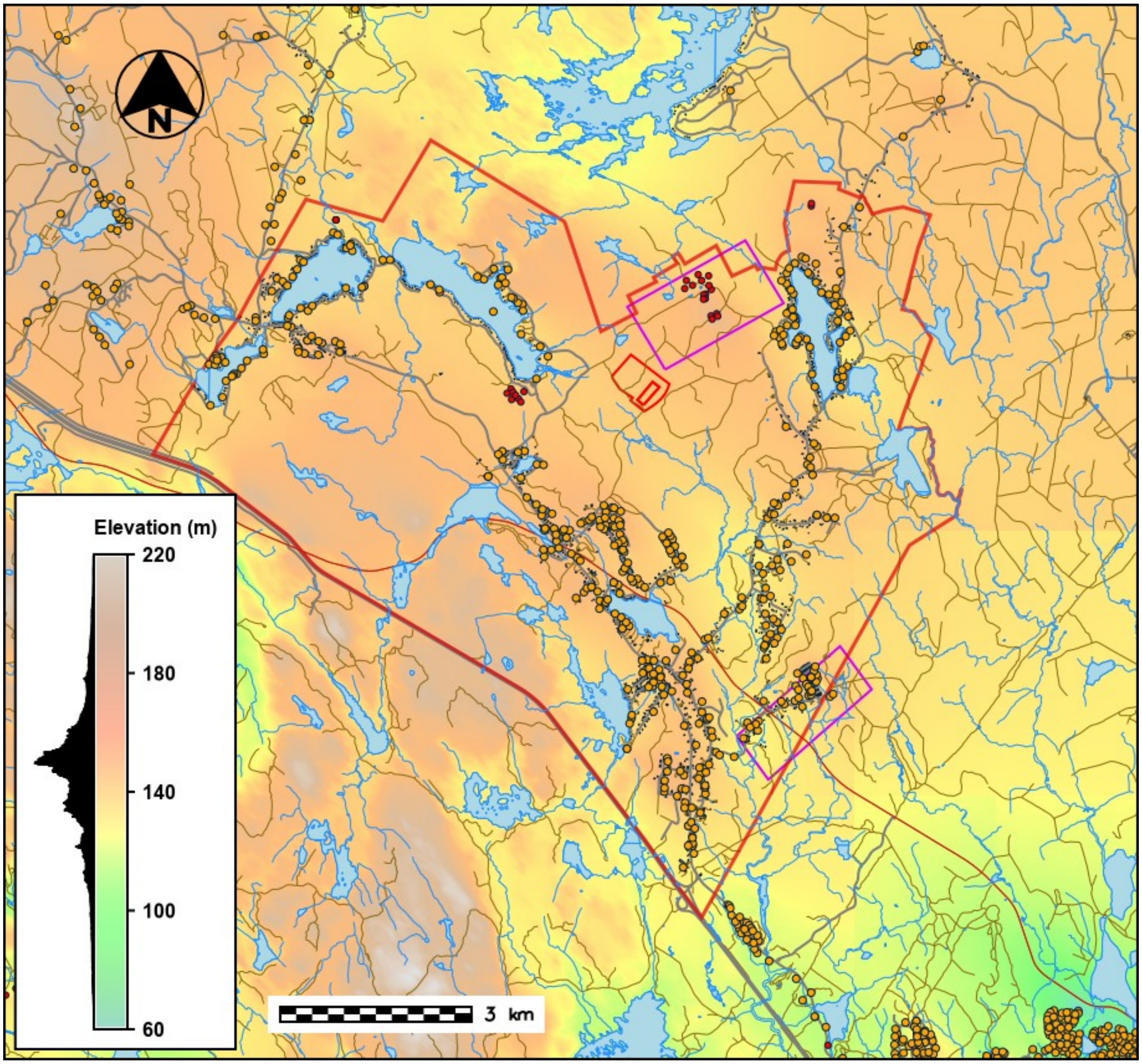

Figure 44: Exposed and buried bedrock surface elevations as interpolated by GIS, with available buried bedrock surface elevation point data locations shown as orange dots for water wells and red dots for exploration drillholes.

zero[80] (all in areas of low surface topography), to 64.5 m.

...cont'd from page 102 thicknesses between the more widely spaced well and drillhole data. This approach was used assuming that the bedrock surface created by long-term pre-Quaternary erosion and by more recent Wisconsin, Illinois, and earlier Pleistocene glacial ice flows should be relatively smooth across the bedrock surface elevation data interpolation area. The caveat regarding having possibly missed narrow bedrock valleys in footnote 81 to the production of Figure 44 also applies to Figure 45.

[80] This is inherent to the method used to interpolate bedrock surface elevations, particularly in modelling areas where data is sparse and widely spaced, thus resulting in narrow bedrock valleys not being mapped.

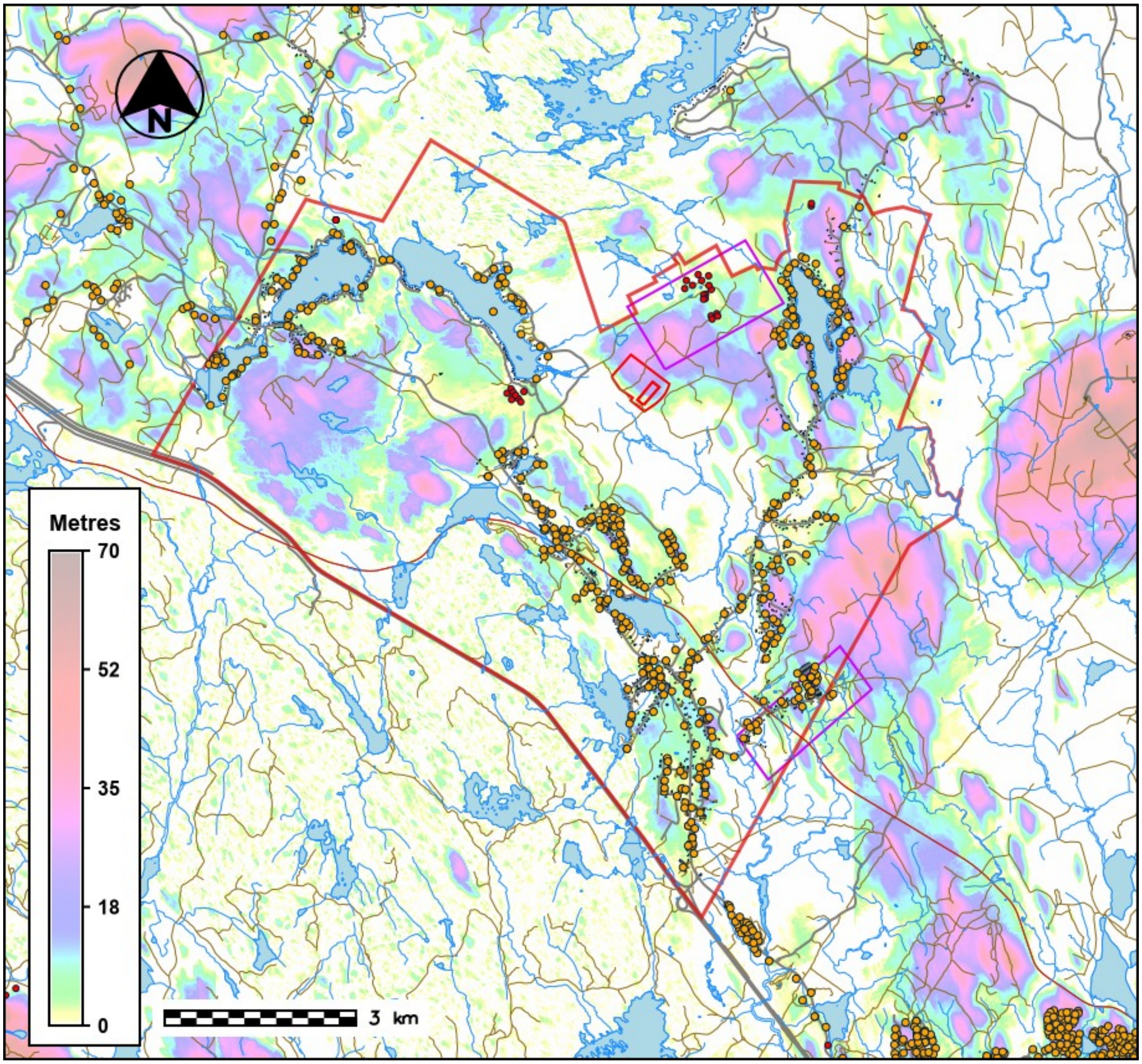

Figure 45: Overburden thickness calculated by subtracting Figure 44 bedrock surface elevation values from Figure 22 ground surface elevation values.

Table 11. Summary of calculated overburden thicknesses within the Uniacke SPS study area.

Thickness (m)	Total area (m^2)	% of study area		Thickness (m)	Total area (m^2)	% of study area
-20 to -10	1,121,910	1.40		25 to 30	1,542,162	1.92
-10 to -5	7,419,121	9.24		30 to 35	1,034,251	1.29
-5 to 0	16,557,551	20.62		35 to 40	693,509	0.86
0 to 5	22,992,653	28.63		40 to 45	493,535	0.61
5 to 10	12,008,725	14.96		45 to 50	207,074	0.26
10 to 15	7,894,728	9.83		50 to 55	91,060	0.11
15 to 20	5,151,546	6.42		55 to 60	67,557	0.08
20 to 25	2,999,212	3.74		60 to 65	23,725	0.03

Table 11 summarizes the relative distribution of overburden thickness greater than zero within the Uniacke SPS study area.

Dug wells are typically excavated to refusal at bedrock or to depths of about 6.7 m (maximum reach of larger excavators), and deeper wells may contain 2 to 4 m of water depth assuming a surficial HU piezometric level 2 to 3 m below ground surface. As such, this suggests that 5 m of unconsolidated Quaternary material with proper saturation depth should satisfy the needs for a dug well. Assuming the presence of surficial material with adequate permeability, adjusting for the bedrock surface elevation interpolation errors as noted above (i.e. values below zero in Table 11), and avoiding elevations too high to obtain saturated soils within excavator reach, then up to 60% of the Uniacke SPS study area may be expected to meet the above criteria for dug wells.

It is interesting to note that some of the bedrock faults as interpreted in Figure 43 from lineament analysis are visible as lineaments also in Figure 45, illustrating that narrow fault-related bedrock valleys have very likely been missed by the bedrock surface elevation interpolation done. Those faults also appear to truncate and/or divide areas with thicker overburden.

8.3.2 Parts of the study area with best estimated potential for dug well success

Dug well construction success is best assured where there is sufficient thickness of high enough permeability Quaternary material at locations with the surface relief is such that excavators are likely to be able to reach those aquifer materials.

Those areas of the Uniacke SPS study area that most likely to meet those Quaternary material lithology, thickness, and ground surface elevation relief conditions, those parts of the study area that are estimated to have the greatest overburden thickness per Figure 45 which also lie within those areas of Figure 42 that contain sandier Beaver River Till, while avoiding drumlin areas due to their likelihood of containing more clays, and also due to their higher elevations where saturated soils may be out of excavator reach. Figure 46 is an overlay map of Figures 42 and 45 that shows what parts of the Uniacke SPS study area meet those combined conditions in consideration of the adjustments as made earlier to account for zero values in Table 11.

Hence, notwithstanding any narrow bedrock valleys that may have been missed during the interpolation of the greater area bedrock surface elevation, based on the green-shaded parts of Figure 46, approximately 40% of the Uniacke SPS study area is conservatively estimated to be able to best meet the conditions for dug well construction success, with the relative degree for that success being represented by the intensity of the green shading in the figure.

There unfortunately is no data available on the quality of the groundwater produced from any of the very few dug wells that are located within this report's Figure areas, or from any dug wells located outside of these Figure areas that are still close enough to be representative of conditions at the Uniacke SPS study area, so readers must refer to and are limited to general introductory paragraphs of this section of the report for knowledge on probable local dug well water quality.

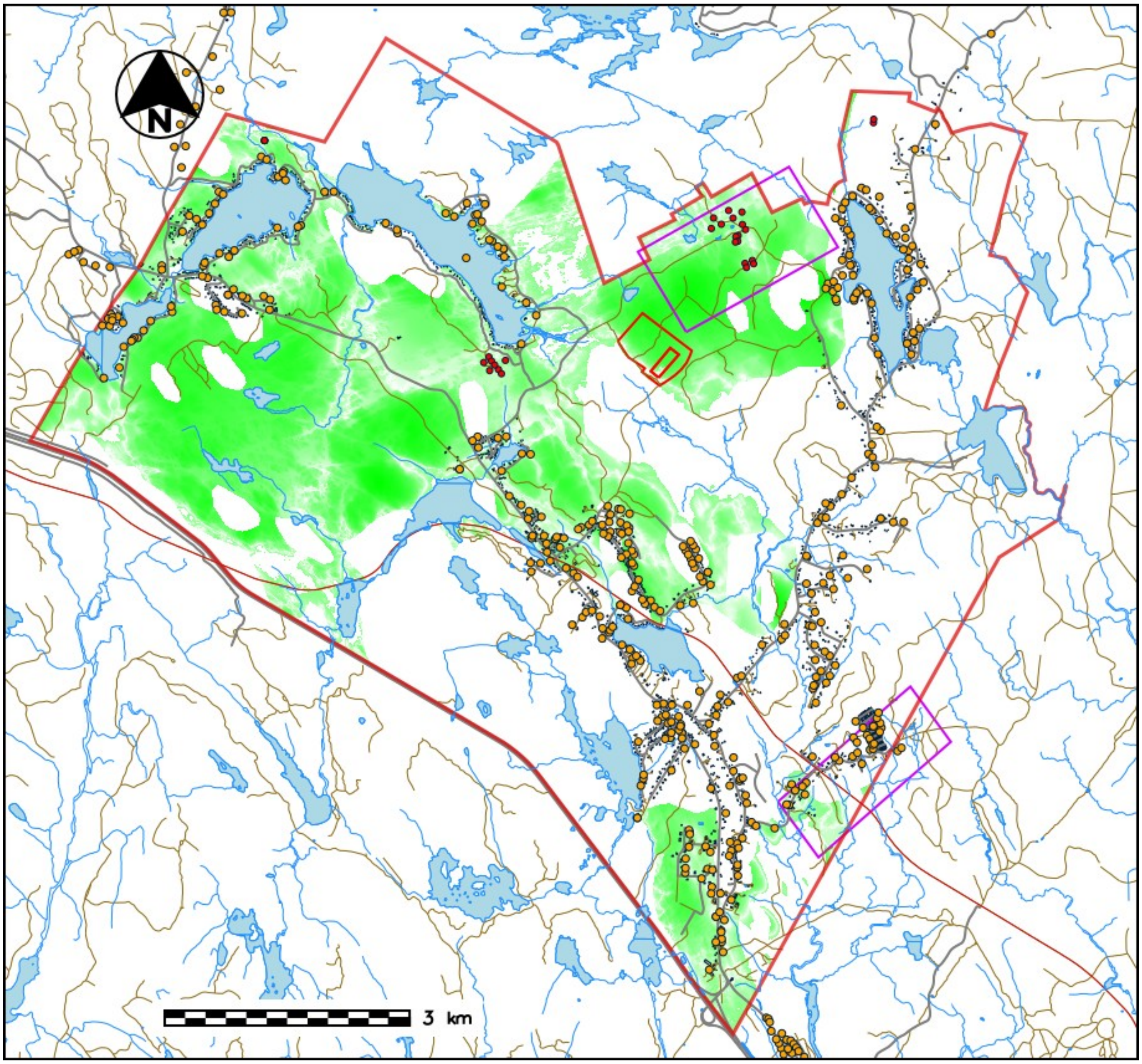

Figure 46: Overlay of Figures 42 and 45 to show areas likely of best dug well construction success within the Uniacke SPS study area.

8.4 Physical hydrogeologic characteristics of the bedrock HUs

This section of the report will first look at the physical hydrogeological and well construction characteristics of the four bedrock HUs within and around the Uniacke SPS study area – well yields, static groundwater levels, well depths and casing lengths, both collectively and individually, as well as groundwater recharge and general well water supply sustainability therefrom, and well interference. Then it looks at well water supply hydrogeochemical characteristics, again both collectively and individually. The levels of coverage detail will by necessity be commensurate with the amounts of relevant data that is available for each HU.

8.4.1 Tabular and graphically map-based summary data presentation

Table 12 provides statistical summary data for key aquifer and well construction characteristics from the Nova Scotia well log database for the 1,516 records drilled wells that plot with better than 1,130 m accuracy within the Figure 43 mapping area (with some errors likely due to wells possibly plotting in bedrock units of non-interest and/or outside of the mapping area), and for the 783 records that plot with better than 125 m accuracy within the Figure 43 mapping area for all bedrock HUs combined and separately for each bedrock HU. Table 13 provides statistical summary data for the same key aquifer and well construction characteristics, but for the 483 wells with better than 125 m UTM accuracy that plot within the Uniacke SPS study area.

Table 12. Statistical summary of key aquifer and drilled bedrock well construction characteristics for wells plotting within the Figure 43 mapping area.

		No. of data records	% of total records	Max.	Min.	Mean	1st quartile	Median	3rd quartile
All HUs, 1,516 wells, 1,130 m accuracy	Well depth (m)	1,502	99.08	196.1	2.7	69.3	45.7	67.0	91.4
	Casing depth (m)	1,356	89.45	73.1	1.1	12.4	6.1	9.4	15.2
	Bedrock depth (m)	1,278	84.30	91.4	0.0	8.5	1.5	4.3	12.2
	Static level (m)	685	45.18	75.8	0.0	8.0	3.0	6.1	9.1
	Yield (LPM)	1,453	95.84	454.0	0.0	17.4	4.5	9.1	18.2
	Yield (LPM/30m)	1,292	85.22	372.1	0.0	16.6	1.9	5.2	16.9
All HUs, 783 wells, 125 m UTM accuracy	Well depth (m)	781	99.74	191.5	13.7	78.9	56.3	76.1	97.4
	Casing depth (m)	701	89.53	46.6	2.4	14.0	6.1	12.2	18.3
	Bedrock depth (m)	680	86.85	42.0	0.0	9.3	1.8	5.2	13.7
	Static level (m)	372	47.51	50.9	0.0	8.0	3.0	6.1	10.2
	Yield (LPM)	762	97.32	454.0	0.0	17.7	4.5	9.1	18.2
	Yield (LPM/30m)	682	87.10	319.6	0.0	14.1	1.6	4.3	13.7
Granodiorite HU, 2 wells, 125 m UTM accuracy	Well depth (m)	2	100	103.5	57.9	80.7	69.3	80.7	92.1
	Casing depth (m)	2	100	13.4	6.1	9.7	7.9	9.7	11.6
	Bedrock depth (m)	2	100	10.7	3.4	7.0	5.2	7.0	8.8
	Static level (m)	1	50	5.5	5.5	5.5	5.5	5.5	5.5
	Yield (LPM)	2	100	5.5	2.3	3.9	3.1	3.9	4.7
	Yield (LPM/30m)	2	100	3.2	0.8	2.0	1.4	2.0	2.6
Glen Brook Formation HU 1 well, 125 m UTM accuracy	Well depth (m)	1	100	109.6	109.6	109.6	109.6	109.6	109.6
	Casing depth (m)	1	100	13.1	13.1	13.1	13.1	13.1	13.1
	Bedrock depth (m)	1	100	8.5	8.5	8.5	8.5	8.5	8.5
	Static level (m)	0	0	--	0.0	--	--	--	--
	Yield (LPM)	1	100	13.6	13.6	13.6	13.6	13.6	13.6
	Yield (LPM/30m)	1	100	4.2	4.2	4.2	4.2	4.2	4.2
Cunard Formation HU 61 wells, 125 m UTM accuracy	Well depth (m)	61	100.00	134.0	30.5	62.5	50.2	60.9	68.5
	Casing depth (m)	59	96.72	41.7	5.2	14.4	6.1	12.2	20.7
	Bedrock depth (m)	56	91.80	39.6	0.0	10.8	2.7	8.1	18.3
	Static level (m)	32	52.46	12.2	0.9	5.6	3.0	6.1	7.6
	Yield (LPM)	60	98.36	181.6	2.3	22.1	6.8	17.0	22.7
	Yield (LPM/30m)	59	96.72	140.9	0.7	17.9	5.4	11.2	23.4

Table 12. Statistical summary of key aquifer and drilled bedrock well construction characteristics for wells plotting within the Figure 43 mapping area.

		No. of data records	% of total records	Max.	Min.	Mean	1st quartile	Median	3rd quartile
Beaverbank Formation HU 87 wells, 125 m UTM accuracy	Well depth (m)	87	100.00	140.7	18.3	74.0	54.8	73.1	91.4
	Casing depth (m)	78	89.66	43.5	5.8	16.8	6.3	12.2	24.3
	Bedrock depth (m)	75	86.21	41.1	0.6	12.2	2.0	7.0	21.5
	Static level (m)	37	42.53	19.8	1.5	6.3	3.0	6.1	9.1
	Yield (LPM)	87	100.00	136.2	1.1	18.3	4.5	9.1	21.6
	Yield (LPM/30m)	78	89.66	223.6	0.3	20.8	1.7	5.3	18.0
Taylors Head Formation HU 632 wells, 125 m UTM accuracy	Well depth (m)	630	99.68	191.5	13.7	81.1	60.9	79.2	101.4
	Casing depth (m)	561	88.77	46.6	2.4	13.5	6.1	12.2	16.8
	Bedrock depth (m)	546	86.39	42.0	0.0	8.8	1.8	4.6	13.1
	Static level (m)	302	47.78	50.9	0.0	8.5	3.0	6.1	11.6
	Yield (LPM)	612	96.84	454.0	0.0	17.2	4.5	8.1	18.2
	Yield (LPM/30m)	542	85.76	319.6	0.0	12.7	1.6	3.7	11.2

Table 13. Statistical summary of key aquifer and drilled bedrock well construction characteristics for wells with 125 m or better UTM accuracy plotting within the Uniacke SPS study area.

		No. of data records	% of total records	Max.	Min.	Mean	1st quartile	Median	3rd quartile
All HUs, 483 wells	Well depth (m)	483	100.00	191.5	13.7	78.2	60.9	79.2	97.4
	Casing depth (m)	437	90.48	38.1	2.4	11.7	6.1	12.2	12.2
	Bedrock depth (m)	418	86.54	35.0	0.0	6.5	1.5	3.4	10.0
	Static level (m)	248	51.35	30.5	0.0	6.9	3.0	6.1	9.1
	Yield (LPM)	473	97.93	227.0	0.5	14.6	4.5	7.7	15.9
	Yield (LPM/30m)	430	89.03	279.6	0.2	11.3	1.5	3.6	11.2
Granodiorite HU, 2 wells	Well depth (m)	2	100	103.5	57.9	80.7	69.3	80.7	92.1
	Casing depth (m)	2	100	13.4	6.1	9.7	7.9	9.7	11.6
	Bedrock depth (m)	2	100	10.7	3.4	7.0	5.2	7.0	8.8
	Static level (m)	1	50	5.5	5.5	5.5	5.5	5.5	5.5
	Yield (LPM)	2	100	5.5	2.3	3.9	3.1	3.9	4.7
	Yield (LPM/30m)	2	100	3.2	0.8	2.0	1.4	2.0	2.6
Cunard Formation HU 29 wells	Well depth (m)	29	100.00	121.8	30.5	63.5	50.2	60.9	74.0
	Casing depth (m)	27	93.10	30.5	5.2	11.3	6.1	10.7	12.2
	Bedrock depth (m)	24	82.76	25.0	0.0	6.4	1.2	3.8	9.1
	Static level (m)	18	62.07	12.2	0.9	4.6	3.0	4.1	6.1
	Yield (LPM)	28	96.55	68.1	2.3	19.2	6.8	17.0	23.8
	Yield (LPM/30m)	27	93.10	52.2	1.4	15.3	5.0	11.2	21.4

Table 13. Statistical summary of key aquifer and drilled bedrock well construction characteristics for wells with 125 m or better UTM accuracy plotting within the Uniacke SPS study area.

		No. of data records	% of total records	Max.	Min.	Mean	1st quartile	Median	3rd quartile
Beaverbank Formation HU 61 wells	Well depth (m)	61	100.00	121.8	18.3	78.4	60.9	80.7	92.3
	Casing depth (m)	53	86.89	27.4	5.8	10.5	6.1	12.2	12.2
	Bedrock depth (m)	50	81.97	25.9	0.6	5.4	1.5	3.0	7.5
	Static level (m)	31	50.82	12.2	1.5	5.3	3.0	4.6	6.1
	Yield (LPM)	61	100.00	136.2	1.1	15.0	4.5	9.1	13.6
	Yield (LPM/30m)	53	86.89	139.8	0.3	10.3	1.4	3.2	7.9
Taylors Head Formation HU 391 wells	Well depth (m)	391	100.00	191.5	13.7	79.3	60.9	79.2	97.4
	Casing depth (m)	355	90.79	38.1	2.4	11.9	6.1	12.2	12.5
	Bedrock depth (m)	342	87.47	35.0	0.0	6.7	1.5	3.4	10.4
	Static level (m)	198	50.64	30.5	0.0	7.4	3.0	6.1	9.1
	Yield (LPM)	382	97.70	227.0	0.5	14.3	4.5	6.8	15.9
	Yield (LPM/30m)	348	89.00	279.6	0.2	11.2	1.5	3.4	10.8

The well yields reported in the Nova Scotia well log database and summarized in Tables 12 and 13 are airlift (or blow) test yields. These are the volumes of water produced per minute that drillers measure using buckets (or very frequently only estimate from water flowing overland) and stopwatches during the well development that is done (to clear debris from wells) following well construction. But these airlift tests are a crude method of evaluating water water volumes wells may be able to produce because they are typically carried out with drilling bits sitting at or very near the bottoms of wells[81], usually for periods of about one hour, which is too short a duration to reliably assess long-term well capabilities. As such, depending on depending on the aquifer and depths to water-bearing zones in wells, multiplying driller airlift test results by 0.50 to 0.75 may help to give a general estimate of possible longer-term well yields.

Another problem with making direct use of airlift testing results in groundwater assessments is that due to the way residential wells are drilled[82] (domestic wells amount to more than 98.42% and 98.34% of the wells represented in Tables 12 and 13), airlift well test results and depths can vary considerably across short distances, making it very difficult if not impossible to properly

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[81] Well pumps are typically placed 3 to 5 m off well bottoms, or higher (mostly for commercial wells where the goal should be to avoid dewatering major water-bearing fractures).

[82] Wells drilled for domestic purposes are drilled at locations that are limited to small property boundaries and are typically advanced only as deep as necessary to yield the necessary volumes of water to meet single residential needs (which NSE (2011) suggests (with no references to justify their number) is 1,350 L/day, or about 1 L/min, although in followup work to ewC (2023a) and in ewC (2024a, 2024c) using Statistics Canada (2021) data, in Nova Scotia a combined industrial/commercial/residential demand of 411 L/day per capita, or a residential-only demand of 215 L/day per capita (860 L/day per home) was found to be more appropriate). As such, they are not drilled to greater depths as would be carried out if the goals were to optimize well yields, as would often be done for commercial wells). So reported airlift test well yields and depths can vary significantly across small distances and are not necessary always representative of local or area aquifer, making it extremely difficult if not impossible to characterize aquifers based on well yield data alone.

characterize and compare hydrostratigraphic units based on airlift well test yield data alone.

Therefore, to help with the subject spatial aquifer analysis, we have normalized reported well yields against well depths in our GIS by calculating well yields per 30 m (100 feet) of open borehole[83] to obtain values of litres per minute per 30 m of open borehole (LPM/30m), which in the absence of any other data are akin to well specific capacity – a measure of yield per metre of drawdown experienced over specific periods of time – which can be more properly compared across the current study areas and between HUs of interest.

The "static level" values in Tables 12 and 13 represent those for non-pumping (natural, stable) water levels as reported in Nova Scotia well log database records[84]. They are of significance in that together with well total depth (TD), they define the amounts of cold-water storage[85] available in wells. Also, together with well yield, static water levels define what the minimum pumping capacity should be for wells to properly meet water demand. Finally, static groundwater levels can change over time: locally as the drawdown created when pumping (ref. Figure 8); seasonally with rises in groundwater levels during rainier springs and autumn and drops in water levels during drier summers; and also over time due to increases in groundwater withdrawals as communities grow (particularly if withdrawal volumes exceed recharge). So static water levels (or their rate of change over time), if measured carefully, may serve as indicators of groundwater recharge and water source/aquifer supply sustainability.

Tables 12 and 13 also show the numbers and percent of total wells for which data are reported so readers can assess the relative statistical reliability of the summaries (i.e. the greater the number of wells represented, the likely the statistically summary is to be correct). Finally, Tables 12 and 13 present the first quartile, median (second quartile) and third quartile values (what the values are at the 25%, middle, and 75% positions within value-ranked data) for each parameter to show the relative significance of the minimum, average and maximum values given.

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[83] Calculated individually for each and every well within the Figure 43 mapping area, regardless of reported UTM location accuracy, by dividing reported airlift test well yields (L/min) by the distance (in metres) from the bottoms of well casings to the total well depths bottoms of wells, then multiplying that value by 30 to obtain values for LPM/30m to represent wells drilled to depths of approximately 110 m with 6 m of casing.

[84] A significant caveat in using most if not nearly all of the static water level values reported in the Nova Scotia well log database is that drillers typically finish drilling, develop wells (drawing water levels to or near the bottoms of wells), then pull drilling rods and leave drilling sites typically within about one hour of completing their airlift yield tests. This gives insufficient time for water levels to properly recover in wells from which to properly measure correct static water levels. Further, most drillers do not have the electronic water level measuring instruments needed to accurately measure depths to the surface of water levels in wells, and frequently guessing those water depths by dropping stones into the wells to time how long it takes to hear the "plopping sound" they produce when hitting the water surface. As such, they serve only as a crude (and often incorrect) interpretation of static water levels – only static water levels reported from pumping test should be considered to be accurate.

[85] The amount of water kept in storage (available for pumping) in lower-yielding wells from the recharging of whose wells overnight when water demands are reduced.

8.4.2 Well construction cost related factors – Bedrock, casing and well depths

The ranges of bedrock depths, well casing[86] lengths, and well depths within and around the Uniacke SPS study area are summarized in Tables 12 and 13.

Comparing the first two sections of Table 12 shows that in the subset of 783 wells for which locations were reported with better than 125 m accuracy, well depths and casing lengths are generally slightly greater than for the 1,516 lot of wells with lesser location accuracy. This could be a function of well ages, since casual observations suggest that drillers are advancing wells a bit deeper today than in the past. Also, the reported bedrock depths are generally greater for the subset of 783 wells than they are for the larger dataset.

In terms of wells plotting as having been drilled into the individual bedrock HUs that are common to the Figure 43 mapping area and the Uniacke SPS study area, wells drilled into the Cunard Formation HU are generally shallowest, followed by those drilled into the Beaverbank Formation, which are generally 11 m to 15 m deeper, with wells drilled into the Taylors Head Formation HU being generally deepest (7 m to 1 m deep still).

However, there appears to be more commercial wells drilled into the Taylors Head Formation HU. Casing lengths appear to be greater generally for wells that plot as having been drilled into the Beaverbank Formation HU than for wells plotting in the other two HUs within the Figure 43 mapping area, with the reverse appearing to be the case for wells located within the smaller Uniacke SPS study area.

Casing lengths, and by extension, total well depths, may be a function of overburden thickness, rather than bedrock HU characteristics (except perhaps due to bedrock erodibility by glaciers). Casing lengths may also be a function of the thickness of the weathered/fractured zone at bedrock surfaces, into which well casings should be, and often are advanced to greater depths into the bedrock to help keep surface contaminants out of the open borehole sections of wells.

To help assess these two characteristics as a part of the process to better understanding the different study area bedrock HUs, the same raw data used to obtain the mean and median values in Tables 12 and 13 for casing length were subtracted from bedrock depths to assess possible differences in shallow bedrock HU weathering/fracturing, and the raw data used to obtain the mean and median values for total well depth were subtracted from casing lengths to help

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[86] Well casings are used to hold back overburden to prevent it falling into wells, and also to seal the open bedrock portion of wells from the surface and possible related contaminants. Also, well casings are used to seal off water from shallow heavily fractured bedrock that could likewise contain surface water and contaminants, either as recharge through soil or along broken bedrock surfaces then along the outside of casings into the sections of open borehole. Drillers are required install a minimum of 6.1 m of casing in wells drilled for residential purposes (a minimum of 12.2 m of casing is needed for municipal water supply wells), and to seal casings with bentonite (montmorillonite clay) – a phyllosilicate mineral, chemical formula $(Na,Ca)_{0.33}(Al,Mg)_2(Si_4O_{10})(OH)_2{\cdot}nH_2O$ – a low permeability material with high swelling index and good void filling capacity (also used in the drilling industry as a component of drilling mud, in cosmetics, in landfills, pet foods, and for fining wine).

compare the amounts of open borehole in wells[87] within each of the three bedrock HUs that are common to the Figure 43 and Uniacke SPS study areas. Table 14 summarizes those results.

Table 14. Mean and median lengths of well casing penetration into bedrock and of open borehole below casings as calculated from the Table 12 and 13 data for the Figure 43 and Uniacke SPS study areas for wells with 125 m or better UTM accuracy.

Hydrostratigraphic Unit	Area of consideration	Well casing penetration depths into bedrock (m)		Lengths of well open borehole (m)	
		Mean	Median	Mean	Median
All HUs	Figure 43 mapping area	4.8	4.1	63.0	60.9
	Uniacke SPS study area	5.1	4.6	66.0	67.0
Cunard Formation HU	Figure 43 mapping area	3.8	3.1	46.7	44.2
	Uniacke SPS study area	4.9	4.7	49.5	48.7
Beaverbank Formation HU	Figure 43 mapping area	4.8	4.3	56.7	54.8
	Uniacke SPS study area	5.0	4.3	67.3	69.1
Taylors Head Formation HU	Figure 43 mapping area	4.9	4.3	65.4	65.5
	Uniacke SPS study area	5.2	4.6	67.0	67.0

The data in Table 14 suggests that casing penetration depths into bedrock and open borehole lengths are generally greater within the Uniacke SPS study area than in the overall Figure 43 mapping area, except for open borehole length in the Taylors Head Formation HU, which are the same in both areas. The data in Table 14 also suggests a generally thicker shallow bedrock weathering/fracturing zone in the Taylors Head Formation HU than the other two HUs, although the differences within the Uniacke SPS study area are not large, but with a higher median value for wells plotting as being in the Beaverbank Formation HU within the Uniacke SPS study area.

Finally, the data in Table 14 for the Figure 43 mapping area shows progressively increasing open borehole lengths for wells in the Cunard, Beaverbank and Taylors Head Formation HUs, respectively, whereas within the Uniacke SPS study area, open borehole lengths are similar within the Beaverbank and Taylors Head Formation HUs, both of which are greater that for wells in the Cunard Formation HU. This suggests that more water-bearing fractures, and/or (at first glance) better developed water-bearing fractures may have been encountered at shallower depths in wells drilled into the Cunard Formation, than in the other two bedrock HUs.

That being said, while somewhat similar trends between bedrock HUs appear in the mean and median values for well yield and for LPM/30m for both the Figure 43 and Uniacke SPS study areas, the maximum values, and to a lesser degree the 3rd quartile values for well yield and LPM/30m suggest that whose water bearing fractures that are better may be much better within the Taylors Head Formation HU, than in the other two bedrock HUs. This makes sense as relates to the greater competence anticipated of the Taylors Head Formation greywacke – where bedrock

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[87] Noting that wells drilled for domestic purposes are generally advanced only to the depths necessary to obtain adequate yields to meet average single home residential needs.

fracture apertures should be expected to be larger and more consistently open, and over generally greater length, than would be expected within the generally softer, less competent metamorphosed siltstones and slates of the Beaverbank and Cunard Formations, where greater chance of fine-material smearing would be expected within faults and fracture zones in these latter two bedrock formations.

This was also confirmed from down-hole video camera inspections of wells at the Valley Gate Mobile Home Park, where fractures (albeit fewer in numbers in the fracture per metre scale) in production wells drilled into greywacke of the Taylors Head Formation were observed to be intact and highly water-bearing, whereas one of the exploratory test wells drilled into the Beaverbank Formation, which intercepted a known bedrock fault that had also been mapped years before in former mines within the Mobile Park, was found to be very highly fractured (fractures in the cm scale, with rock fragments falling off the borehole walls onto the video camera) was able to yield only less than 1 L/min.

There is unfortunately not sufficient data on the granodiorite HU to assess its characteristics.

Graphical spatial representation and analysis of the bedrock HU physical hydrogeologic characteristics within the Uniacke SPS study area

Figure 45 in Section 8.3.1, which was produced to show the overall spatial distribution of overburden thickness in terms of the potential for constructing dug wells within the Uniacke SPS study area, also characterizes bedrock depths at and around the study area.

To help further illustrate/understand physical bedrock HU characteristics and help identify well construction needs – and thus give insight on likely cost ranges for new well construction – Figure 47, 48 and 49 were produced to show the spacial distributions of study area bedrock depths, well casing lengths, and total well depths, respectively.

These maps were interpolated[88] directly from the same well log data from wells with 125 m and better location accuracy as was used to produce Figure 45 and Tables 12 and 13, but without any of the adjustments for surface topography, as that level of detail isn't necessary for what follows.

Figure 45 can be used to help evaluate possible casing lengths (and thus casing material costs) in relatively highly granular fashion across the Uniacke SPS study area, recognizing that well casings often need to be advanced only short distances into competent (non-weathered, non-

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[88] Figures 47, 48 and 49 were interpolated using data with better than 125 m location accuracy (no drillhole data used) and the GRASS GIS v.surf.rst module to produce 5m x 5m raster maps by spatial approximation analysis using point data to floating-point raster format by regularized spline interpolation with a tension value of 50, a min. of distance of 40 m along splines, smoothing of 0.1 (minor variances to suit source data ranges) with no anisotropy. All data points across the Figure 43 mapping area were used for computation, but to reduce process times and keep maps relevant to project scope, the Uniacke SPS study area was used as a "mask" to record results. The r.contour module was used to produce contour lines with intervals selected pending raster values.

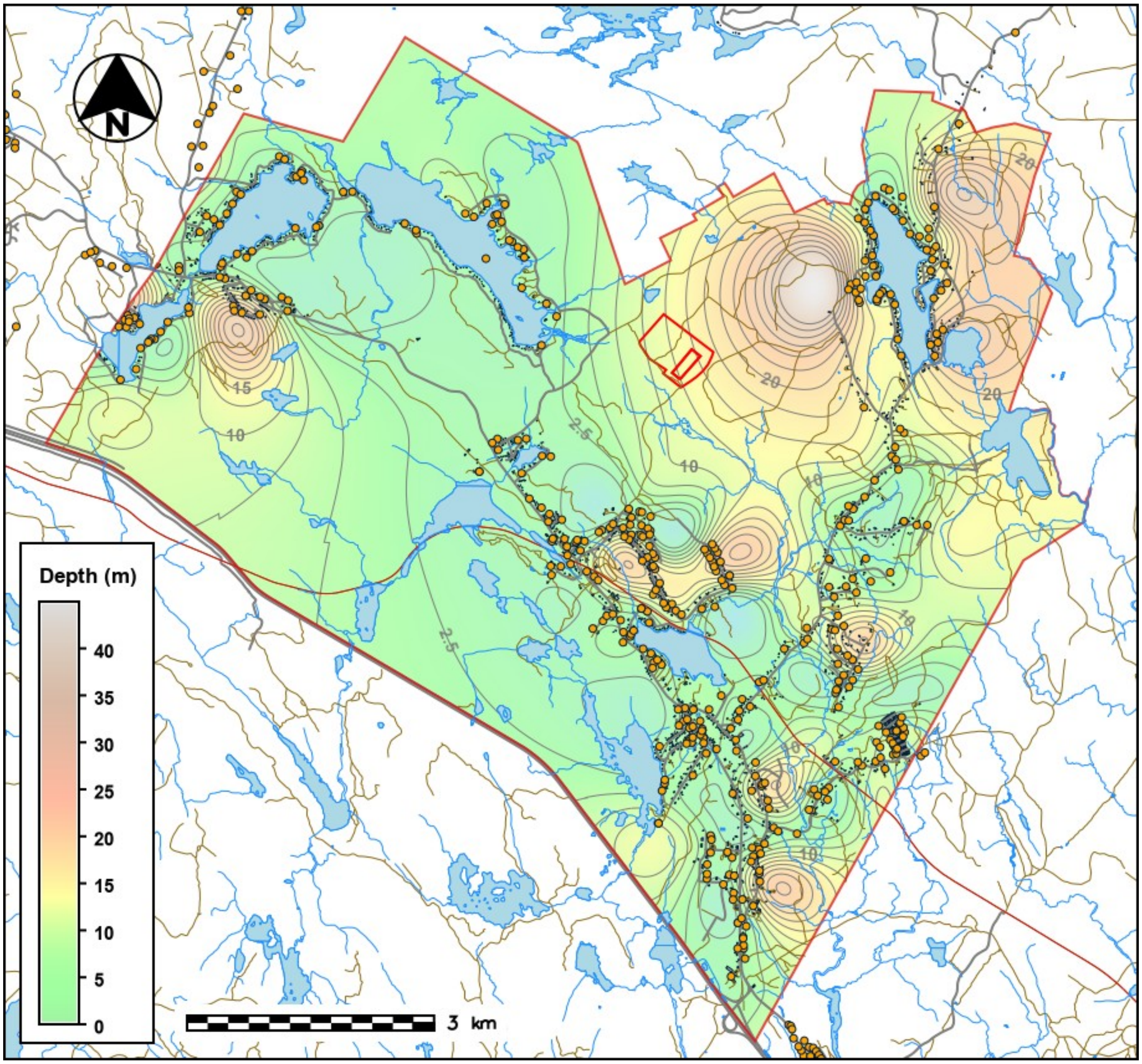

Figure 47: Bedrock depths (contour interval 2.5 m) as interpolated from raw data for wells with better than 125 m location accuracy.

fractured) bedrock. However, as was noted earlier, where the upper part of the bedrock is weathered and/or fractured well casings should be, and often are advanced to greater depths into the bedrock to help keep surface contaminants out of the open borehole.

To help evaluate that particular bedrock HU characteristic across the study area, as was done for Table 14, the raw data used to interpolate the bedrock depth raster values in Figure 47 were subtracted from the data used to produce Figure 48 casing length raster values, to produce Figure 50[89], which shows the spatial distribution and thickness of what likely represents poorer integrity upper-zone bedrock across the Uniacke SPS study area, and also of the extra casing lengths (and

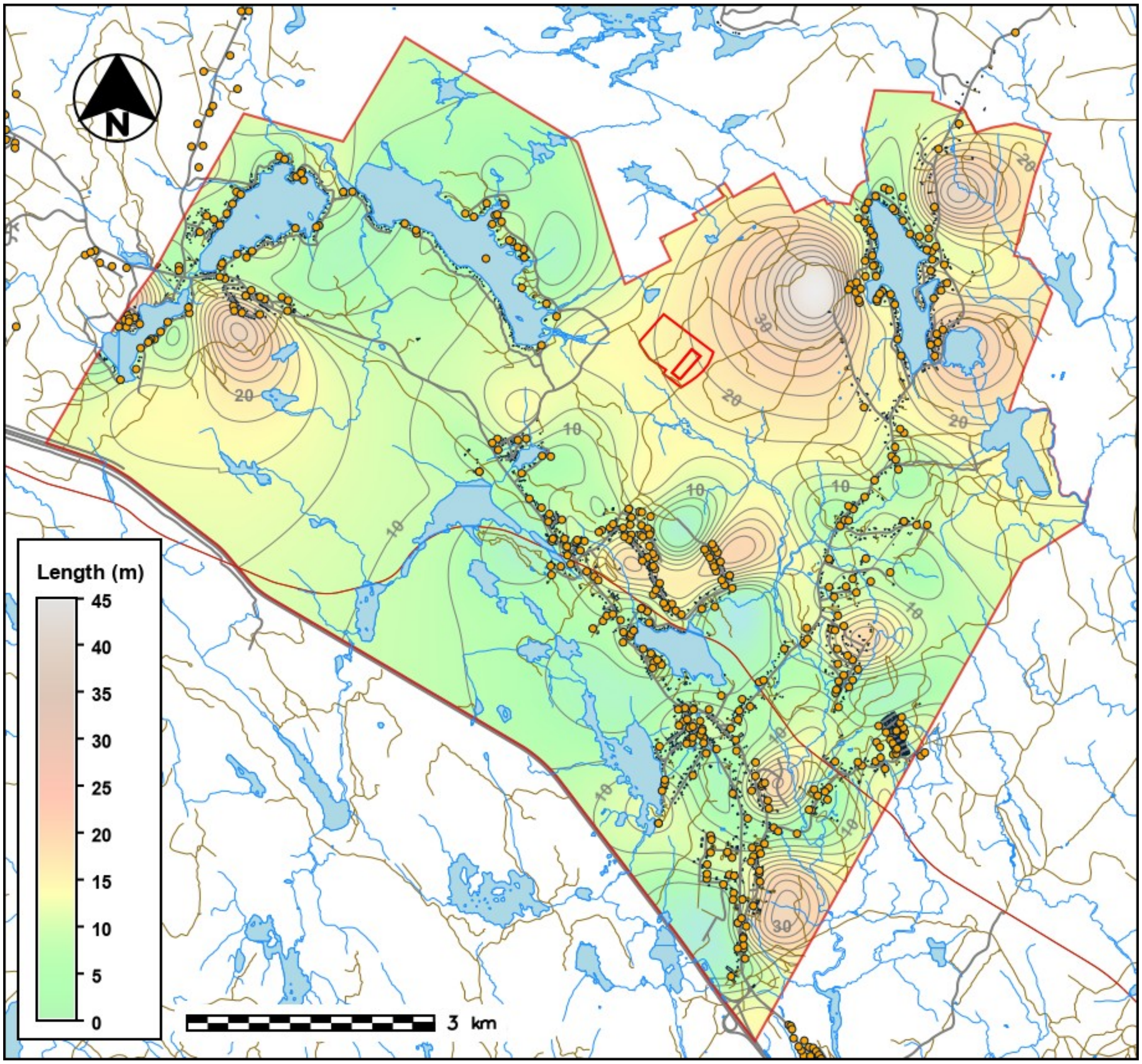

Figure 48: Casing lengths (contour interval 2.5 m) as interpolated from raw data for wells with better than 125 m location accuracy.

thus also increased ranges of cost) that may be deduced from Figure 45 alone.

Likewise, data used to interpolate casing length raster values in Figure 48 were subtracted from data used to produce Figure 49 to create Figure 51[89], which shows the spacial distribution and lengths of open borehole in wells. Since for residential wells the amount of open borehole in wells is generally related to well yield, then Figure 51 may also help to visually conceptualize possible HU well yield capacity as was discussed above regarding the data in Table 14.

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[89] Figures 50 and 51 were produced in the same manner as Figures 47 to 49, using the same general v.surf.rst parameter values to generate these raster maps, with contours generated from those raster values.

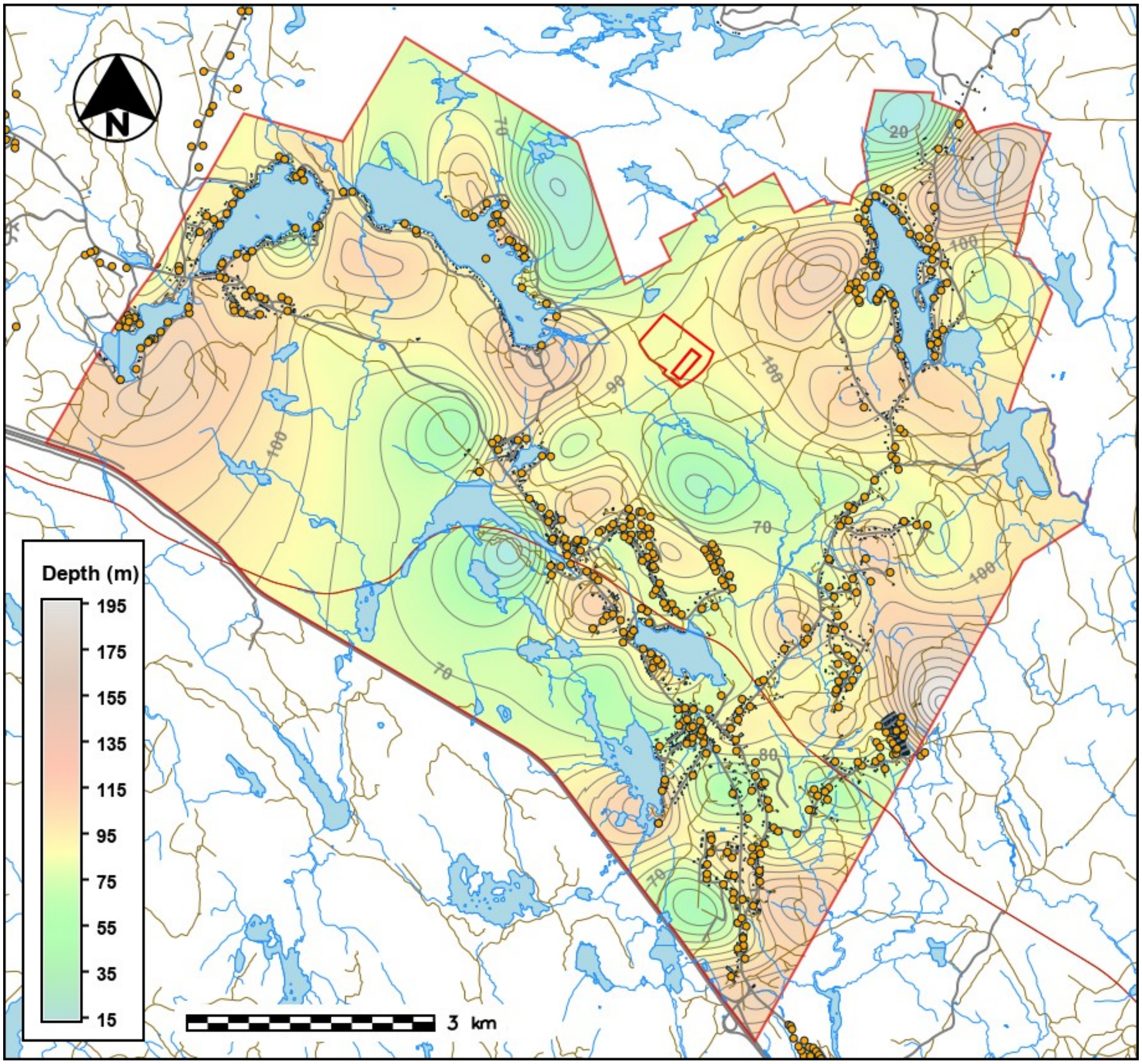

Figure 49: Total well depths (contour interval 10 m) as interpolated from raw data for wells with better than 125 m location accuracy.

There is an apparent general correlation between the thicker weathered/fractured bedrock zones shown in Figure 50 to possible faulted areas as identified from lineaments and shown in Figure 39. However, the areas with greater casing penetration into bedrock also roughly contradictorily coincide with areas shown in Figure 48 to have shorter casing lengths, and also somewhat with areas with less overburden thickness as shown in Figure 44, so the thicker possible weathering that is suggested by greater casing penetration into bedrock may instead, or also be associated with fresh groundwater recharge chemical interactions.

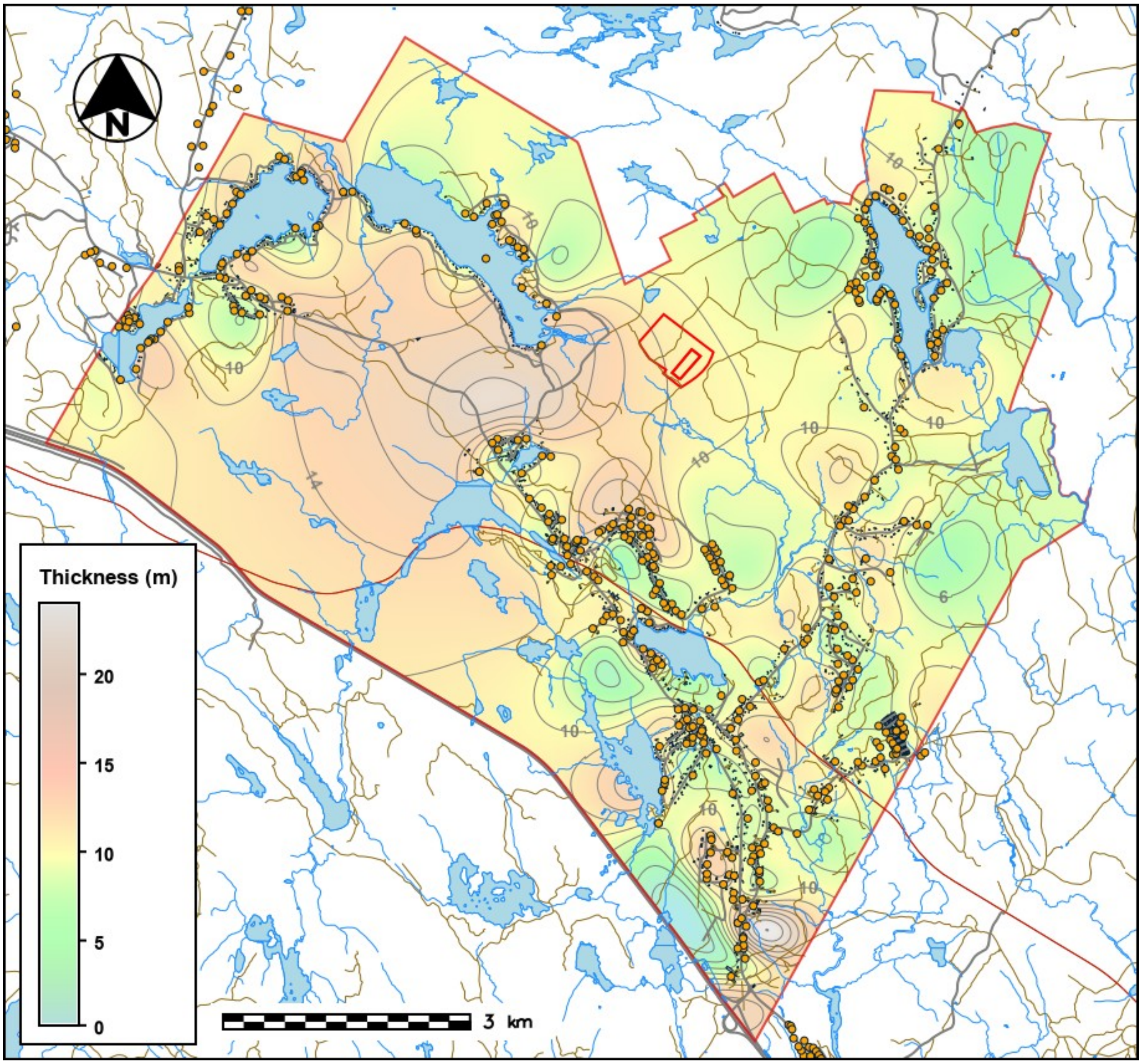

Figure 50: Thickness of shallow bedrock surface weathering/fracture zones (contour interval 2 m) as estimated from calculated well casing penetration depths into bedrock and interpolated using values from raw data for wells with better than 125 m location accuracy.

Bedrock well construction costs

Based on the data presented in Tables 12 and 13 and in the maps in Figures 48 and 49, to meet typical residential water needs, assuming a cost of $115 to $150 per metre for 150 mm diameter wells for both well casing materials, labour and equipment for drilling (ranges of summer/fall 2024 cost estimates obtained from drillers for other assignments), and casing shoes, well caps and well grouting, then wells drilled in the southwest central parts of the Uniacke SPS study area may be expected to cost $5,800 to $13,800 at the lower price ranges, and $7,400 to $17,800 at

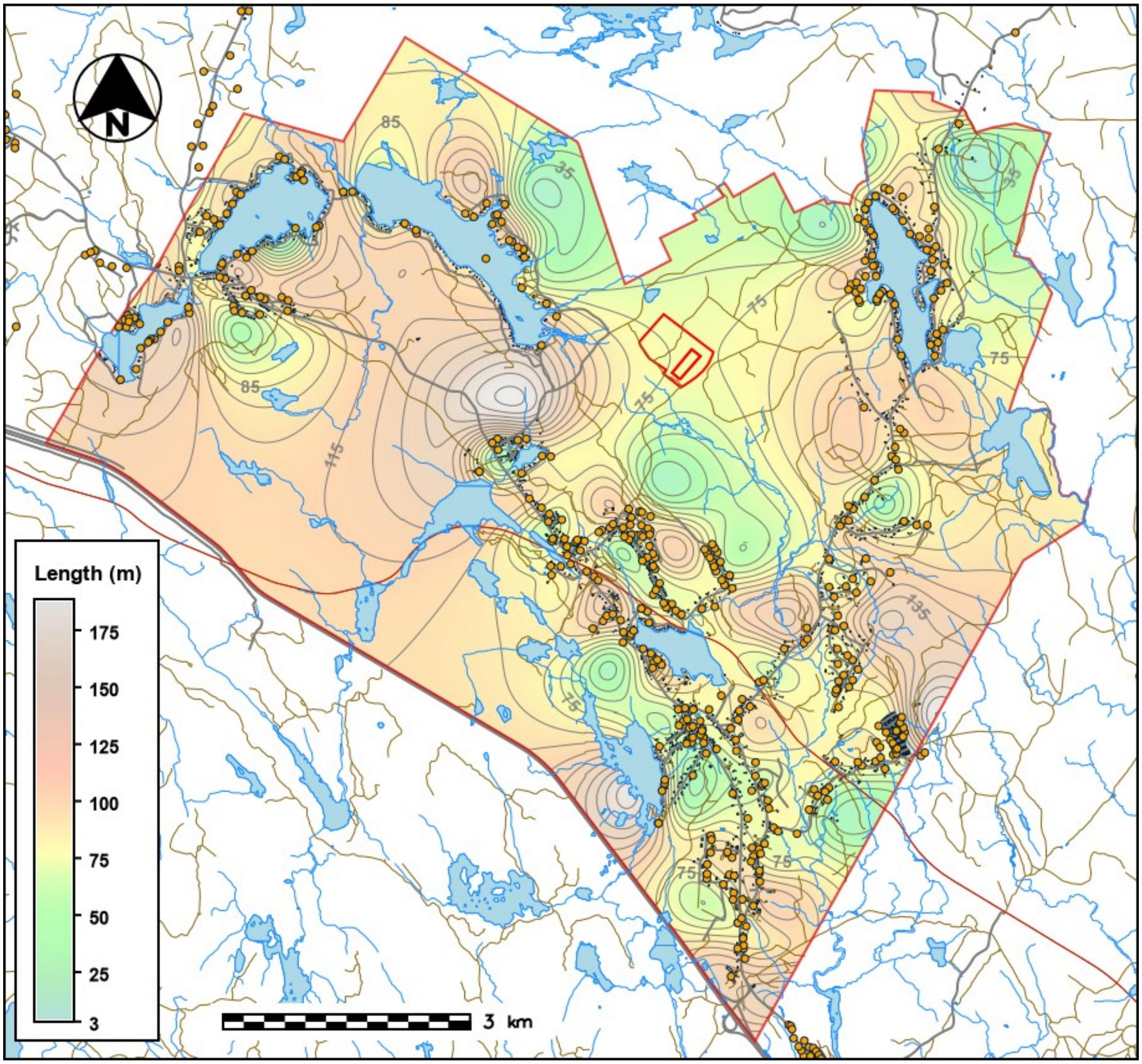

Figure 51: Open borehole lengths (contour interval 10 m) as calculated and interpolated from raw data from wells with better than 125 m location accuracy.

the higher price ranges before costs for pitless adapter, pump installations and indoor systems.

Wells that are drilled in the western, northern and eastern-southeastern boundary parts of the Uniacke SPS study area, particularly in areas with drumlins, would cost more to construct due greater well depths and casing lengths needed, and may in general be expected to cost $13,800 to $20,700 at the lower price ranges, and$17,800 to $26,800 at the higher price ranges before costs for pitless adapter, pump installations and indoor systems.

Readers must note that the drilling depths reported in the well log databases and as shown in the figures above are based on constructing wells to meet water needs within an existing community, with existing well interference and static well water levels. Development and increasing population density will increase aquifer stresses, which could lower groundwater levels in existing wells, such that they may need to be deepened to compensate for possible well interference issues (there is more discussion on this later in this report).

8.4.3 Aquifer confinement

As regards aquifer confinement, the Cunard, Beaverbank and Taylors Head Formation HUs are frequently exposed or buried under only relatively very thin overburden veneers within much of the Meguma Terrane, and as such, these bedrock HUs are typically not viewed as being confined, although exceptions may exist where they deeply buried.

That being said, static well water levels (see Section 9.1) are often found to be much shallower than the first occurrence depths of finding any water-bearing fractures, than the depending upon their depths and lateral and vertical continuity, those water-bearing fractures often respond during pumping tests as being confined. However, that can vary from location to location within the Meguma Terrane.

The bedrock HUs beneath the Uniacke SPS study area may be subject to either of the above, depending on location within the study area. Of the 16 pumping test data available within the Uniacke SPS study area, only one record reports storativity (see Section 9.3) – for one of the production wells serving the Valley Gate Mobile Home Park, and that storativity value (Freeze and Cherry, 1979) suggests that the water-bearing fractures in that well are likely confined. More details are provided in Section 9.3.

There may be many more occurrences of HUs being confined within the Uniacke SPS study area and environs, as indicated by some of the area wells being reported as being flowing wells, and based on groundwater levels reported and mapped and viewed in cross-section across the study area (see Figures in Section 9.1.1).

9.0 Uniacke SPS study area well yields

This section of the report considers the key parameters that can affect well yields for existing and/or possible future well owners. These include:

- static groundwater levels and available well cold-water storage,
- individual well yields as defined from well development airlift yield testing by drillers,
- general aquifer capability as defined from pumping tests,
- estimates of aquifer groundwater storage,
- estimates of the aquifer replenishment by recharge from the surface and from precipitation, and
- issues relating to well interference from pumping many wells together within relatively densely populated parts of any community.

These are each covered in the following sections.

9.1 Static groundwater levels and well cold-water storage

Static groundwater levels are the depths at which the groundwater surface in wells will stabilize under non-pumping conditions (of note: they are the least reported parameter, and thus the parameter with the lowest level of confidence in Tables 12 and 13). They are of significance in that together with well total depth (TD), they define the amount of cold-water storage available in wells. Also, together with well yield (see Sections 9.2 and 9.3), static water levels also define what well pumping capacities should be for wells to properly satisfy water demand. Table 15, which is copied directly from NSE (2011) (the source for their suggested residential 1,350 L/day unknown and is debatable – more on that later), gives an example of those needs.

Table 15. Examples of wells that meet a water supply target of 1,350 L/day.

Well depth (m)	Minimum well yield (L/min)
20 (66 ft)	10.6 (2.3 igpm)
40 (131 ft)	9.1 (2.0 igpm)
60 (197 ft)	7.6 (1.7 igpm)
80 (262 ft)	6.1 (1.3 igpm)
100 (328 ft) and deeper	4.6 (1.0 igpm)

Finally, static groundwater levels can change over time, seasonally, and also over time with water withdrawals (especially if withdrawal volumes exceed recharge). So static water levels (or their rate of change over time), if measured carefully, may serve as indicators of groundwater source/aquifer sustainability.

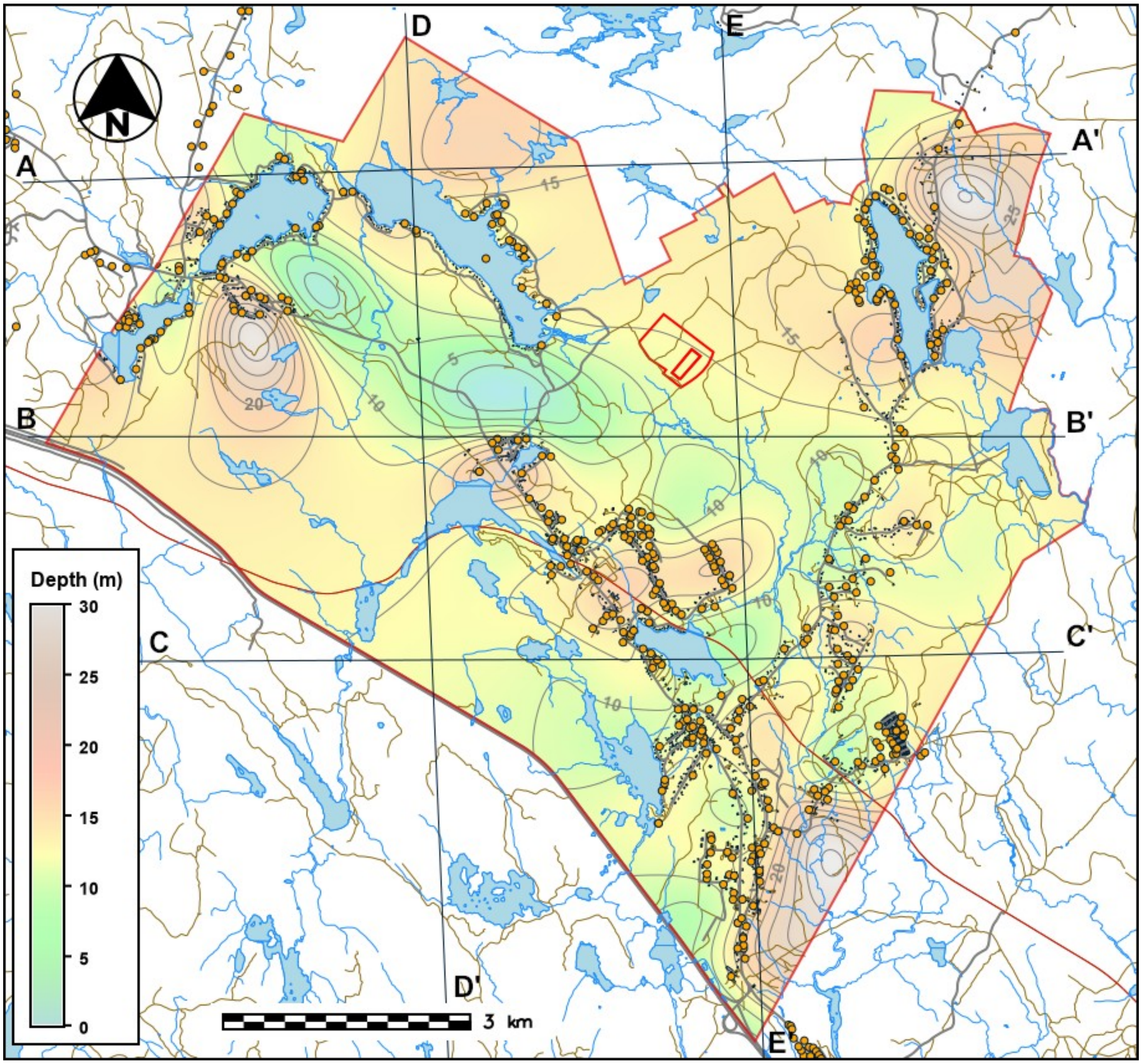

Figure 52: Static groundwater level depths (contour intervals 2.5 m) as calculated and interpolated from raw data from wells with better than 125 m location accuracy, also showing Figure 53 cross-section locations.

9.1.1 Static groundwater levels

Figure 52[90] shows the spatial distribution of static groundwater (piezometric) depths as reported for wells with better than 125 m location accuracy across the Uniacke SPS study area. From

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[90] Interpolated using data from wells with better than 125 m location accuracy and GRASS GIS v.surf.rst module as for earlier maps, but due to data sparsity requiring a tension value of 150 and smoothing of 0.006. All 372 available data points across the Figure 43 mapping area were used for computation, but to reduce process times and keep Figure 52 relevant to project scope, the Uniacke SPS study area (which contains only 248 data points was used as a "mask" to record results. Again, the r.contour module was used to produce contour lines.

Table 13, static groundwater levels within the Uniacke SPS study area range from zero (flowing well conditions, an example is shown in Figure 5) to 30.5 m (average 6.9 m, from 248 wells with such data). It must be noted that, assuming good casing seals in wells, these would represent bedrock HU piezometric levels, which depending on the levels of hydraulic communication between HUs may be different than the piezometric levels within the overlying overburden.

The maximum reported static groundwater level depth is 12.2 for wells drilled into the Cunard and Beaverbank Formation HUs (averages of 4.6 m and 5.3 m, respectively), with no flowing well (artesian) conditions reported in either of these two bedrock HUs. The maximum and average static groundwater depths in wells drilled into the Taylors Head Formation HU are 30.5 m and 7.4 m, respectively, with flowing conditions reported for only 4 of the 198 well records with static water level information.

With a few exceptions, groundwater levels generally follow ground surface topography, but in a somewhat subdued manner due, which will vary based on overall HU permeability. So due to the subdued nature of the groundwater surface topography (or piezometric level) relative to surface topography, as can be clearly seen when comparing Figure 52 to the study area’s ground surface topography in Figure 22, actual groundwater level depths are generally greater where surface topography is highest (in the west and northern parts of the study area) and shallower where ground surface topography is lowest (central portions of the Uniacke SPS study area). The cross-sections presented in Figures 53 and 54 help to illustrate this.

In Figure 53, the blank in cross-section AA’ is a function of no groundwater (piezometric) level extrapolation data being available in that part of the Figure 52 mapping area (the blank part of the cross-section lies outside of the Uniacke SPS study area). It must be noted also that the piezometric elevations shown in both Figures 53 and 54 are interpolated approximations[90] based on a combination of clumped (closely spaced) and very sparse (only 372 data values overall, 248 within the Uniacke SPS study area) and widely spaced data, and that due to the rubber-banding effect of the GRASS GIS v.surf.rst module interpolations where no data exists, some of the piezometric elevations may be shown as being above both the bedrock and the ground surfaces.

Piezometric levels as signs of possible confined HU and recharge/discharge conditions

Having stated what is said in the last paragraph above, however, it is entirely possible for piezometric surfaces to be above both the tops of HU surfaces and the ground surface (ref. Figure 5 in Section 2.3 of this report), where either HUs in their entirety, or the water-bearing fractures encountered within them (more likely to be the case within the Uniacke SPS study area and environs), are confined.

Such conditions are clearly exemplified by the four wells that are drilled within the Taylors Head Formation HU which have been reported to be flowing (i.e. piezometric surfaces above the ground surface).

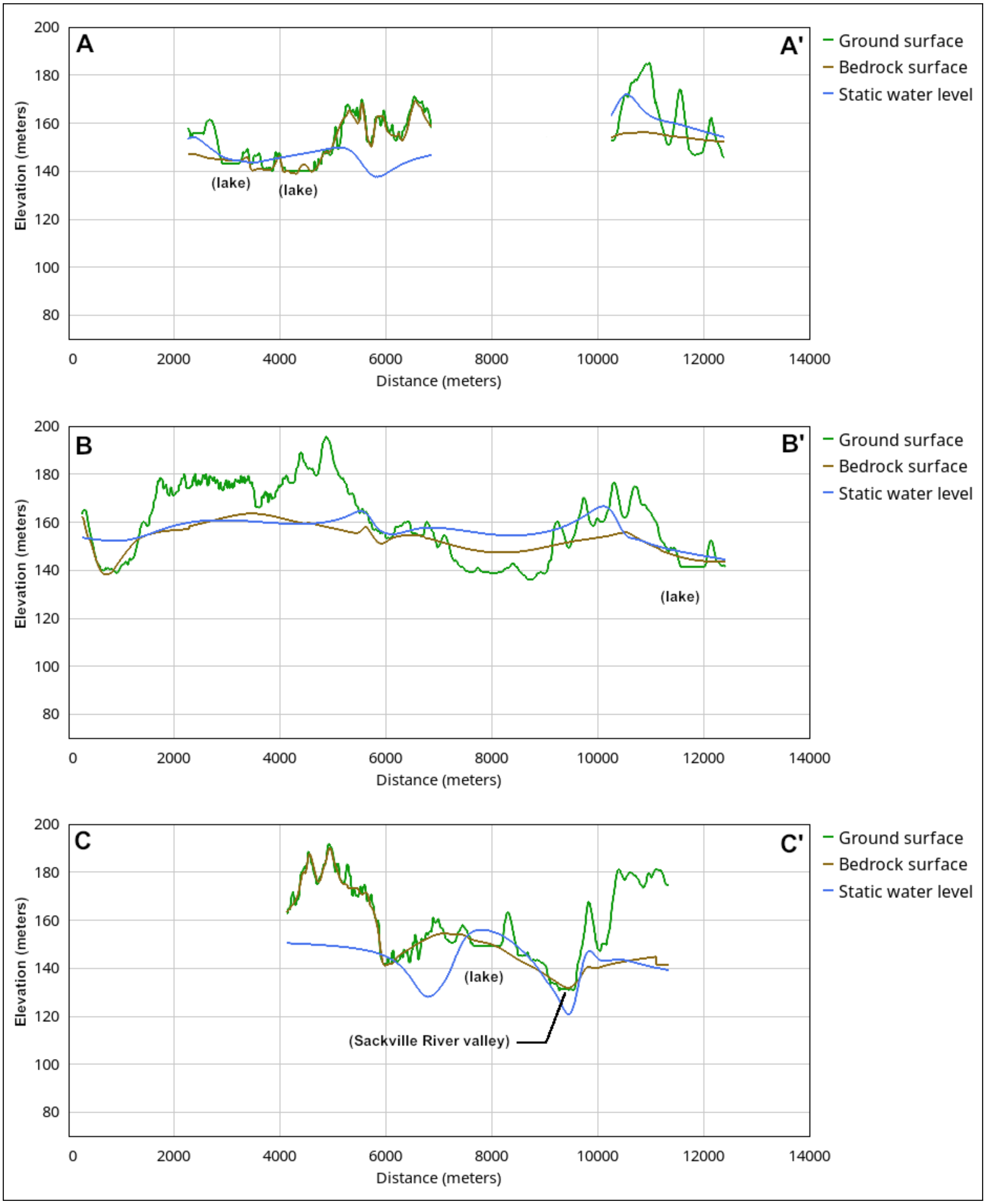

Figure 53: East to west cross-sections AA', BB' and CC' showing the interpolated ground surface, bedrock surface and groundwater (piezometric) elevations (CGVD2013) across the Uniacke SPS study area.

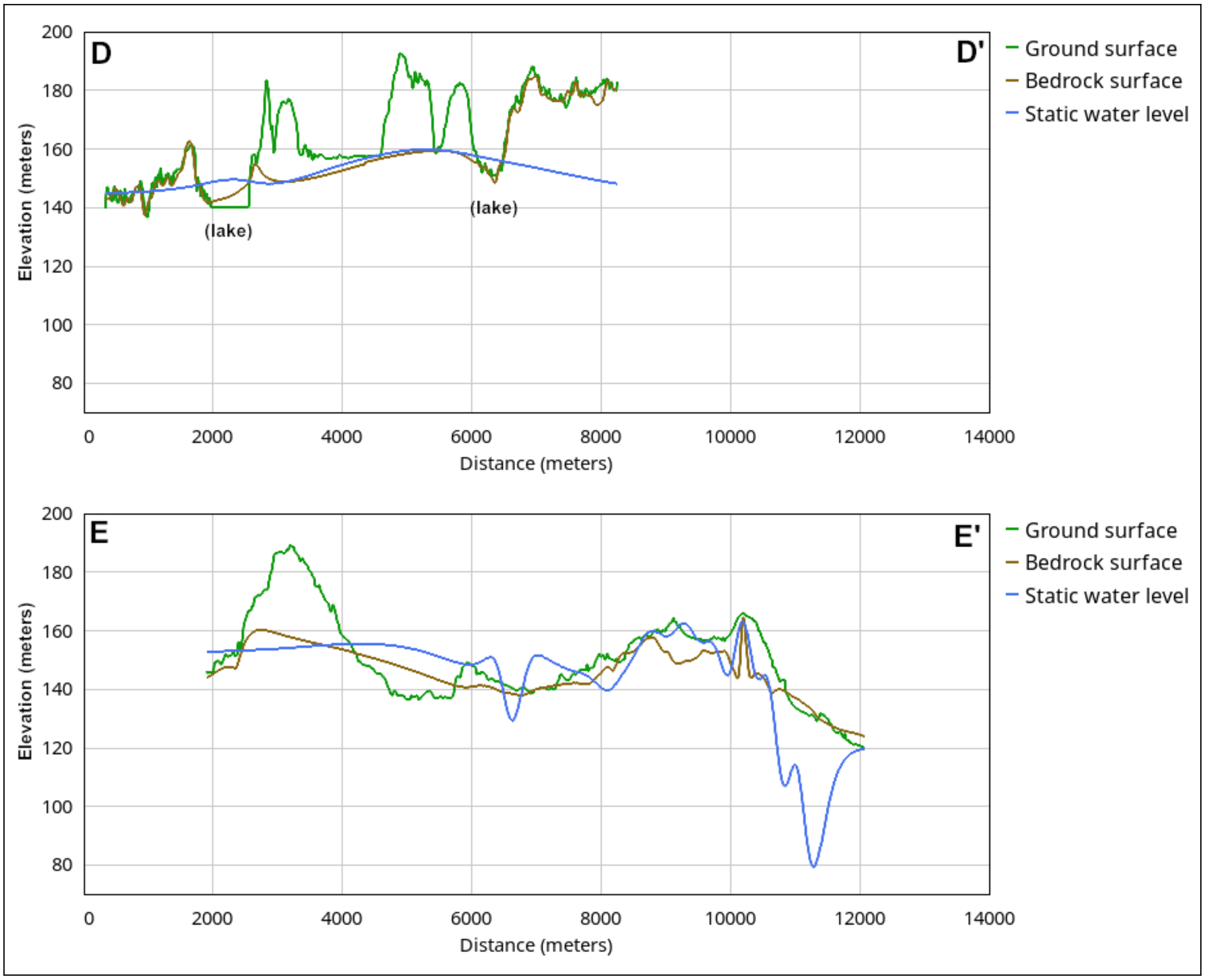

Figure 54: North to south cross-sections DD' and EE' showing the interpolated ground surface, bedrock surface and groundwater (piezometric) elevations (CGVD2013) across the Uniacke SPS study area.

In areas with steep, deep and narrow bedrock surface valleys, bedrock HU piezometric elevations may often be above those lower-elevation bedrock surface elevations.

And in areas with low surface topography, both bedrock and overburden groundwater piezometric levels may be above ground surface. Such examples include the four wells noted above that were drilled into the Taylors Head Formation HU and reported to be flowing. Also, many if not all of the lakes located within the Uniacke SPS study area (labelled as such and shown as flat areas in cross-sections AA’ to DD’ in Figures 53 and 54 – note also where bedrock surfaces area extrapolated to be very near ground surfaces) are locations where the bedrock HU piezometric surfaces are above their respective bedrock surfaces – the lakes within the Uniacke SPS study area in essence all act as “windows onto the groundwater piezometric surface”.

As such, based on the cross-sections in Figures 53 and 54, Pigott, Cockscomb, Uniacke and Nicholson Lakes and likely some if not most of their inlet tributaries and outlet streams represent local groundwater discharge areas, where groundwater from the underlying bedrock HUs (which piezometric levels are above those lake bottom elevations) serves as the baseflow (versus flash flow, which occurs as surface water supply from precipitaiton) to and likely a large percentage of the total water supply available to feed those lakes, particularly during dryer times.

Conversely, Pentz Lake and the parts of the Sackville River and most of its tributaries that flow within the Uniacke SPS study area are groundwater recharge areas – notably, areas where the stream and river bottom elevations appear to be “above” the groundwater piezometric elevations in those areas, such that water may “leak” from those streams and the Sackville River to help recharge the underlying bedrock (and perhaps partly the overburden) HUs.

9.1.2 Groundwater level fluctuations over time

Having noted the causes for piezometric level inaccuracies for Figures 52 to 54, static water levels are never “static”, but vary over time, by significant amounts at certain times and locations, depending on local topography, aquifer depth, time of year versus availability of precipitation and groundwater recharge, pumping at nearby wells, among other causes.

As such, static groundwater levels at individual wells should be expected to vary and fluctuate naturally both seasonally, and from year to year, depending on the amounts of precipitation received, on how much of that precipitation becomes groundwater as recharge during any particular water year, and during in antecedent years over greater periods of time.

As well, groundwater levels may be made to drop over time, sometimes significantly, as growing groundwater withdrawals from increasing and widespread well water use in densely populated areas may create stresses on aquifers, particularly if withdrawals exceed groundwater recharge, as communities age.

To help define what those seasonal and annual groundwater fluctuations are, Nova Scotia Environment has reinstated its groundwater elevation observation well network (NSE, 2022), and nearly continuous recent data plus some historic data are available from most of their network system wells. The nearest network observation wells completed in Goldenville Group formations, however, are located quite some distance from the site, at Lawrencetown (network well 043) and at Musquodoboit Harbour (network well 078).

Figure 55 shows the historic high and low groundwater levels for them for the periods 1978 to the end of 2020 and 2008 to the end of 2020, respectively, along with year 2020 water levels. Additionally, Figure Valley Gate Park Ltd. agreed to allow one of its observation wells, which is located closest to the mobile home park entrance, to be used in the Ecology Action Centre’s now defunct Groundswell project (Jones and Jamieson, 2017). Figure 56 shows groundwater levels measured over a slightly greater than 3 year period from that well.

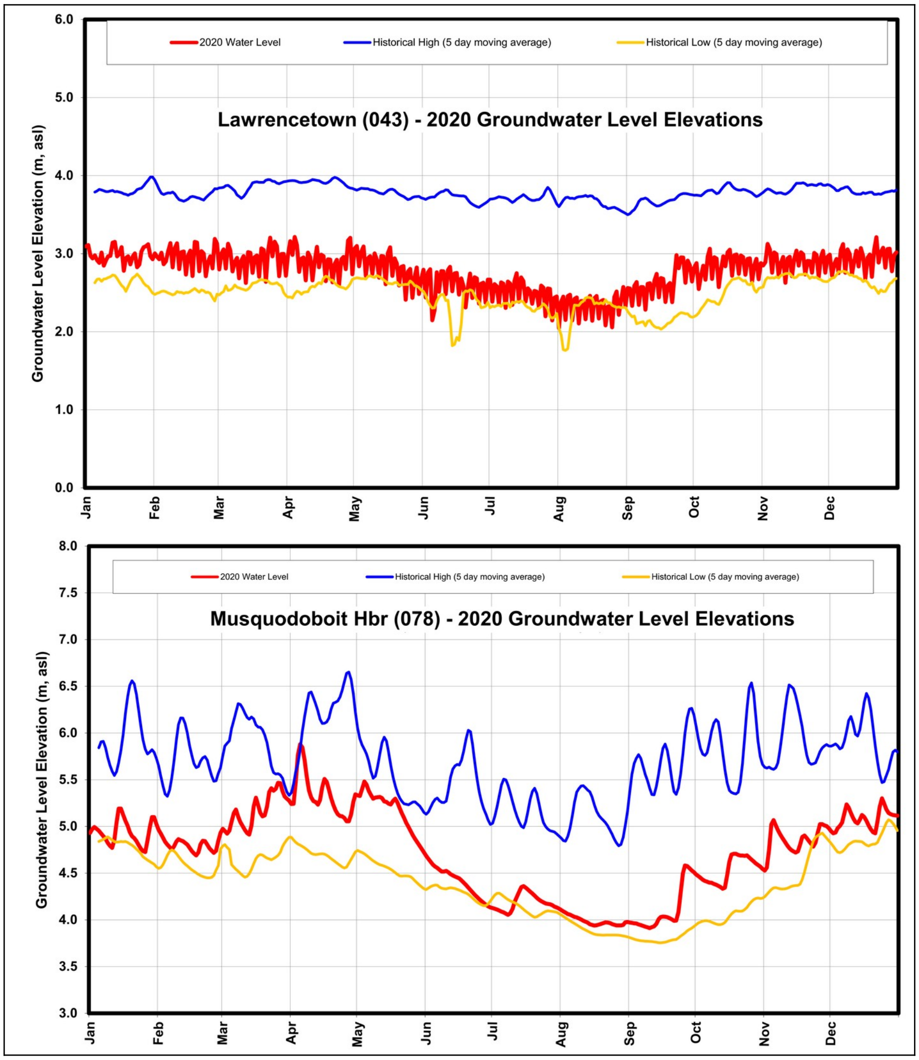

Figure 55: Historic groundwater levels at NSE (2022) Lawrencetown and Musquodoboit Harbour network observation wells.

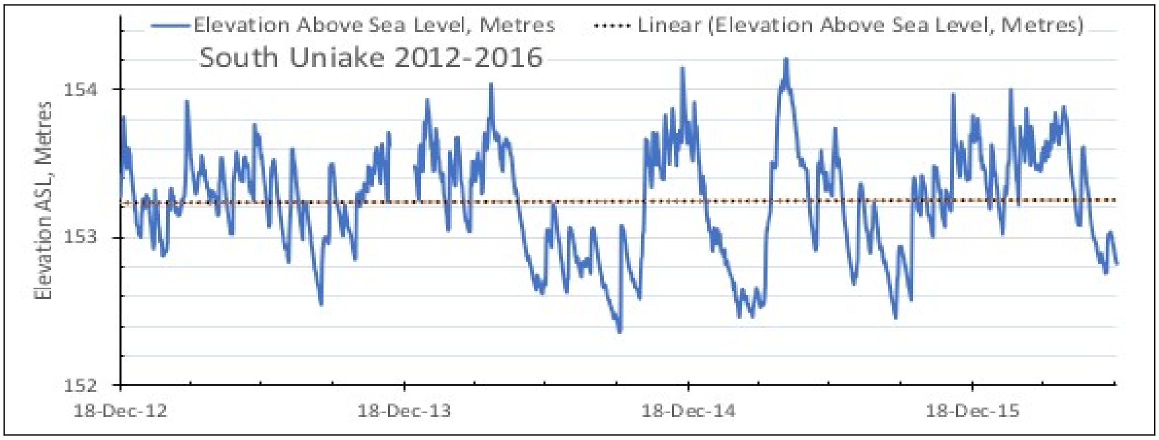

Figure 56: Groundwater levels at South Uniacke (Jones and Jamieson, 2017).

The Lawrencetown well shows about a 1 m annual water level fluctuation, with a nearly 2 m overall historic range over time. The 2020 data (in red) shows what may be a nearby well pumping or tidal effect on groundwater levels at that location. The Musquodoboit Harbour well shows about a 1.8 m annual water level fluctuation, with about a 2.5 m overall historic range over time. The observation well located closer to the site at South Uniacke shows a 1.3 m to 1.8 m annual water level fluctuation over it’s short 3½ duration of record.

Based on the above, wells drilled within the Uniacke SPS study area should be expected to experience natural (non-pumping) annual groundwater level fluctuations within the 1 to 1.8 m range, with perhaps around a 2 m of variation over several years.

The nearest NSE (2022) network observation well that has been completed in the Cunard Formation is located in Fall River, approximately 10.5 southeast of the southern boundary of the Uniacke SPS study area (the Fall River well 076). Because of its long distance from the study area, and due to significant present and likely also future population densities between the Fall River well 076 and the study area, the Fall River well 076 is not considered to be representative of conditions for the Cunard Formation HU within the Uniacke SPS study area. However, the data from it is presented in Figure 57 to show what may be considered by ewC (2024b) to be an extreme anthropogenic groundwater impact due dense population well water supply overuse.

Figure 57 shows the historic groundwater levels at the Fall River 076 observation well for the period 2008 to the end of 2022. Plot a) shows the historic high and low daily average groundwater elevations for that period of record, plus daily average well water elevations for the year 2022. Plot b) shows daily average water elevations spanning the entire period from March 2008 to (with some data gaps) the end of 2022. Plot c) shows annual average groundwater elevations at well 076 from 2008 to the end of 2022.

Plot a) shows that annual groundwater elevation fluctuations have ranged from around 2.7 m to approximately 7.0 m over the 2008-2022 period of record, showing large summer-time dry period declines in groundwater levels, followed by near full recovery in the fall. The data for 2022 follows the more extreme fluctuations. Plots b) and c) show an overall decline in groundwater elevation at that well at a rate of approximate 0.4 m per decade.

Overprinted onto that declining groundwater trend in plot c) is a biannual rise and drop that coincides with a similar trend in precipitation, in which summer drought conditions in Nova Scotia have (oddly) occurred on even-numbered years[91] for approximately the past decade.

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[91] This somewhat curious even-numbered year biannual drought cyclicity is present in nearly all precipitation records across Nova Scotia. Based on the 150 years of climate data reviewed for the Truro climate stations in Section 5.3.2 of this report, although overall precipitation has not changed significantly (by only a few mm) over that period climate record, this biannual drought cyclicity is a part of a longer-term cyclic pattern where 10 to 12 yearly periods of biannual summer droughts (with makeup precipitation received during winter months) are followed by 10 to 12 yearly periods s of wetter, more normal precipitation (with less severe winter to summer variability), perhaps due to combined cyclicity of Solar activity and Atlantic Ocean decadal currents.

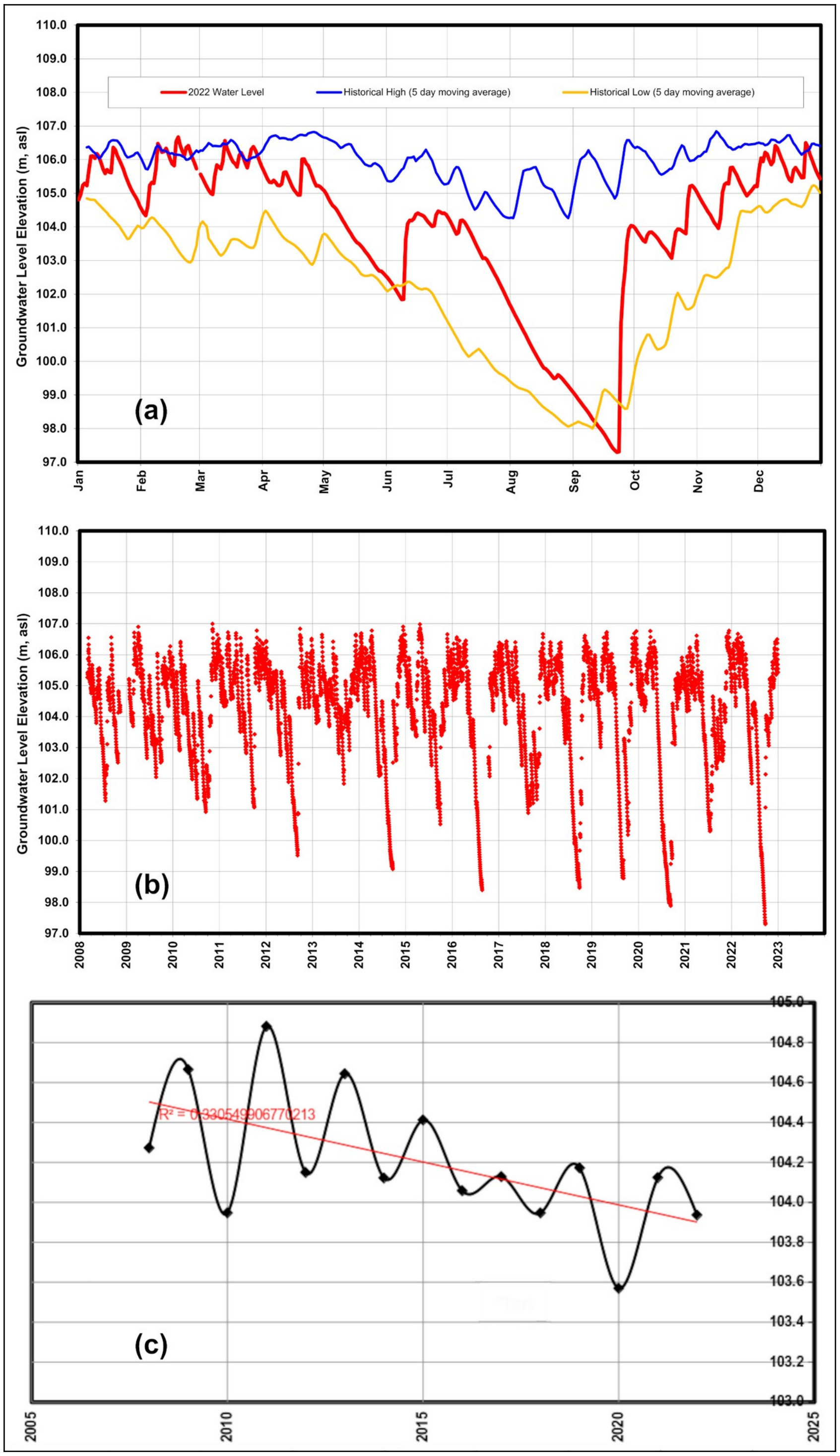

Figure 57: Groundwater elevations at the NSE (2022) Fall River (076) observation network well: a) record daily average high (blue), minimum (yellow) and 2022 (red) data, b) daily average data from 2008 to the end of 2022, and c) annual averages for the period 2008 to the end of 2022.

9.1.3 Well cold water storage

In the Uniacke SPS study area, 248 well records give both total well depth (TD) plus static water levels. The water column heights (cold-water storage in wells) calculated from those (TD minus static water level) for all bedrock HUs combined range from 15.2 m to 185.4 m (median and average values are both 72.8 m, with 1st and 3rd quartile values of 53.1 m and 91.4 m, respectively). With no safety margin applied, this represents total cold-water storage volumes ranging from 280 L (way too little storage for all but the highest-yielding wells) to 3,410 L (may be required for very low-yielding wells), and an overall average of 1,340 L.

For reference, NSE (2021) suggests that wells drilled for a typical household of four residents requires about 1,350 L of water per day (however, based on Statistics Canada (2021) data, in Nova Scotia, a combined industrial/commercial/residential demand of 411 L/day per capita (equivalent to 1,645 L/day per home of 4 residents), or a residential-only demand of 215 L/day per capita (860 L/day per home).

For wells drilled into the Cunard Formation HU within the Uniacke SPS study area, cold-water storage depths range from 28.6 m to 118.8 m (median and average values of 57.9 m and 60.8 m, respectively, with 1st and 3rd quartile values of 47.7 m and 71.6 m, respectively). With no safety margin applied, this represents total cold-water storage volumes ranging from 527 L (still too little storage for all but the higher-yielding wells) to 2,185 L, and an average of 1,119 L.

For wells drilled into the Beaverbank Formation HU within the Uniacke SPS study area, cold-water storage depths range from 28.9 m to 115.7 m (median and average values of 71.6 m and 71.4 m, respectively, with 1st and 3rd quartile values of 51.8 m and 86.8 m, respectively). With no safety margin applied, this equals total cold-water storage volumes ranging from 532 L (again too little storage for all but the higher-yielding wells) to 2,129 L, and an average of 1,314 L.

For wells drilled into the Taylors Head Formation HU within the Uniacke SPS study area, cold-water storage depths range from 15.2 m to 185.4 m (same as for the overall values for all bedrock HUs combined), with median and average values of 73.1 m and 74.0 m, respectively, and 1st and 3rd quartile values of 54.8 m and 94.4 m, respectively. With no safety margin applied, this represents total cold-water storage volumes ranging from 280 L (way too little storage for all but the highest-yielding wells) to 3,412 L, and an average of 1,362 L.

Again, as noted previously, there is insufficient data available for wells drilled into the granodiorite to make any colt-water storage range assessments.

Readers are again advised that static water levels are usually measured right after wells have been drilled, developed, and drilling tools pulled from wells. Therefore, water levels often have not stabilized when measured. Further, few drillers use proper water level measuring tapes to record water levels, but instead may estimate static water levels by dropping stones into wells and timing for the “slopping” sound when they hit the water. So the static water levels as reported by Kennedy and Fisher (2022) must be used with caution for assessing available cold-water storage ranges and means.

Further, typically, static water levels are measured only when wells are newly drilled, or when pumps are installed in them (which data does not make it into the well database, or any other database), and static water levels are very rarely measured afterwards. Therefore, and due to the natural and artificial groundwater level fluctuations discussed in Section 9.1.2, while general reports of static groundwater levels in residential wells may serve as a general guide, the static water level values reported in the well log databases should not be used to make definitive assessments on pumping effects or source/aquifer sustainability over time, unless there are numerous wells in one area that have been drilled at different dates over time.

9.2 Driller blow test results

Driller blow tests are typically carried out during well development at the end of well drilling. In Nova Scotia, wells are typically developed (to remove drill cuttings, water with high turbidity, and to clear water-bearing zones of debris) for periods of about one hour. During that time, depending on borehole conditions, the driller may raise and lower the drilling rods and bit in an effort to clear as many zones as may be thought to produce water. But at the end of the well development, the drilling bit is usually kept a the very bottom of the hole to blow[92] all debris from the bottom of the well.

During this final stage of well development, drillers will estimate the volume of water produced by, and blown out of, the well, frequently by using a bucket and stopwatch, but at times also by simply estimating the volume of water flowing on the ground away from the well.

Blow testing, or airlift yield testing, is a crude method of evaluating what water volumes wells may be able to produce (see caveat, footnote 84). Because blow testing is done with the drilling bit sitting at the very bottom of the hole, blow test results never represent true well pumping conditions[93], because the groundwater gradients at and in the aquifer around the well that drive water into the well during blow testing are not the same. Further, driller blow tests are of too short a duration to reliably define long-term well capabilities. As such, depending on the depths to the water-bearing zones in a well, multiplying driller blow test results by 0.50 to 0.75 may help to give a better general estimate of possible longer-term well yields.

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[92] Today's rotary-percussion drilling rigs use air-actuated drilling bits. Compressed air is blown down inside hollow threaded drilling rods to the drilling tool to make the carbide hammer-bit reciprocate. That compressed air, which then leaves the bit, forces rock drill cuttings and water back up the annular space between the drilling rods and the borehole to surface to be shovelled away from the well.

[93] Well pumps are typically kept 3 to 5 m off the bottoms of wells to allow debris to collect over time without causing damage to pumps, and with proper well pumping the goal is to never allow drawing the water level down to the pump, whilst the pump would draw air, which can damage pump impellers and motors.

9.2.1 Well yield data rankings and general statistical summary accuracy

Reported driller airlift yield test rates from Table 12 for all 1,453 wells with data that, regardless of well location accuracy that have apparently been constructed within the Figure 43 mapping in all bedrock HUs combined, range from 0 L/min to 454 L/min and average 17.4 L/min, with median and 1st and 3rd quartile values of 9.1 L/min, 4.5 L/min, and 18.2 L/min, respectively. Those wells 762 wells with data in Table 12 with better than 125 m location accuracy also range from 0 L/min to 454 L/min and average 17.7 L/min, with the same ranked data distribution as for the 1,453 wells with data.

As such, the subset of 762 airlift yield test values for wells which location accuracy is better than 125 m within the Figure 43 mapping area appears to adequately represent the 1,453 values for all wells regardless of location accuracy. And the proportion of wells with airlift yield test data is over 95% in both of these categories, so notwithstanding the inaccuracies that may exist in data collection by drillers, the statistical summaries of the airlift yield test data and data subset is considered to be fairly representative of the data collected.

Regarding the normalized well yield values of LPM/30m, those for the subset of wells with better than 125 m location accuracy (682 wells with data) are slightly lower than the dataset for 1,292 wells with lesser location accuracy – with maximum, mean and median values of 319.6 LPM/30m, 14.1 LPM/30m, and 4.3 LPM/30m, respectively, versus 372.1 LPM/30m, 16.6 LPM/30m, and 5.3 LPM/30m.

Having somewhat established the adequacy of the statistical summaries for data from the larger Figure 43 mapping area, in Table 13 for the smaller-yet subset of data for 473 wells (nearly 98% data frequency) with better than 125 m location accuracy that fall in all HUs combined within the Uniacke SPS study area, airlift yield test result values range from 0.5 L/min to 227 L/min and average 14.6 L/min, with median, 1st and 3rd quartile values of 7.7 L/min, 4.5 L/min, and 15.9 L/min, respectively.

So while the well yields represented within the Uniacke SPS study area have no zero yielding wells, the values for wells within the study area are slightly lower overall than within the larger Figure 43 mapping area, and with the largest yielding wells located outside of the Uniacke SPS study area.

Regarding the 430 normalized well yield values of LPM/30m from wells with better than 125 m location accuracy from all bedrock HUs within the Uniacke SPS study area in Table 13 versus those 682 data values from Table 12 for the Figure 43 mapping area, the values presented in Table 13 are also generally lower (but also with no zero values) – with maximum, mean and median values of 279.6 LPM/30m, 11.3 LPM/30m, and 3.6 LPM/30m, respectively from Table 13, versus the 319.6 LPM/30m, 14.1 LPM/30m and 4.3 LPM/30m, respectively from Table 12.

9.2.2 Reported well yields by bedrock HU within the Uniacke SPS study area

To begin, there is insufficient data for wells plotting as having been drilled into the granodiorite that underlies the southwestern part of the Uniacke SPS study area, so the discussion that follows will be limited to the Cunard, Beaverbank and Taylors Head Formation HUs.

From the Table 13 statistical data, wells that plot as being drilled into the Cunard Formation HU appear to have the overall highest yields (mean and median values of 19.2 L/min and 17.0 L/min, respectively), followed by wells drilled into the Beaverbank Formation HU (mean and median values of 15.0 L/min and 9.1 L/min, respectively), with mean and median values of 14.3 L/min and 6.8 L/min, respectively, from wells drilled into the Taylors Head Formation HU.

However, the highest (maximum) reported well yields rank in reverse at 279.6 L/min, 139.8 L/min and 68.1 L/min for the Taylors Head, Beaverbank and Cunard Formation HUs. This is likely a result of the greater competence generally of the Taylors Head Formation's mostly greywacke bedrock, and thus the greater integrity of water-bearing fracture zones, in which fines smearing along fracture zones is expected to be less than in the other two bedrock HUs.

Table 13 shows similar trends for the normalized yield LPM/30m values, except the mean value for the Taylors Head Formation HU is higher, due largely to propensity for greater water-bearing fracture integrity to exist within that HU.

Well yield distributions based on reviews of the raw tabulated data

Table 16 summarizes the ranges of well yields reported within the Uniacke SPS study area as per the raw data used to produce Table 12, for the study area overall, and per bedrock HU.

Table 16. Well yield distribution within the Uniacke SPS study area based on raw tabulated data.

Yield range (L/min)	All HUs combined (473 wells)		Cunard Fm. HU (28 wells)		Beaverbank Fm. HU (61 wells)		Taylors Head Fm. HU (382 wells)	
	Number	% of total	Number	% of total	Number	% of total	Number	% of total
< 0.6	4	0.85	0	0.00	0	0.00	4	1.05
0.6 - 1	3	0.63	0	0.00	0	0.00	3	0.79
1 - 2	27	5.71	0	0.00	3	4.92	24	6.28
2 - 4	73	15.43	1	3.57	9	14.75	62	16.23
4 - 10	191	40.38	9	32.14	30	49.18	151	39.53
10 - 20	76	16.07	5	17.86	8	13.11	63	16.49
20 - 40	68	14.38	11	39.29	6	9.84	51	13.35
40 - 60	16	3.38	1	3.57	2	3.28	13	3.40
60 - 100	8	1.69	1	3.57	3	4.92	6	1.57
>100	7	1.48	0	0.00	0	0.00	5	1.31
Totals	473	100.00	28	100.00	61	100.00	382	100.00

Among the wells with better than 125 m location accuracy, only 1.48% of the wells located within the Uniacke SPS study area have driller-reported well yields below the 1,350 L/day (0.94 L/min) that is suggested by NSE (2011), while only 0.85% of all wells are reported by drillers to have airlift yield test results below the 860 L/day per residence as indicated by Statistics Canada (2021). Those wells plot as having been drilled into the Taylors Head Formation HU.

Allowing for a conservative safety factor yield that is twice what is suggested by NSE (2011) and indicated by Statistics Canada (2021), then 7.2% and between that and 1.48% of all future wells drilled within the Uniacke SPS study are may, at worse, be expected to experience difficulties obtaining those two respective minimum yield rates. Based on the Table 16 data, most of those wells would be expected to fall within the Taylors Head Formation HU, but some should also be expected to be within the Beaverbank Formation HU as well.

Again based on the yield-size distributions in Table 16, it appears that greater numbers of future wells drilled within the Uniacke SPS study are should proportionately be expected to produce more low/moderate to good yields within the Beaverbank Formation HU, and than in the Taylors Head Formation HU, followed by the Cunard Formation HU. However, more future wells drilled into the Cunard Formation HU should proportionately be expected to produce moderate/good to high yields than in the other two bedrock HUs, although considerably greater numbers of wells that have already been drilled into the Taylors Head Formation HU have produced yields above 20 to 40 L/min, and only wells drilled into the Taylors Head Formation HU have produced yields above 100 L/min.

Well yields normalized to depth (LPM/30m) distributions based raw tabulated data

Table 17. Open-borehole normalized well yield (LPM/30m) distribution within the Uniacke SPS study area based on raw tabulated data.

Yield range (L/min)	All HUs combined (473 wells)		Cunard Fm. HU (28 wells)		Beaverbank Fm. HU (61 wells)		Taylors Head Fm. HU (382 wells)	
	Number	% of total	Number	% of total	Number	% of total	Number	% of total
< 0.5	24	5.58	0	0.00	2	3.77	22	6.32
0.5 - 1	34	7.91	0	0.00	4	7.55	29	8.33
1 - 2	85	19.77	1	3.70	13	24.53	71	20.40
2 - 5	113	26.28	6	22.22	15	28.30	91	26.15
5 - 10	61	14.19	6	22.22	10	18.87	45	12.93
10 - 20	51	11.86	7	25.93	3	5.66	41	11.78
20 - 40	36	8.37	5	18.52	3	5.66	28	8.05
40 - 60	9	2.09	2	7.41	1	1.89	6	1.72
60 - 100	13	3.02	0	0.00	1	1.89	12	3.45
>100	4	0.93	0	0.00	1	1.89	3	0.86
Totals	430	100.00	27	100.00	53	100.00	348	100.00

Table 17 summarizes the ranges of well yields normalized to depth as calculated from data available within the Uniacke SPS study area from the raw data used to produce Table 12, for the study area overall, and also per bedrock HU.

Among the wells with better than 125 m location accuracy within the Uniacke SPS study area, wells drilled into the Beaverbank Formation proportionately have the highest LPM/30m values, followed by the Taylors Head Formation HU. However, the Taylors Head Formation HU appears to have a greater number, and also proportion, of the highest LPM/30m values across the Uniacke SPS study area than in the other two HUs. Again, this is likely due to the greater competency of the Taylors Head Formation greywacke bedrock and thus, also better overall fracture flow characteristics.

9.2.3 Graphical/spatial review of well yields within the Uniacke SPS study area

The maps[94] in Figures 58 and 59 show the spatial and size range distribution for driller-reported airlift yield test result and calculated open-borehole normalized yield LPM/30m values within the Uniacke SPS study area.

While in Figure 58 and 59 some of the airlift yield test result distribution appears to be somewhat correlated to bedrock lithology – particularly with the Beaverbank Formation mapped along much of the north flank of the South Uniacke syncline, but also with the Beaverbank Formation in the western part of the southern flank of that syncline. However, areas of Figure 58 with higher well yields, and also in Figure 59 with higher LPM/30 values, also appear to correlate with many of the lineament-interpreted faults as shown in Figure 39 – most clearly along the possible faults that appear to be responsible for establishing Uniacke, Murphy and Pentz Lakes.

In Figures 58 and 59, other parts of the Uniacke SPS study area in which there may be airlift well yield and LPM/30m value correlations with lineament-interpreted faults may include well yields and LPM/30m in the area between Pigott and Cockcomb Lakes, well yields along the north shore of Pigott Lake, at the southeast shore at the southern end of Cockscomb Lake, and in the vicinity of the two coves on the eastern (near Cove Rd.) and western (near the end of Jorphie Dr.) sides of Lewis Lake.

Unfortunately, it is not possible, or very difficult at the very least, to identify other well yield and/or LPM/30m value correlations with lineament-interpreted faults elsewhere within the Figure 58 and 59 mapping areas due to significant lack of well data within most of the other parts of the Uniacke SPS study area.

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[94] Raw driller-reported data and calculated values for well records giving better than 125 m location accuracy interpolated with the GRASS GIS v.surf.rst module with same settings as were used to generate Figure 52, but because of the wide range in data values, with a tension value of 3,550 and a smoothing value of 0.1 applied to generate Figure 58, and a tension value of 3,200 and smoothing value of 0.1 applied to generate Figure 59, as require to render mapping values within the data ranges presented in Table 13. Again, the r.contour module was used to produce the contour lines, which are linear for the map in Figure 58, but logarithmic for Figure 59.

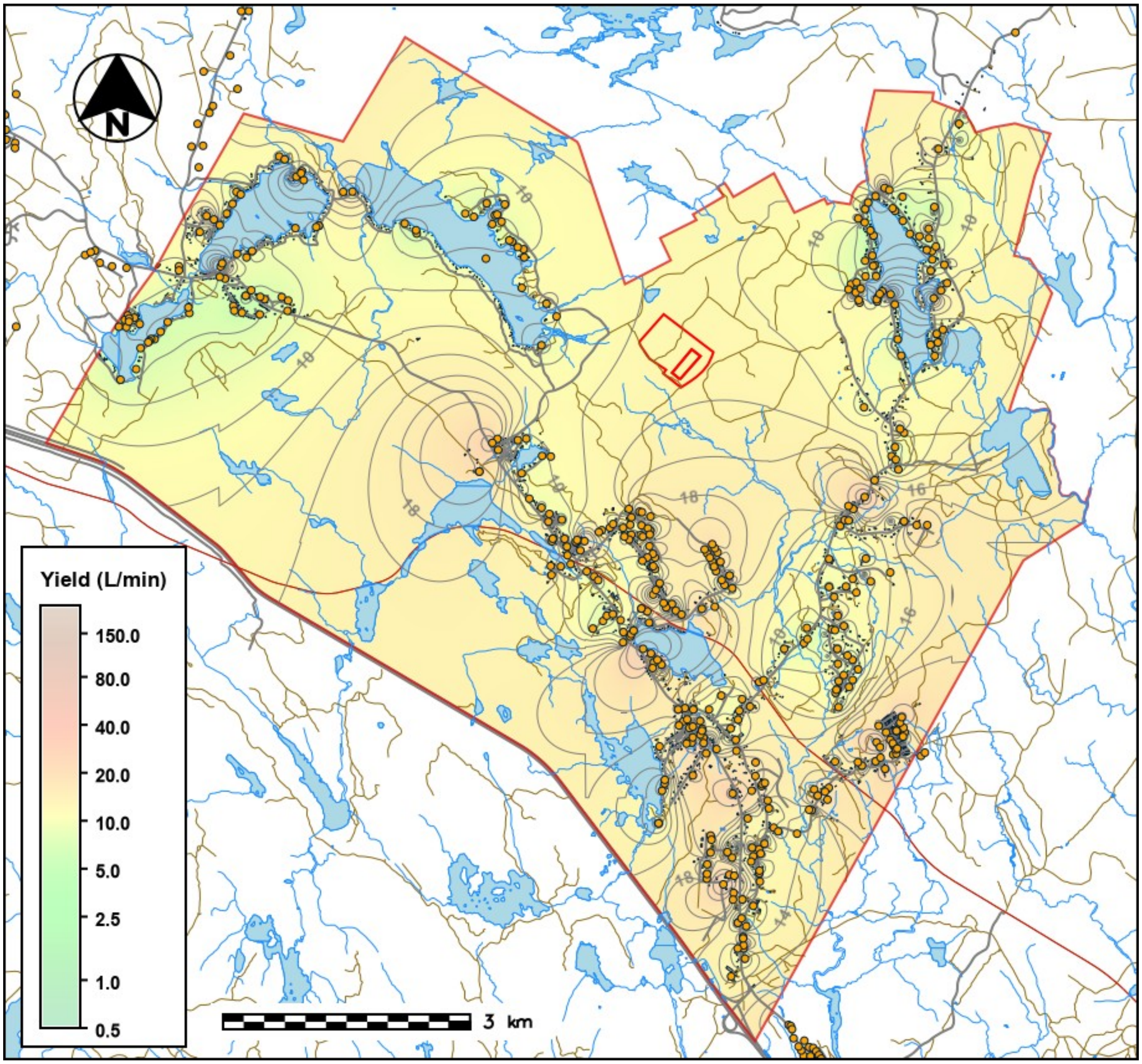

Figure 58: Interpolation of driller-reported airlift yield test values for wells with better than 125 m location accuracy. Note that the colours in the map legend are scaled logarithmically, whereas the contour lines on the map are scaled linearly with interval of 2 L/min.

9.3 Pumping test data

The Nova Scotia pumping test database (Drage, 2018; Kennedy, 2022) includes records for 16 pumping tests for wells drilled within the Figure 43 area (see figure for locations):

- thirteen of which were drilled into the Taylors Head Formation HU, where:
    - three are located northwest and outside of the Uniacke SPS study area,
    - two are located roughly at the centre of the study area, and

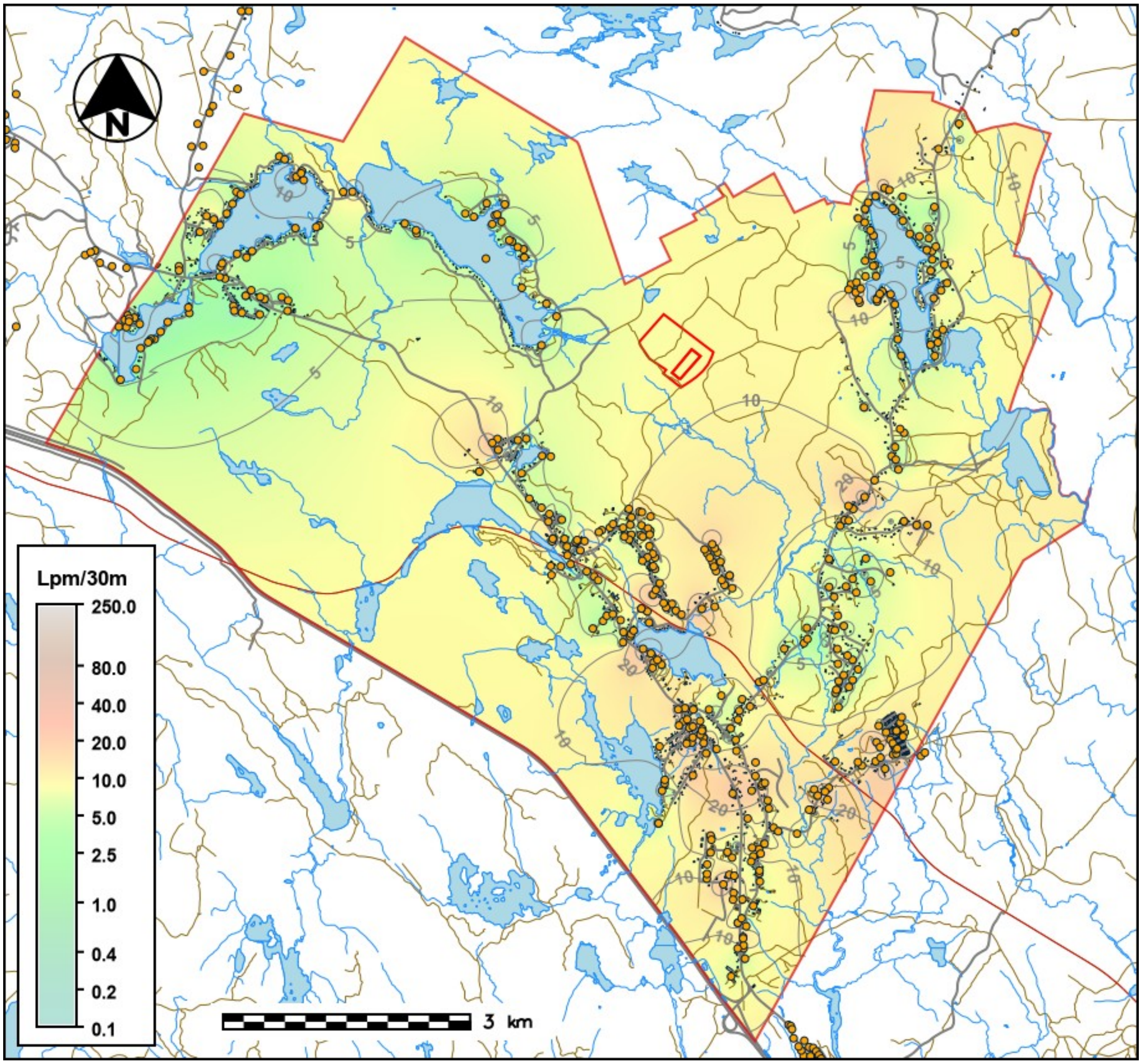

Figure 59: Interpolation of calculated yields normalized to length of open borehole (Lpm/30m) for wells with better than 125 m location accuracy. Note that both the colours in the map legend and the intervals for the contour lines on the map are scaled logarithmically.

  - eight are located at the Valley Gate Mobile Home Park), and

- two of which were drilled into the Beaverbank Formation HU, all of them located in the Valley Gate Mobile Home Park (one was pump tested twice, in 1990, and again in 2004).

Additionally, three of at least 81 wells that were drilled in 2013 into the Taylors Head Formation HU within the community along the south shore of Long Lake, which wells are centred approximately 2.5 km north of the Uniacke SPS study area, had pumping tests carried out on them (ewC, 2014). However, none of the well log information or pumping test data relating to those wells can be found in the Nova Scotia well log database (NSE, 2019; Kennedy and Fisher, 2022) or the Pumping test database (Drage, 2018; Kennedy, 2022). Notwithstanding, data from those pumping tests is also included in the analysis that follows.

Table 18 summarizes all of the above-noted pumping test data.

9.3.1 Pumping tests and data – defined

Pumping tests, as are summarized in Table 18, typically involve pumping a well or a number of wells in a very controlled fashion while monitoring the effects pumping on the aquifer at the producing well(s) plus at as many other wells (observation wells) as possible to assess more distal aquifer effects. Pumping tests are typically done for periods of 6, 12, 24, 48, 72 hours, or longer, using constant pumping rates. At the pumping well(s), wellheads are set up with a meter and a throttle valve to measure and regulate (keep constant) the test pumping rate, and water levels in the pumping and observation wells are measured as they drop over time with pumping and recover following the pumping test.

During pumping tests, water levels in the pumping well(s) and as many non-pumping observation wells as possible are carefully measured (usually to the millimetre), typically over the base-10 log of time (every minute first, with progressively longer periods between readings) during the course of the test. After a predetermined test duration, or upon reaching a predefined available drawdown[95], the pump is stopped and the rate of water level rise during well recovery is also measured (also on the log of time).

The water level/time data collected during the pumping tests is plotted on log-log or semi-logarithmic paper, depending on the interpretation method used (the Theis (1935) or the Jacob (1947) Hantush (1964)), and the shape of the curves or slopes of the lines in the plots are used to calculate a value called Transmissivity (T), which along with Storativity (S), are the two parameters used to describe an aquifer’s ability to contain and transmit water though it and into wells, and from which water levels at and around the pumping and observation wells can be determined for various different pumping rates over both time and distance.

The coefficient of Transmissivity (T) is the aquifer hydraulic conductivity multiplied by aquifer saturated thickness penetrated by the well. It is the rate at which water will flow through a vertical strip of the aquifer.

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[95] The available drawdown of a well is the maximum desired depth beyond which the water level should be allowed to drop due to pumping. Often times, available drawdown is defined as being a few metres above the top of the pump (to avoid the pump drawing air). But a better practice is to set available drawdown to avoid dewatering major water-bearing zones (to avoid hydraulically damaging them, particularly important for commercial or municipal wells that are typically pumped non-stop for extended periods of time). The ideal pumping test will use a pumping rate that is estimated such that the water level in the pumping well is anticipated to be brought down to at least 75% of the available drawdown to properly stress the aquifer at the well, and well water level recovery measurements should taken until be at least 80% of that drawdown has been recovered.

Storativity (S), the coefficient of storage (values for S were not obtained for any of the pumping tests that are summarized in Table 18, but S is significant for making well interference determinations as discussed in section 9.8 of this report), represents the volume of water released per unit of aquifer storage area per unit change in aquifer head. In confined aquifers, S is a result of compression of the aquifer when the head is reduced during pumping. In unconfined aquifers, S is the same as the specific yield of the aquifer.

Values for S, which require that water level measurements and, thus, values for T be obtained from non-pumping observation wells, are defined by:

$$S = \frac{2.25 \bullet T \bullet t_0}{r^2}$$

where;

T = Transmissivity obtained at the observation well of interest,

r = distance from the pumping well to the observation well,

t_0 = time (in days) at the zero drawdown intercept at the observation well.

The values for S for unconfined fractured bedrock aquifers are poorly defined in the literature (Neilsen, 2002), but may range from around 0.006 (Maréchal et al, 2006) to 0.3 (Driscoll, 1986; Freeze and Cherry, 1979), whereas values are typically much lower for confined aquifers.

With T calculated, then the safe long-term pumping rate for the well being tested can be determined from (Farvolden, 1959):

$$Qs_t = \frac{0.7 \bullet T \bullet s}{0.183 \bullet \log(t)}$$

where;

Q = sustainable yield over time period (t) in m^3/day

s = available drawdown (in m),

t = time since the start of pumping (in minutes)

The multiplier 0.7 in the equation above serves as a safety factor and the value 0.183 is a constant that is related to one log cycle of pumping time (t).

The values obtained for Qs_t (where t is usually 20 years, or Qs_{20}), is the pumping rate at which the tested well may in theory be pumped continuously 24/7 for a period of 20 years before the water level in that well is dropped to the depth of the available drawdown. Values for Qs_{20} are usually conservative in that, in addition to the safety factor applied to the equation used to calculate them, they assume that no recharge occurs during the 20 year period of pumping.

Table 18 Summary of available pumping test data within and around the Uniacke SPS study area.

Pump test ID	HAN-36.1	HAN-36.2	HAN-36.3	HAN-18	HAN-14	HAN-26.6	HAN-26.5
Easting	427149	427240	427325	433341	434233	438166	438368
Northing	4974670	4974551	4974425	4972363	4971548	4969078	4968928
Bedrock HU	Taylors Hd	Taylors Hd	Taylors Hd	Taylors Hd	Taylors Hd	Taylors Hd	Taylors Hd
NSE well number	140052	140053	140054	891831	791592	51033	50987
Well ID	P15-1	P15-2	P15-3	--	--	Well 14	Well 13
Well depth (m)	183	183	183	72.54	99.06	62.5	105.2
Test year	2014	2014	2014	1989	1979	2005	2005
Test duration (hours)	48	48	48	72	72	72	96
Static water level (m)	6.99	9.74	--	-0.03	3.02	2.11	3.28
Pump set depth (m)	--	--	--	67.06	96.01	54.4	--
Ave. pump rate (L/min)	9.85	13.31	9.00	27.27	4.55	91.51	38.42
Avail. drawdown (m)	171	168	--	67.06	89.92	28.89	20.49
Max. drawdown (m)	44.46	44.72	40	17.37	27.55	21.25	15.78
Total recovery (m)	38.61	33.85	34	16.56	--	20.6	12.21
Recovery minutes	180	180	--	50	--	1060	500
Transmissivity (m^2/d)	0.03	0.22	0.16	1.18	--	8.13	3.52
Qs_{20} (L/min)	2.67	17.53	13.06	27.3	5.7	88.85	--
Storativity	--	--	--	--	--	--	--

Pump test ID	HAN-26.2	HAN-1	HAN-26.1	HAN-17	HAN-26.3	HAN-26.4	HAN-2
Easting	438406	438408	438452	438472	438472	438487	438493
Northing	4968939	4969216	4969316	4969382	4969382	4969146	4969254
Bedrock HU	Taylors Hd	Taylors Hd	Beaverbank	Beaverbank	Beaverbank	Taylors Hd	Taylors Hd
NSE well number	831253	731768	831254	891804	891804	50986	--
Well ID	Well 2	Well 1A	Well 1	Well 6	Well 6	Well 12	Well 2B
Well depth (m)	91.5	35.05	109.8	91.44	90.8	105.2	91.44
Test year	2004	1972	2004	1990	2004	2005	1972
Test duration (hours)	168	72	72	72	72	72	72
Static water level (m)	5.09	7.62	7.17	2.34	3.05	7.17	5.18
Pump set depth (m)	90	33.53	91.5	85.34	86.4	85.5	82.3
Ave. pump rate (L/min)	27.50	35.45	11.61	65.00	19.05	11.32	27.27
Avail. drawdown (m)	30.91	25.91	27.83	57.91	58.95	65.83	77.11
Max. drawdown (m)	12.1	25.91	25.8	20.62	57.58	25.09	75.59
Total recovery (m)	11.52	27.71	25.6	--	56.34	24.28	75.59
Recovery minutes	90	390	80	--	75	100	300
Transmissivity (m^2/d)	2.87	0.95	0.65	5.12	0.38	0.52	0.2
Qs_{20} (L/min)	33.56	13.6	6.84	65	8.47	--	6.8
Storativity	--	--	--	$7.15x10^{-4}$	--	--	--

Pump test ID	HAN-26.7	HAN-3	na	na	na	--	--
Easting	438493	438493	437018	436406	436403	--	--
Northing	4969254	4969254	4978660	4978219	4977730	--	--
Bedrock HU	Taylors Hd	Taylors Hd	Taylors Hd	Taylors Hd	Taylors Hd	--	--
NSE well number	--	731988	--	--	--	--	--
Well ID	Well 3	Well 2A	Well 6	Well 26	Well 71	--	--
Well depth (m)	219.2	191.72	61	42.7	30.49	--	--
Test year	2004	1973	2014	2014	2014	--	--
Test duration (hours)	72	72	48	48	48	--	--
Static water level (m)	7.67	12.07	0	1.27	4.6	--	--
Pump set depth (m)	152.4	178.31	57.9	39.7	27.5	--	--
Ave. pump rate (L/min)	9.23	26.82	6.67	20.87	21.17	--	--

Table 18 Summary of available pumping test data within and around the Uniacke SPS study area.

Avail. drawdown (m)	144.73	166.12	55	38.83	19.94	--	--
Max. drawdown (m)	102.39	98.24	41.4	36.5	19.8	--	--
Total recovery (m)	67.56	94.55	34.78	26.72	11.74	--	--
Recovery minutes	620	300	204	500	1410	--	--
Transmissivity (m^2/d)	0.05	0.26	0.08	0.43	1.17	--	--
Qs_{20} (L/min)	2.74	15.9	2.01	5.91	9.01	--	--
Storativity	--	--	5.69×10^{-4}	8.06×10^{-4}	8.12×10^{-5}	--	--

9.3.2 Interpretation of the pumping test data from Table 18

It is important to recognize that all of the pumping test data summarized in Table 18 is for wells drilled into bedrock with secondary permeability (fracture flow) only – earth-water Concepts inc. carried out 11 of 19 pumping tests in Table 18, and all showed clear fracture flow characteristics, with approximately half of those 11 wells experiencing limitation boundaries[96] during testing.

The following further summarizes the pumping test data presented in Table 18:

- The average pumping rates that were able to be used to carry out the pumping tests ranged from 4.6 L/min to 91.5 L/min (mean 25.0 L/min).
- The static water levels in the test wells ranged from flowing to 12.07 m m below the tops of casings (mean 4.91 m).
- The percentages of total drawdown experienced relative to available drawdown ranged from 25.9% to 100% (mean 64.4%).
- The percentages of total recovery relative to total drawdown ranged from 59.3% to 106.9% (mean 87.8%57.02 m) over periods ranging from 50 to 1,410 minutes (mean 377 minutes). The test with greater than 100 percent recovery was either not started with a fully recovered static level (from previous testing likely done on it), or precipitation during that pumping test may have cause the static level to rise during the pumping test,

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[96] Pumping test boundary conditions are identified when the slope of the rate of drawdown over time (as plotted on the log of time) changes during a pumping test.

A relative increase in the rate of drawdown usually signifies what's referred to as a "limitation boundary" – a condition that usually represents a change in aquifer permeability; i.e. a hydraulic response where the progressively expanding area of aquifer water level drawdown encounters different strata or lithologic facies (hydrostratigraphic unit) of lower permeability in the case of aquifers with primary permeability, or where fracture systems end or become much narrower and less conductive in the case of aquifers with secondary or fracture-flow permeability. A relative decrease in the rate of drawdown usually signifies what's referred to as a "recharge boundary" – a condition where the expanding area of aquifer water level drawdown encounters either: different strata or lithologic facies with higher permeability (whether that be from a bedrock HU or from recharge leaking from an overlying overburden HU, or a source of surface water in the case of aquifers with primary permeability; or in the case of aquifers with secondary or fracture flow permeability, larger fracture systems may be able to more quickly feed water to the aquifer system, or recharge from an overlying overburden HU, or a source of surface water. Sources of surface water may include wetland, streams and rivers, lakes, the ocean, which may all be sources of concern, particularly in areas with industrial land uses or with septic systems.

also likely affecting the pumping drawdown data and thus that well's test results.

- The values for Transmissivity (T) ranged from 0.03 to 8.13 m^2/day (mean 1.44 m^2/day).
- It appears that observation well data (or responses to pumping) were available for only four (one at the Valley Gate Mobile Home Park and three at Long Lake) of the 19 pumping tests summarized in Table 18. Storativity (S) values for them ranged from 8.12x10-5 to 8.06x10-4 (mean 5.43x10-4).
- The values (likely calculated by Kennedy, 2022) for 20-year well yields (Qs_{20}) range from 2.0 L/min to 88.8 L/day (mean 19.1 L/day).

The values for Storativity (S) in Table 18 are all within the range that Freeze and Cherry (1979) and (Maréchal et al, 2006) consider to be representative of confined aquifers, thus suggesting that the fracture systems in the wells for which values for S were calculated are confined.

Based on the well depths and values given for available drawdown in Table 18, it is assumed that all of the Qs_{20} values would have been calculated assuming that water levels in the tested wells can and are brought down to just above the tops of their pumps. That may be fine for residential wells, where wells are mostly used during the day and water levels in them can typically fully recover at night, thus generally keeping most if not all of the major water-bearing fractures wet.

However, it is generally **not appropriate** to pump commercial wells or central water supply wells such that the water levels in them drop below most, or any of their major water-bearing fractures. That's because many if not most commercial, multi-residential building water supply wells, and central water supply wells (such as wells serving small satellite communities – the Valley Gate Mobile Home Park is one example – or municipal water supply wells) are frequently kept pumping continuously for several hours, to days, weeks, or months at a time.

Pumping any well at the prescribed Qs_{20} rates calculated based on available drawdown being at the pump will allow many if not all of the the major water-bearing fractures encountered by and feeding those wells to become dewatered over time (which in some instances may be very short). If such fracture dewatering is allowed to progress any distance away for the pumping wells within their fracture-flow aquifer systems, air will become entrained into the aquifer's fracture plumbing system, which can severely reduce aquifer hydraulic conductivity, and thus greatly reduce well yields, often such that they can no longer be used.

There is a very clear example of this within the Uniacke SPS study area, as illustrated by the Han-17 and HAN-26-3 pumping tests in Table 18 (two separate tests that were done 14 years apart on the same well). That community water supply well was overpumped when first commissioned, and within only slightly more than a half decade had to be shut down, because due to that very short period of overpumping, the Qs_{20} for that well dropped by 87%, resulting in a water supply loss of about 34,600 L/day if it had been initially pumped at a rate that would have avoided dewatering the major water-bearing fractures that feed that well.

9.4 Available measures to mitigate future low yielding wells

Section 9.2.2 of this report identified from Table 16 (a summary of a review of all wells with better than 125 m location accuracy) that around 1.5% of the future wells within the Uniacke SPS study area might be expected to not meet the 1,350 L/day (1 L/min) capacity that NSE (2011) suggests is needed to meet average residential needs. And only about 0.85% of future wells within the Uniacke SPS study area might not be meet the 860 L/day figure for homes of four from (the Statistics Canada (2021), which represents demand by both urban and rural residential water users.

Four well construction options exist that can help to mitigate demand deficits regarding those future lower-yielding wells:

1) drilling those wells deeper in the hope to intercept deeper water-bearing fractures,
2) drilling an additional well in the hope to be able to supplement the first,
3) hydraulic fracturing[97] inferior yielding wells after they have been developed in the hope that can increase their yield, or
4) surging[98] lower yielding wells in the hope to improve their yield.

Drilling wells deeper, or drilling second wells, may or may not resolve all low-yield situations, and drilling second wells can most certainly be very expensive, and as such, it may be more economically prudent to consider one or both of the latter two options.

Hydraulic fracturing is effective mostly for extremely low-yielding wells – generally wells with less than 1 to 2 L/min airlift test yield results. Hydraulic fracturing may not always be successful with slightly higher yielding wells, mostly because the fracturing systems used in the water

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[97] A process wherein: 1) a string of threaded piping with an inflatable rubber packer attached at the bottom of the piping is lowered into the well; 2) the rubber packer is inflated using compressed air; and 3) water is pumped at as high a volume and pressure as possible to feed water into any narrow bedrock fractures; while 4) monitoring water pumping pressures to look for drops in pressure, in the hope to open up narrow non-producing bedrock fractures and/or to clear any debris that may be present in open fractures in the hope that water returning to the well may carry that debris with it into the borehole. This technique is similar to that employed by the petroleum industry, using much better up-hole and down-hole pressure, flow, and seismic monitoring under extreme control to stimulate oil and gas wells – only done in very deep strata that is typically 1 km or more below and out of any hydraulic communication from water-bearing aquifer horizons. The petroleum industry uses propant sand (pure well-rounded, small-grained quartz sand) to help keep any newly produced fractures open to ensure success, whereas hydraulic fracturing in the water industry does not, so there is no insurance of success when hydraulically fracturing water wells.

[98] Well surging is a process that involves pulling the drilling rods from the newly drilled well and replacing the drilling bit at the end of the drilling rods with a surging block (a tool with rubber disks that are the diameter of the borehole), then advancing that surging tool back into the well while rapidly moving it up and down in the well to flush water in and out of any water-bearing bedrock fractures, thus removing debris that may be present in them – much like using a plunger to unplug a stopped toilet, but on a much larger scale. Additionally, because of the power available from a drilling rig, high water pressures may be exerted across tight bedrock fractures to potentially open them up and/or to extend existing water-bearing fractures, thus increasing their yield.

industry typically cannot supply the required water pumping volumes and pressures needed to effectively open up or extend fractures – the process, therefore, mostly results simply in clearing out the debris from existing water-bearing fractures with the return water.

Further, most if not all of the hydraulic fracturing setups that are available in Nova Scotia cannot test wells after applying the procedure, as would be done by a drilling rig during well development, unless the crew is able to lower a pump into the well and power it to measure its post-treatment production rate.

The rates for hydraulic fracturing (year old pricing) run between $3,500 and $3,800 per well, excluding any followup efforts to measure the procedure's success by temporarily installing a pump in the well, which may cost another $500 to $1,000.

Alternatively, well surging can be done immediately after drilling a well and having done some development yield testing to confirm that it surging is needed, without removing the drilling rig from the well. And following the surging, the same drilling rig can be used to blow compressed air into the well to both clear any debris that may have washed out of fractures and fallen to the bottom of the well, to further clean out and develop existing (or newly produced) fractures, and to carry out a followup airlift yield test.

The rates for surging an existing well (year old pricing) run between $3,000 and $3,500, which includes mobilization/demobilization to/from the well site, and followup airlift yield testing. Costs would likely be less if surging is done immediately upon newly drilling a well since remobilizing equipment to the well site would not be required.

9.5 Groundwater recharge

The following addresses the effects of climatic (precipitation) conditions on aquifers over the longer term. In doing so, the following sections look and at surface land-based conditions in terms of where and how that precipitation may be divided between surface runoff and water available to infiltrates soils, and to eventually provide recharge to aquifers.

The importance of understanding how much groundwater recharge may be available in any given area of interest, is that recharge is that determines the longer-term, sustainable availability of water to supply aquifers and wells, and from this, to determine how many homes might be able to be sustainably supported over the long-run with on-site water supply for new and growing community development.

Groundwater recharge estimates can be done by many approaches, the two most-used for studies such as this one being:

1) the ultra-conservative per-lot based water balance approach, as presented in Appendix B of NSE (2011), or

2) the much more realistic (but still adequately conservative) aquifer-based water balance approach that:
    a) includes larger areas around new or existing development sites,
    b) takes into account both surface water flow and groundwater flow gradients, at the micro-scale and at the macro-scale as necessary, and
    c) which also accounts for other groundwater users outside of individual development project sites with larger municipal planning areas.

Our preferred approach in nearly all study cases is number 2), as it is more technically correct and much better and more complete addresses most all issues related to groundwater recharge.

The information needed to assess possible water availability to aquifers by either method (or for any other type of water supply well field review), requires defining the following:

a) the watershed and/or aquifer extent and recharge capture area size (needed for both methods, but which is limited to lot size only for method 1 above),
b) total annual precipitation (required for both methods above),
c) a groundwater recharge coefficient for the groundwater recharge capture area (required for both methods above), and
d) total water demand by other groundwater users within the subject capture area, which must be subtracted from the total recharge available to the site under consideration (this is not required for method 1).

Per NSE (2011) and other departmental policies, this forth criteria also includes reserving 50% of all available recharge for surface water (stream, lake) and related ecosystem maintenance.

These items are discussed in the four following sub-sections, with the latter being addressed only vaguely, because there are no other groundwater users within the anticipated groundwater recharge capture zones immediately around the Uniacke SPS study area.

9.5.1 Groundwater flow and potential groundwater recharge capture areas

Estimating groundwater recharge capture areas requires first identifying surface watershed boundaries, then defining the associated regional and local groundwater flow regimes likely within those areas.

Groundwater flow can be differentiated as regional, intermediate, or local (Tóth, 1962, 1963; Freeze and Cherry, 1979) – with flow between each being possible without distinct boundaries.

Regional groundwater flow involves recharge occurring at the top of the province, with deep and long-distance flow toward the ocean, and which typically involves long groundwater residence times. Regional flow in reference to the Uniacke SPS study area, which is situated over top of the province's central surface water divide (see Figures 23 and 24, also 60), is expected to be complex. Within and from the northern third of the study area, regional groundwater flow should be expected to be mostly to the north toward the Avon River and the Minas Basin, with possibly also some easterly flow into the Shubenacadie River watershed. Within and from the southern two-thirds of the Uniacke SPS study area, regional groundwater flow would be expected to be largely to the south toward the Atlantic Ocean; via the Sackville River primary watershed, but also radially in a southwesterly direction via the Indian River primary watershed, as well as southeasterly into and through the Shubenacadie River primary watershed.

Intermediate flow , which would be expected to closely parallel the regional flow and include recharge at and along all four of the inter-boundaries of the St. Croix River, Shubenacadie River, Sackville River, and Indian River primary watersheds into each of those four respective watersheds (see Figure 24 on page 42), would be equally complex. As such, there would be anticipated intermediate groundwater flow:

- out of the northern third of the Uniacke SPS study area directly into the St. Croix and Shubenacadie River primary watersheds via their respective sub-watersheds 1DE-1-C-3, 1DE-1-C-8, 1DE-C-10, and IDG-1-CC,
- out of the southern two-thirds of the Uniacke SPS study area directly into the Indian River sub-watersheds 1EH-3-J and 1EH-2, as well as
- into and out of the south-central (one-third of) Uniacke SPS study area directly from the Sackville River sub-watersheds 1EJ-4-H, 1EJ-4-G and 1EJ-4-F toward the Sackville River and directly out of the Uniacke SPS study area via sub-watershed 1EJ-4-F.

As was suggested by Tóth (1962, 1963), and which is well illustrated from the above for the Uniacke SPS study area, the groundwater-sheds for both regional and intermediate flows can and often do transcend surface watersheds. Which is why any future new industrial and residential development and related groundwater studies done to assess their potential impacts to existing groundwater supply sources and well owners must correctly address the complexity that exists with the intermediate groundwater flow sources of water within the study area.

Local-scale groundwater flow typically involves groundwater recharge at local knolls and flow discharge within nearby valleys. As such, local-scale groundwater flow piezometric surfaces will usually parallel surface topography, in a subdued manner.

One of several examples on how local-scale groundwater flow might/would serve to supply water (and thus, need be correctly understood) to existing and new wells drilled in the Uniacke SPS study area includes the local groundwater recharge that occurs in the area of high elevation just south of Cockscomb Lake. From that local higher elevation area, there would be local northward groundwater flow toward wells drilled for existing (and possibly future) homes constructed along the shore of the lake, and also southerly and southwesterly groundwater flow toward Black Brook to where, based on the presence of the Mount Uniacke Community Park just south of Hwy 1, notwithstanding some potential wetland areas, future new residential development and well construction is probably quite likely be carried out.

Although there currently exists no known empirical data within the Uniacke SPS study area, the concept discussed above regarding surface sub-watershed basins (which could, and probably should be taken to more detailed sub-basins for individual future development groundwater assessment studies) may be used to make rough estimates of groundwater flow directions, and from which more detailed approximations of the regional, intermediate and local groundwater recharge areas within the Uniacke SPS study area may (and should) be made.

To do so at any greater level of detail than has been done above would require carrying out a kind of watershed analysis that is beyond the scope of this current assignment. That being said, however, since the Uniacke SPS study area encompasses the boundaries of four primary surface watersheds, one can, for the sake of simplicity, use GIS to draw buffer zones (at 250 m, 0.5 km, and in the likely extreme, 1 km) around the Uniacke SPS study area that are likely to encompass the three zones of groundwater influence from existing and future water wells (and which should be considered in future, more-detailed groundwater assessments) in regards to the intermediate and local groundwater-sheds affecting the study area.

As such, these buffer zones around the Uniacke SPS study, as shown in Figure 60, can be used to estimate total groundwater recharge catchment areas that are likely available to the entire study area. These constitute the total surface area within the Uniacke SPS study area boundaries of 8,030 ha, plus the 9,158 ha, 10,285 ha, and 12,588 ha areas around it.

9.5.2 Precipitation

Precipitation was discussed at length in Section 5.3 of this report, which will not be repeated here. However, from Table 6 in Section 5.3.2 (page 50), the total amounts of precipitation received (as rain and snowmelt) within the greater Uniacke SPS study area is currently about 1,499 mm/year, which is anticipated to possibly increase to about approximately 1,549 mm/year by sometime in the early 2100's.

9.5.3 Groundwater recharge coefficients

Kennedy et al (2010) have published values for groundwater recharge coefficients for the entire province. They have ascribed a value 0.17 for the St. Croix River primary watershed (roughly 33.63% of the northern Uniacke SPS study area's groundwater recharge from precipitation), a value 0.14 for Sackville River and Shubenacadie River primary watersheds (approximately 41.34% of the south-central and easternmost Uniacke SPS study area groundwater recharge from precipitation), and 0.16 for the Indian River primary watershed (about 30.65% of the western Uniacke SPS study area's groundwater recharge from precipitation).

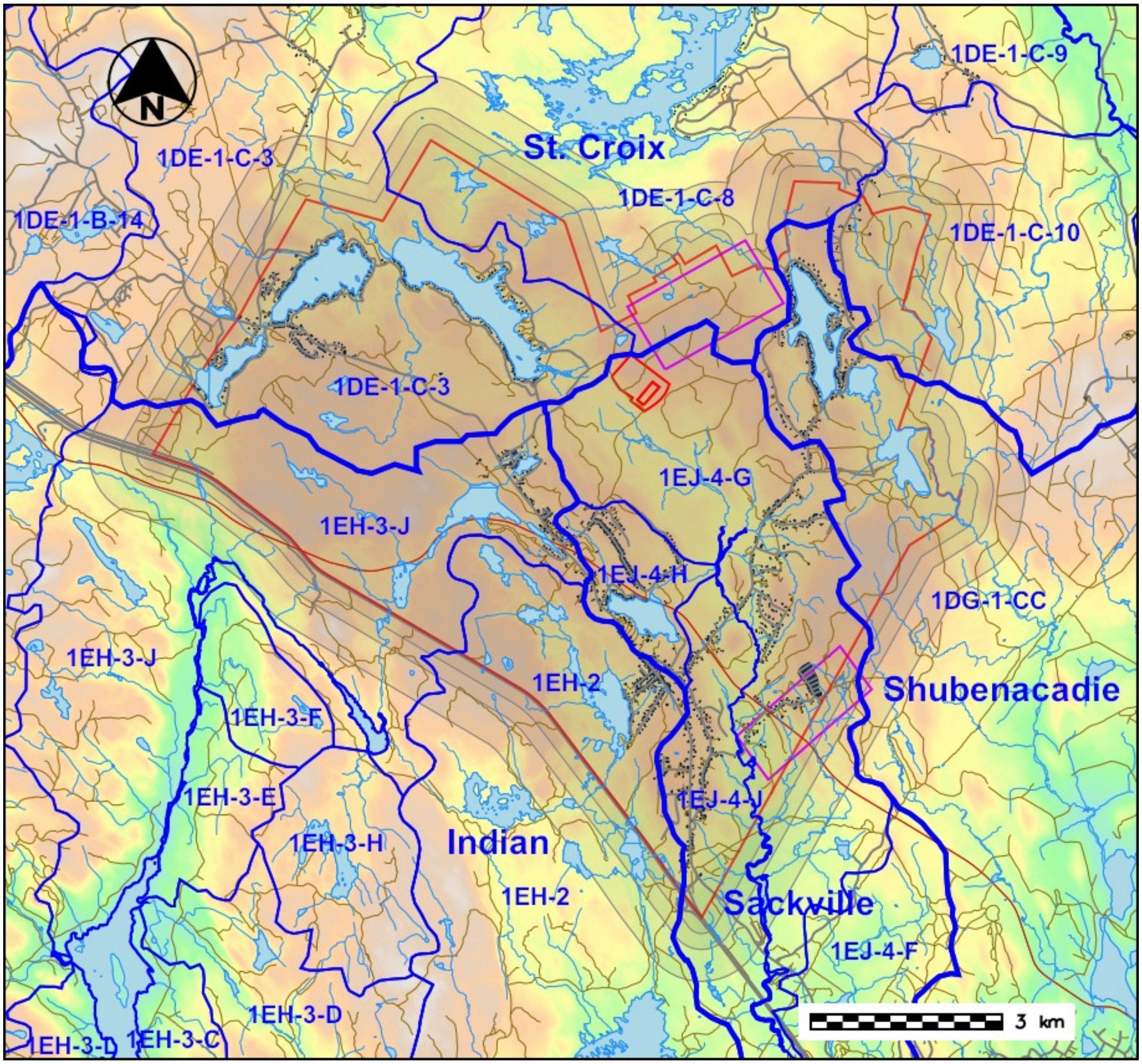

Figure 60: The 250 m, 0.5 km and 1 km buffer zones drawn around the Uniacke SPS study area from which to estimate groundwater recharge catchment.

9.5.4 Estimated groundwater recharge

Using method 2) as noted at the start of this section of the report, the total amounts of annual groundwater recharge available for use as well water supply may be calculated by the equation:

$$Q_{rech} = A_{rech} \bullet P \bullet I \bullet E$$

Where:

Q_{rech} = Available groundwater from the overall recharge area (in m^3/yr),

A_{rech} = Overall groundwater recharge area (in m^2),

P= Annual precipitation (in m/yr),

I= Groundwater recharge coefficient, and

E= Percentage of recharge reserved for baseflow and ecological use.

Table 19 summarizes the estimated volumes of groundwater recharge and the approximate number of homes (or home equivalents) that may be served applying the noted of recharge areas as discussed above. The groundwater recharge coefficient "I" values as noted above were used in proportion to the areas of each of the four primary watersheds with the recharge areas. Note that the groundwater recharge catchment areas that were used for calculations are listed in Table 19 were not adjusted for topography (i.e. for the greater lengths of areas along slopes).

Table 19. Estimates of groundwater recharge and numbers of existing and potential future new homes (or equivalent) that could be served within the Uniacke SPS study area.

Groundwater recharge areas		Possible total groundwater recharge[1] volume (m^3/yr)	Possible allocation[2] to well and/or surface water withdrawals (m^3/yr)	Number of homes[3] potentially able to be served
Description	Total surface precipitation capture area[4] (m)			
Study area only	80,298,791	19,728,297	9,864,148	20,019
250 m buffer around study area	91,584,905	22,501,138	11,250,569	22,832
0.5 km buffer around study area	102,852,467	25,269,422	12,634,711	25,641
1 km buffer around study area	125,881,173	30,927,254	15,463,627	31,382

1. Assuming 1,499 mm/yr precipitation and snowmelt and a groundwater recharge coefficients as noted in the text across across various percentages of the Uniacke SPS study area also noted in the text.
2. Half the value in column 2, as required by NSE for permitting if approvals were sought-after and as suggested also by NSE (2011).
3. Proportion of total allocation based on the much more conservative 1,350 L/day per home (or equivalent) suggested by NSE (2011), for 365 day years.
4. Values not adjusted for topography.

The groundwater recharge values and numbers of homes within the boundaries of the Uniacke SPS study area only is likely too conservative, the values for the 1 km buffer area is may not be conservative enough; the values and numbers of homes within the 250 m and 0.5 km buffer areas are considered to be more reasonable.

9.6 Aquifer water storage vs potential community water demand

Both the Quaternary and the bedrock sets of HUs present at and around the Uniacke SPS study area will carry water in storage. And where most of the wells that are currently (and anticipated new wells to be in the future) are drilled bedrock wells, although those well will obtain their water directly from the bedrock, the water present in the Quaternary HUs may serve as source to replenish that water with the bedrock.

The four bedrock HUs that underlie the Uniacke SPS study area and nearby groundwater recharge areas depend entirely on bedrock fractures and joints for water storage and flow. That fracture density (thus aquifer groundwater storage) may be expected to vary considerably between HUs and within each bedrock HU, depending on the severity of bedrock jointing and on fracture frequency, orientation, continuity, and relative degree of aquifer unit confinement.

The very limited number of values available locally for storativity (S) point to confined bedrock HU conditions, for which a value for specific storage may be perhaps around 0.1% locally, if those bedrock units are in fact confined. However, except for one S value obtained from a tested well located northeast of the Uniacke SPS study area, the available S values available are at the upper margin of the values suggested for confined aquifers (Freeze and Cherry, 1979; Maréchal et al, 2006) and as such, some of the groundwater beneath the Uniacke SPS study area may, in some places at least, be contained within only partially confined or unconfined aquifer units.

For unconfined consolidated (bedrock) aquifer materials, Freeze and Cherry (1979) suggest that aquifer porosity may range from 0 to 10% in shale and fractured crystalline and metamorphic rock, but they further suggest that solid samples of unfractured metamorphic rock rarely have porosities that are larger than 2%.

In light of the transmissivity (T) and storativity (S) values obtained from local pumping tests and the apparent bedrock fracturing and faulting that is thought to possibly be present within and around the Uniacke SPS study area (i.e. the lineament interpreted faults shown in in the area (i.e. the faults and lineaments shown in Figure 39), then conservatively, water storage porosity values of 0.5% to 2% might be assumed as reasonable for both the confined and unconfined portions of the local fractured bedrock HUs.

Freeze and Cherry (1979) also suggest porosity value ranges of 25% to 50% for sand, 35% to 50% for silt, and 40% to 70% for clay. As such, the Quaternary deposits present within and around the Uniacke SPS study area may be assumed to have a general or average porosity of somewhere between 25% and 35% overall within the study area.

Assuming a saturated thickness of 200 m (depth of the deepest well in Table 13) for the bedrock HUs within the Uniacke SPS study area, and a median overburden thickness of 5 m that is only halfway saturated above the bedrock (i.e. 2.5 m of saturated overburden material), then there could potentially be 91,584,900 m^3 to 366,339,620 m^3 of water stored within the bedrock HUs, plus 57,240,560 m^2 to 80,136,790 m^3 of water stored with the overburden present beneath the 250 m buffer area likely to provide groundwater recharge to the Uniacke SPS study area.

Assuming that the Uniacke SPS study area builds out to the full 20,019 residences (or residence equivalent) within the boundaries of the study area (an unlikely scenario) as listed being supplied with groundwater recharge water indicated Table 19, then the amount of water that may potentially be in storage within the bedrock HUs could supply that number of homes for 9.3 to 37.1 years, and the amount of water that may potentially be in storage within the overburden HUs could supply that number of homes for 5.8 to 8.1 years – this assumes that there is no new groundwater recharge during these periods and that the HUs are allowed to be run dry. Now this is an unrealistic situation, because there always will be groundwater recharge, notwithstanding the length or severity of any droughts that may occur in the future.

9.7 Well interference

Well interference[99] is what happens when two or more closely-spaced wells are pumping at the same time – the drawdown experienced from pumping at each well also affects its neighbouring wells, the total drawdown effect is cumulative, and so the net effect is that the water table or piezometric level in the vicinity of the pumping wells is lowered for all wells. This effect in the sort-term is illustrated in the bottom of Figure 8 in Section 2.4.4 (page 11) of this report, and the net effect over the long-term on piezometric levels is illustrated in the top and bottom parts of Figure 57 in Section 9.1.2 (page 123).

In any development with many closely-spaced homes and wells, there is always a potential for pumping induced well interference problems. This can affect both wells within a new subdivision, and also wells outside that are in close proximity to those new subdivisions.

9.7.1 Calculating well interference

Calculating well interference requires having an understanding of the shape (breadth and depth) of drawdown cones, from which values for Storativity (S) may be obtained for use in those calculations. That typically requires having a large number of wells with detailed data, and is best done using computerized groundwater flow models, which operate based on Theis (1935) equations, and in which the parameters for various buried and otherwise unknown subsurface features can be quickly altered, using a trial and error approach to try to obtain a best fit for parameters in attempts to gain a better understanding of the model domain hydrogeology. But this type of exercise is very time consuming far beyond the scope of this assignment.

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[99] Pumping a well causes the groundwater level in it, as well as the water level within the aquifer the well is drilled into, to become lowered. In homogeneous isotropic aquifers, this would theoretically create a cone-shaped area of drawdown within the aquifer. When these cones of drawdown overlap in areas with densely spaced wells, the effects of drawdown where they overlap are additive. However, since aquifers are usually heterogeneous and non-isotopic – particularly where fracture flow is involved, these cones of drawdown are seldom cone-shaped, but will have a preferential shape and orientation related to the depositional fabric of the aquifers in sedimentary earth materials, and/or of the fracture patterns within the aquifer. The shape and spatial limitations of these combined drawdown areas are typically very difficult to define, even where there are sufficient numbers of tested wells and observation wells, and impossible to define in areas (and that is most areas) where no or very few wells with nearby observation wells have been tested.

As a “quicker” alternative for use on individual development projects, NSE (2011) recommends the use of their “toolkit” spreadsheet, which applies the Theis equation, as one means to “approximate” well interference in the absence of the correct data to use more complicated and costly computer aquifer modelling. However, the criterion they suggest be used to determine whether the calculated interference is acceptable is very theoretical and arbitrary, in that it makes huge assumptions about site hydrogeological data and temporal criteria, much of which is typically not available for most development sites, nor does it take into consideration any local geologic features (it assumes homogeneous, isotropic site hydrogeological conditions), and therefore may not be entirely suitable for many Nova Scotia sites.

Further, the Theis equation involves several simplifying assumptions that must be considered when interpreting the calculation results. For example, the equation assumes radial flow in an infinite, homogeneous, isotropic, porous medium, confined aquifer that receives no recharge. Since there are four hydrogeologically different HUs beneath the Uniacke SPS study area, and neither of them are homogeneous, isotropic, or consist of porous medium, then the prime Theis assumptions do not hold for the study area[100], so the NSE (2011) “toolkit” spreadsheet method cannot be used without modifying the approach and spreadsheet equations.

However, the equations used in NSE (2011) spreadsheet macros are password-protected and cannot modified – it cannot even be verified, which in our view is scientifically unprofessional. For these reasons, we are reluctant to use the NSE (2011) “toolkit” spreadsheet in most cases, and specifically for this assignment re. the Uniacke SPS study area.

9.7.2 Best guesses on well interference for the Uniacke SPS study area

There are two relatively nearby development projects with Meguma bedrock HUs for which we did (reluctantly at client requests, and with clear caveats applied) use the NSE (2011) “toolkit” spreadsheet to assess possible well interference (ewC, 2023a, 2023b).

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[100] Computerized groundwater flow models can partially accommodate these basic Theis assumptions, providing there is sufficient data available to do so, by discretizing the modelling domain according to its geology and hydrogeology – thus allowing for discrete computation of any different HU parameter characteristics across the areas of interest, and at different scales of computation.

Further, where the Theis equation cannot accommodate fracture flow, computer groundwater models may do so by treating fault zones as discrete HU units using the porosity equivalence approach, employing either by double-porosity methods, single fracture, or single vertical (or inclined in the case of 3-D models) dyke methods (Kruseman and de Ridder, 1991), or combination hybrids thereof, and applying gradational changes within and away from to those fault zone features to simulate the effects of branching or adjustment fractures within an otherwise non-porous medium.

Additionally, most computerized groundwater flow models can address leakance between HUs to simulate combined local and regional groundwater flows, variable recharge according to different overburden materials above bedrock HUs or interest (or carry out discrete flow computations within those overburden HUs in the case of 3-D models), and recharge/discharge via wetlands, rivers, and lakes (with varying stages (water levels) within the latter two, as well as total water balance into, within, and out of the modelling areas of concern.

In the one case, only Taylors Head Formation bedrock was present at the development area, for which there were three storativity (S) values from nearby wells but in a structurally different area. For that location, the spreadsheet equation pointed to a residential development density of about one lot per 1.7 hectare as meeting the NSE (2011) well interference acceptability criteria.

The other development area, in Halifax County, which geology appears similar to that underlying the south-easternmost 10% of the Uniacke SPS study area. For all three metasedimentary HUs combined at that location, the spreadsheet equation pointed to a residential development density of approximately one lot per 1.33 to 1.37 hectares likely meeting the NSE (2011) well interference acceptability criteria.

As a very preliminary suggestion, residential development lot densities within the ranges noted above might be appropriate for existing and new future residential development within the Uniacke SPS study area. As such, subtracting major lake, wetland, park and watershed areas from the study area, avoiding well interference may limit the total number of development lots (existing and future) within the overall Uniacke SPS study area to less than about 4,500 for a 1,350 L/day water demand, or about 7,000 lots for assuming an 860 L/day water demand. Of course, since the nature of well interference may vary across the study area, individual studies using appropriate data should be carried out for each new development.

10.0 Uniacke SPS study area well water quality

10.1 Natural well water quality – general background information

Wells drilled into the various formations of the Meguma Supergroup generally produce good quality water, but which can vary locally depending on well location and construction, area land use, and specific local bedrock and soil lithology.

Throughout the province, the Goldenville Group HU has been seen to produce mostly calcium-bicarbonate type waters inland, to sodium-chloride type waters nearer the ocean (although sodium-chloride type waters may result from the use of winter road maintenance salt), typically with medium alkalinity, generally neutral pH, low-to-medium hardness, and generally total dissolved solids. Iron and manganese can both exceed the Health Canada (2024)[101] aesthetic objective values of 0.3 and 0.02 mg/L[102], respectively, as well as the manganese health objective value of 0.120 mg/L, with manganese (generally more difficult to treat) often present only slightly above lab detection levels. Arsenic may also be problematic in Gold Districts.

Depending on location, particularly in gold districts, well water from the Goldenville Group may also naturally contain arsenic in concentrations above the Health Canada (2020) health objective value of 0.010 mg/L.

Wells drilled into the various formations of the Halifax Group also produce generally good quality water, except iron concentrations in water from the Halifax Group are frequently more elevated that they would be from wells drilled into the Goldenville Group. This is largely due to the Halifax Group formations, particularly the Cunard Formation, containing larger amounts of iron-sulphides (pyrite, pyrrhotite, arsenopyrite). Water alkalinity and pH may be slightly lower than in waters from the Goldenville Group.

Also, because of the finer-grained nature of the original rock before metamorphism, uranium values in groundwater from the Halifax Group may be elevated, and frequently above Health Canada (2024) guideline.Because of the presence of uranium in the rock (see “hotter spot” in the southern part of the Uniacke SPS study area in Figure 35 correlates with the Cunard Formation there), radon gas emissions from the Halifax Group into homes may also be a concern.

Wells drilled into granodiorites may be expected to produce generally good quality water, as with the other bedrock HUs present at the Uniacke SPS study area, have been seen to produce calcium-bicarbonate type waters inland, to more sodium-chloride type waters nearer the ocean or

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[101] While in most other provinces the Health Canada Guidelines for Canadian Drinking Water Quality values are just that – guidelines values to guide water professionals, Nova Scotia Environment has elected to adopt those guideline values as regulation values.

[102] One mg/L is roughly equal to one part per million. One mg/L is equal to 1,000 µg/L. One µg/L is roughly equal to one part per billion.

in areas where groundwater is affected by winter road maintenance salt), typically with low-to-medium hardness and total dissolved solids, and pH values near or slightly below neutral. Iron and manganese can both exceed their respective Health Canada (2024) aesthetic objective values of 0.3 and 0.0259 mg/L, respectively, and the health objective of 0.120 mg/L for manganese. This is due largely to the hematization[103] that is common along bedrock fractures. Depending on local, arsenic may also be present within bedrock fractures, resulting in some well waters exceeding its health guideline value.

Uranium is frequently associated with granitic rocks, but not so much with granodiorite. That being said, uranium values in water from wells drilled into granodiorite may still also exceed its health objective guideline value. Experience has shown that uranium concentrations in well waters may trend higher in areas of higher elevation where groundwater oxidation levels (redox[104] state) are highest, and lower in areas of lower elevation or which may be influenced by wetlands. However, those same low redox conditions may also be conducive to iron and manganese becoming dissolved and released into solution in groundwater.

Another concern with the uranium (noted earlier) is the potential for radon[105] gas to be dissolved in groundwater or present in the air in buildings, which in addition to being a carcinogen, in extreme cases may also result in the production of lead 210 (^{210}Pb) in water samples.

While there are Health Canada (2024) guidelines for uranium in water and radon in air, there are no guidelines for radon dissolved in groundwater, which in extreme circumstances may serve as a source of radon to the air – from which health issues may arise, for example, from hot showers.

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[103] Hematite, or Fe2O3, is one of the earth's most abundant minerals and an important ore of iron. It is frequently associated with manganese oxide minerals.

[104] Redox (reduction-oxidation) is a type of chemical reaction that is characterized by the transfer of electrons between chemical species, where the species that loses electrons (the reducing agent) undergoes oxidation (increase in redox state), and the other species (the oxidizing agent) undergoes reduction (gains electrons – a decrease in redox state). This type of reaction occurs between oxygen and iron when steel rusts. Although redox reactions are commonly associated with the formation of oxides from oxygen molecules, oxygen need not be included in all such reactions, as other chemical species (such as nitrogen) can serve the same function.

In underground aqueous environments, the use of oxygen by bacteria will create low redox conditions, under which some of the elements bound in the rock that makes up aquifers, such as iron and manganese, can go into solution to increase their concentrations in well water. Reducing conditions, on the other hand, will cause elements such as uranium to precipitate from solution and decrease its concentration in well water. Because arsenic may exist in two common oxidation states, it can be released from minerals to groundwater under either oxic or reducing conditions.

[105] Radon gas is the sixth progeny product of the radioactive decay of uranium-238 (which progeny are thorium-234, protactinium-234, uranium-234, thorium-230, radium-226, then radon-222). While radon-222 has a half-life (the time it takes for a radioactive element to decay to half its mass by the emission of energy – alpha, beta and gamma particles) of only 3.82 days, its progeny are polonium-218 (half-life 3.05 minutes), lead-214 (half-life 26.8 min.), bismuth-214 (half-life 19.9 min.), polonium-214 (half-life 1.64x10-4 seconds), then lead-210, which has a half-life of 22.3 years and which can contribute to lead in well water. The amount of radon gas that is naturally released directly from bedrock fractures into the air may be high enough to resent as an airborne carcinogenic (lung) concern.

10.2 Natural well water quality – a review of local available data

10.2.1 Tabulated data available within the Figure 43 mapping area

Well water quality results from residential, business, school, or other public wells are normally kept private. Therefore, the only water quality data that is generally publicly available may come from the occasional pumping test and from publicly funded research projects.

There is publicly available water quality data (Kennedy, 2018, 2021) from 20 wells in the Figure 43 mapping area – all of them within the Uniacke SPS study area. Of these, 16 plot as having been drilled into the Taylors Head Formation, 3 plot as having been drilled into the Beaverbank Formation, and one plots within Cunard Formation. But for 6 of the wells (including one in the Cunard Formation), only values for uranium are reported.

Table 20 presents the publicly available data from Kennedy (2018, 2021) for the 14 wells that have more complete numbers of analytical parameters[106].

Table 20. Published water quality data from wells drilled within the Uniacke SPS study area.

Parameter/ Sample ID	Ptest505	Ptest509	Ptest510	Reg5427	Ptest504	Ptest506	Ptest507
Sample year	2005	2004	2004	2017	2005	2004	2004
Easting	438166	438472	438452	433341	438487	438406	438493
Northing	4969078	4969382	4969316	4972363	4969146	4968939	4969254
Location Accuracy (m)	15	15	15	10	15	15	15
Bedrock HU	Beaverbank	Beaverbank	Beaverbank	Taylors Head	Taylors Head	Taylors Head	Taylors Head
Alkalinity (as Ca) (mg/L)	99	84	100	26	310	180	160
Bicarbonate (mg/L)	98.8	83	100	26	310	180	160
Carbonate (mg/L)	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Sodium (mg/L)	1.7	37.5	47.5	3.6	16	45.6	17.4
Potassium (mg/L)	25	0.7	1.6	0.64	2.8	2.7	1.7
Calcium (mg/L)	120	39.6	64.1	5.8	130	93.8	60.6
Magnesium (mg/L)	0.05	7.5	16.6	1.9	36	21.6	14.2
Fluoride (mg/L)	--	--	--	0.05	--	--	--
Sulphate (mg/L)	53	14	34	4.5	64	41	43
Chloride (mg/L)	230	83	140	4.1	98	140	35
Hardness (as Ca) (mg/L)	390	130	228	22	470	323	210
Tot. dissolved solids (mg/L)	**543**	240	381	46	**547**	464	279

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[106] These are for a minimal number of analytical parameters – mostly for the major anions and cations in water, plus arsenic, uranium, iron and manganese. Most lab analysis that are done for more complete general chemistry and metals analysis typically include upward to 60 different analyzed and calculated parameters.

pH	6.53	8.1	7	6.83	7.45	7.4	7.5
Nitrate/nitrite (mg/L)	0.35	0.05	0.58	0.054	0.025	0.25	0.025
Arsenic (µg/L)	1	2	7	0.5	**86**	**10**	**29**
Uranium (µg/L)	2.9	1	1.3	0.05	8	3.3	1.3
Iron (µg/L)	25	25	25	25	240	25	25
Manganese (µg/L)	**36**	**92**	**570**	1	**250**	**2700**	**720**

Parameter/ Sample ID	Ptest508	Reg1767	Reg1770	Reg1811	Reg5428	Reg3114	Reg1547
Sample year	2005	1987	1989	2006	2017	1993	2006
Easting	438368	438533	438408	438208	430871	434222	434892
Northing	4968928	4968977	4969216	4969018	4973241	4971517	4970876
Location Accuracy (m)	15	15	15	15	19	51	145
Bedrock HU	Taylors Head	Taylors Head	Taylors Head	Taylors Head	Taylors Head	Taylors Head	Taylors Head
Alkalinity (as Ca) (mg/L)	130	--	--	99	58	27	120
Bicarbonate (mg/L)	135	--	--	99	58	27	117
Carbonate (mg/L)	0.5	--	--	0.5	0.5	0.01	1
Sodium (mg/L)	77	--	--	1.9	7	7.2	24
Potassium (mg/L)	0.1	--	--	13	1.3	2.9	3.5
Calcium (mg/L)	120	--	--	68	18	8.9	56
Magnesium (mg/L)	24	--	--	0.1	3.5	2.9	8.7
Fluoride (mg/L)		--	--	--	0.05	--	0.1
Sulphate (mg/L)	45	--	--	22	7.2	2	18
Chloride (mg/L)	250	--	--	84	13	18.6	56
Hardness (as Ca) (mg/L)	400	226.7	290	220	58	34.2	180
Tot. dissolved solids (mg/L)	**619**	336	434	274	95	--	255
pH	6.89	7.4	7.7	7.48	6.84	6.3	7.96
Nitrate/nitrite (mg/L)	0.67	--	--	0.025	0.45	0.025	0.84
Arsenic (µg/L)	**24**	**60**	**40**	**30**	0.5	1	--
Uranium (µg/L)	5.6	--	--	3.5	0.68	0.05	6.9
Iron (µg/L)	150	**410**	20	25	69	**24000**	--
Manganese (µg/L)	**66**	**2400**	**170**	**38**	15	**200**	2.1

Highlighted/bold values exceed their Health Canada (2024) guidelines values of: 500 mg/L for TDS (aesthetic); 10 µg/L for arsenic (health); 300 µg/L for iron (aesthetic); and 120 µg/L (health) and 20 µg/L (aesthetic).

10.2.2 A graphical means of assessing groundwater quality – Piper diagrams

What are piper diagrams?

Piper Diagrams were used to to help analyze and augment the water quality information available for this study for wells likely to have been drilled into the each of the Meguma Supergroup HUs, both within and outside of the Uniacke SPS study area.

The use of Piper (1944) Diagrams is a graphic procedure to segregate relevant data to understand the sources of the dissolved constituents in water. It is based on the premise that most natural waters contain cations (positively charged ions) and anions (negatively charged ions) in chemical (electric charge) equilibrium. In water, the major cations are two “alkaline earths”, calcium (Ca^{2+}) and magnesium (Mg^{2+}), and one “Alkali”, sodium (Na^{+}). The common anions are one “weak acid”, bicarbonate (HCO_3^{-}), and two “strong acids”, sulphate ($SO_4^{2-)}$ and chloride (Cl^{-}).

In a Piper Diagram, cations are plotted in the left triangle and anions in the right, with the bases of the triangles representing each of their respective cations and anions. Since lab values are normally reported as mg/L and ions of same charge may have different atomic/molecular weight, lab values need to be normalized based on atomic weight, and the calculated milliequivalent per litre (meq/L) values are plotted as their relative percentage among the cations, and the anions, in each their respective triangles. Thus, each pair of plots shows the ionic proportion of the main cations and anions for each water sample. Those cation and anion plots are then projected into the diamond, and according to the location of the sample plot in the triangles and diamond, hydrochemical facies can be identified. These facies are the diagnostic chemical characteristic of water solutions occurring in hydrologic systems, as explained in Figure 61.

Piper Diagrams can thus help define spatial differences in waters from various sources and provide diagnostic evidence for water mixing from those sources, and help describe temporal changes as groundwater travels through aquifers.

Collecting the data needed to construct this study’s Piper Diagram

Figure 62 shows the Piper Diagram constructed for this study. To obtain the required data, using GIS, the 39.6 km (east-west) by 28 km (north-south) geology maps by Horne et al (2009a, 2009b, 2009c, 2009d) were overlapped onto the well water quality database (Kennedy, 2018, 2021) to extract those records while noting what formations they plot onto. Of the 96 well water quality records extracted, 44 reported well locations with better than 300 m accuracy. Of those, 28 records contained all of the water quality data required to produce Piper Diagrams.

Those 28 well records also reported well locations accuracy better than 180 m; 4 wells plot as having been drilled into the Cunard Formation (none are located within the Uniacke SPS study area), 3 wells plot as having been drilled into the Beaverbank Formation (all are within the

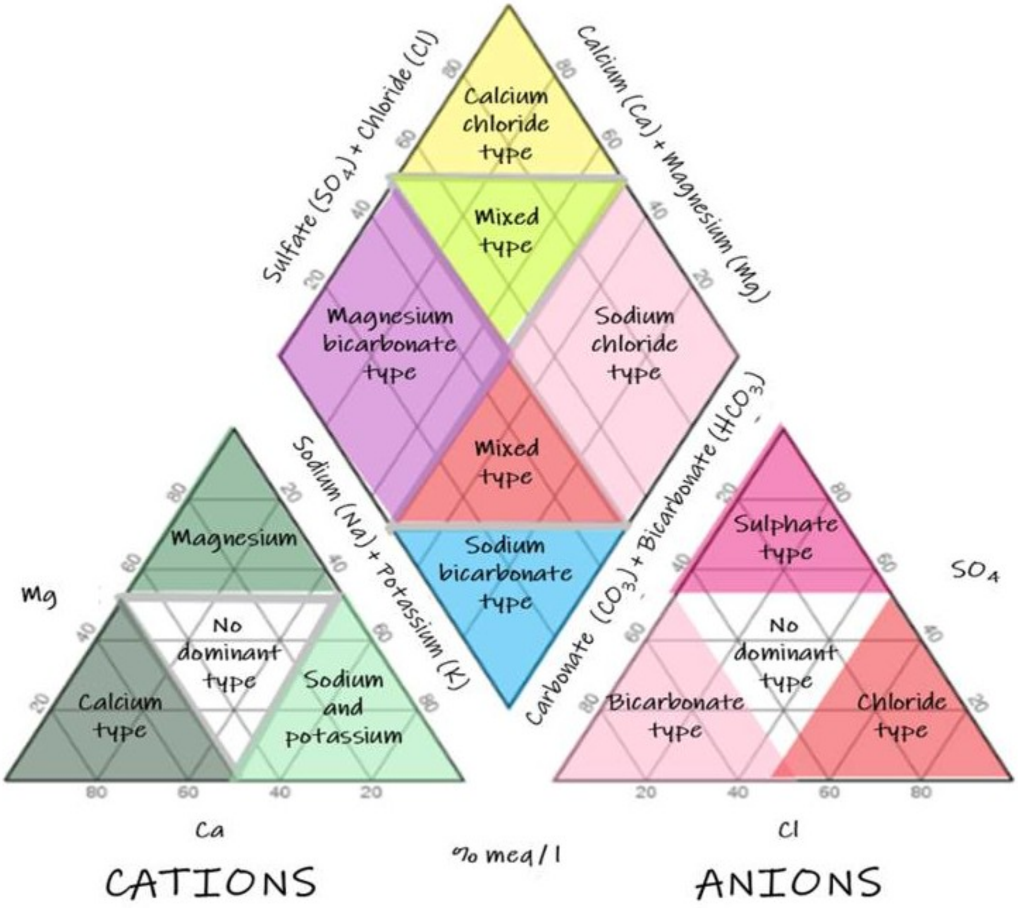

Figure 61: Water hydrochemical facies as defined by Piper (1944) Diagrams.

Uniacke SPS study area boundaries), and 21 plot as having been drilled into the Taylors Head Formation (9 of which are located within the Uniacke SPS study area).

No well records from the Kennedy (2018, 2021) water quality database plot as having been drilled into any of the Meguma granitic rocks within the above-noted 39.6 km by 28 km geologic mapping area.

10.2.3 What the data tells us about well water within the Uniacke SPS study area

Based on Figure 62, groundwater samples from wells drilled in the Beaverbank and Taylors Head Formation HUs within the Uniacke SPS study area are mostly calcium-bicarbonate type waters. Those from the Beaverbank Formation HU that plot as calcium-chloride water are known to have been influenced by road salt – without such road salt effects, wells drilled into the Beaverbank Formation within the Uniacke SPS study area should be expected to plot within the same general water facies grouping as the wells drilled into the Taylors Head Formation.

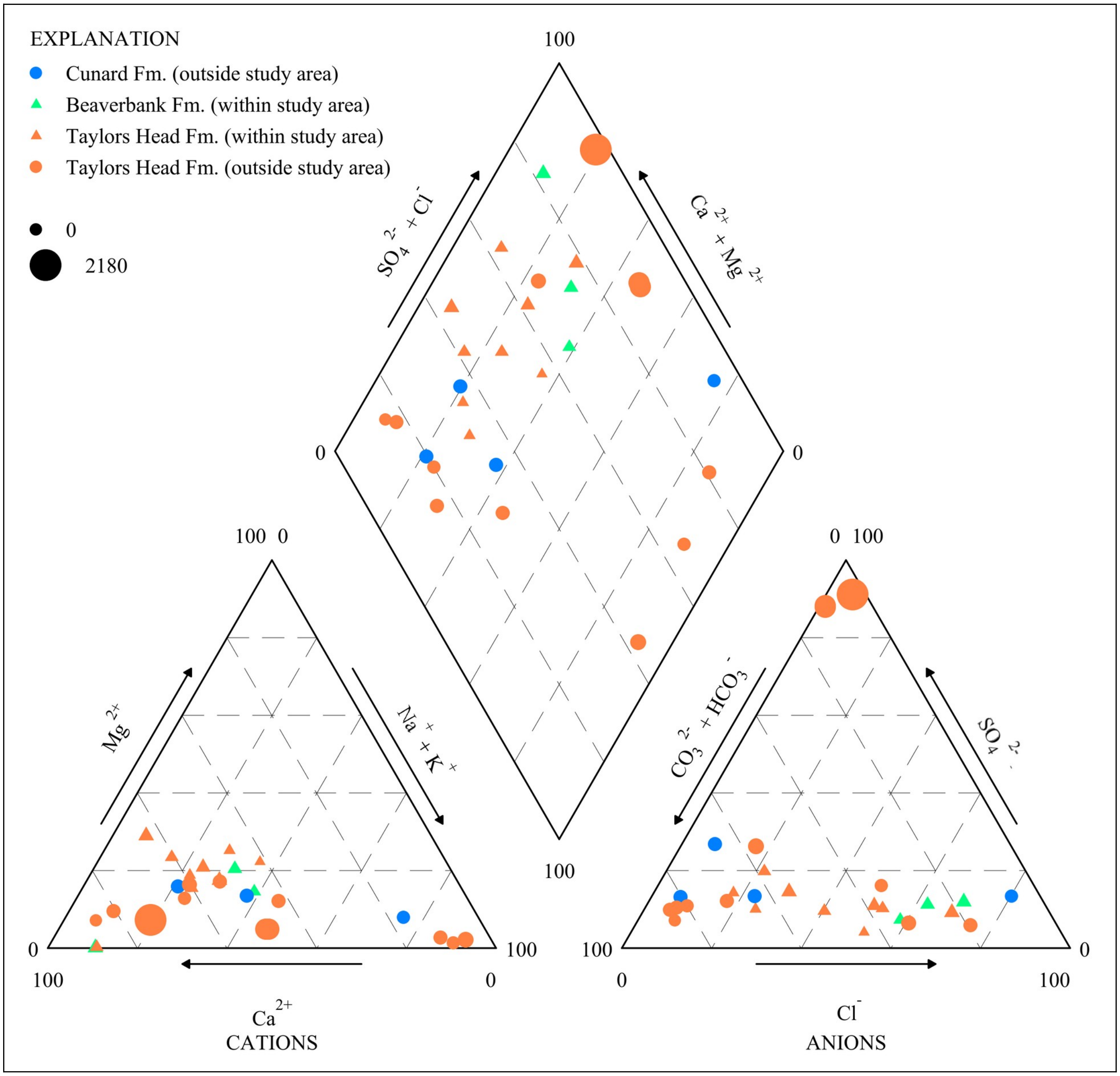

Figure 62: Piper Diagram for the 28 well water samples (Kennedy, 2018, 2021) with required data and better than 180 m recorded location accuracy within the geology map areas of Horne et al (2009a, 2009b, 2009c, 2009d). Data from wells falling within the Uniacke SPS study area are represented by triangles, all other data by circles, with symbol sizes proportional to TDS.

In Figure 62, three of the four water samples from wells drilled in the Cunard Formation HU plot as being generally more bicarbonate-rich, generally, than the bulk of the water samples from the Beaverbank and Taylors Head Formations.

The one Cunard Formation water sample that plots to the far right of both of the cation and anion triangles very much appears to be directly and recently (not long before sampling) influenced by likely nearby road salt sources, as have the three Taylors Head Formation water samples plotting within the same general groupings. The recentness of the road salt effects is indicated by similar positions of those samples for sodium and chloride[107]. This is likely a result of the bedrock fractures present in those wells being in relatively direct hydraulic communication with the surface road salt sources.

Three of the Taylors Head Formation water samples plot as calcium-sulphate type waters, with two of them bordering on being sodium-sulphate type waters. Those three water samples were collected from the far eastern regions of the Horne et al (2009a, 2009b, 2009c, 2009d) mapping within the western edge of the Shubenacadie Geologic Basin, and have clearly been influenced by Windsor Group gypsum and halite (rock salt).

With few exceptions, the water samples represented in Table 20 are all moderately hard to very hard[108], with low to moderate alkalinity and near neutral to slightly above neutral pH.

Samples Ptest506 and Reg1767, with extremely high manganese values from the Taylors Head Formation, are known to have been influenced by old mine workings at South Uniacke – likely as a result of low redox condition created by decomposing mine timbers (these wells line up perfectly with plots of old mine workings by Faribault (1902) and the responses from pumping tests carried out on one of them in the 2010's confirmed hydraulic communication with old mine workings). All other water samples with ID's starting by "Ptest" are also from the same general area – thus the generally high manganese values for them also.

The unrealistically high iron value shown for sample Reg3114 in Table 20 (which appears may have been collected from the Uniacke & District Volunteer Fire Station well?) may be a biased analytical result obtained due to improper water sampling for metals[109].

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107. Sodium is a non-conservative element, in that it has a tendency to react with aquifer materials and become bound to the, thus generally not being able to migrate very far with groundwater flow. By comparison, chloride is a conservative element – it does not react readily with most aquifer materials and as such is able to migrate over long distances along groundwater flow paths. Road salt (the mineral halite) is generally indicated by the presence of sodium and/or chloride with with no sulphate present. As such, sodium and chloride plotting in relatively similar proportions within Piper Diagrams is usually indicative of nearby road salt sources.

108. The simple definition of water hardness is the amount of dissolved calcium and magnesium in the water. Hardness values of 0 to 60 mg/L reported as calcium carbonate is classified as soft; 61 to 120 mg/L as moderately hard; 121 to 180 mg/L as hard; and more than 180 mg/L as very hard.

In hard water, soap reacts with calcium (which can be relatively high in hard water) to form "soap scum". When using hard water, more soap or detergent is needed to get things clean, be it hands, hair, or laundry, and it will often make hands feel like there is a film of residue on them after washing them. Hard water will often leave spots or a film on dishes in dishwashers, or films on shower tiles. Although the effects of hard water may be unsightly, drinking-water may be a contributor of calcium and magnesium in the diet, and the calcium and magnesium that make water hard are present in a form that can be used and is useful to good health.

109. Water samples collected for metals analysis from wells that have not been fully developed may and often do contain suspended solids – aquifer rock material from drilling or rock or mineral deposits originating from bedrock fractures. Unless they are asked to filter those samples, labs will add nitric acid to pH 2 to the metals portion of the samples before running them through the analytical instruments. This low pH will cause any rock or mineral particles suspended in the sample to become dissolved, thus releasing the

...cont'd on page 161

10.3 Other water quality issues – anthropogenic sources

Not included in any of the data available and only briefly mentioned above, but of equal concern to the natural quality issues for well water, are the possible human effects on groundwater quality that can occur in both rural and rural-urban settings. These concerns may include:

- ***Winter maintenance road salt:*** NSTIR has begun to apply winter salt to roads again where before, sand may have been used. They do so based on claims that 3 to 4 times more sand than salt needs to be applied, and that applying that much sand with 5% to 10% salt in it to keep it from freezing will result in just as much salt being applied on roads. Somehow, however, that math does not make sense, so consideration should be given to applying sand (even if it contains 5% to 10% salt) to on-site and nearby roads, if possible to help avoid damage to new on-site subdivision wells. A concern may continue to exist along the East Uniacke Road should NSTIR apply salt to it.
- ***Heating oil tank and related fuel line failures:*** Poorly installed heating oil storage tanks can be subject to early failures, and fuel transfer lines placed under concrete floors may leak for long periods of time before getting noticed. The tills present on- and near-site are sandy likely thin and thus, may not offer much protection to groundwater against heating oil tank spill events – their thickness does not appear equally distributed across the area and precipitation percolating through the tills may still reach deeper aquifer units, which effects are difficult to mitigate.
- ***Fuelling service stations:*** Underground storage tank leaks and spills at filling islands, past and present, always pose a threat to groundwater supplies. Additionally, numerous shallow monitoring wells are typically placed around service stations, which are very rarely if ever properly decommissioned, and which can serve to direct present or past fuel spills into deeper groundwater-bearing horizons.
- ***Vehicular spills:*** Although these may involve few events and smaller volumes that are are often easy to spot and deal with, accidents involving bulk fuel delivery vehicles present a much larger threat to well water supplies and can involve large volumes of petroleum that underground, are more difficult to deal with. And although most doing backyard oil changes today dispose of their used oil properly, such was not the case in the past, particularly in rural areas. And unless their fuel tanks were emptied, old abandoned vehicles may also have leaked that fuel into the soil and bedrock.

...cont'd from page 160 elements that make up those suspended particles, thus providing for false-hire results for metals. Elevated values for aluminum and iron are typical of this.

By all rights, any potable water supply that contains suspended solids should be analyzed to include what is contained within those suspended particles (which samples would also register high turbidity values – their source should also be investigated). However, that sample will NOT be representative of the aquifer, but solely of poor well conditions. Groundwater samples collected for metals analysis from suspect wells (i.e. incompletely developed new wells) which purpose is to characterize aquifers should be field filtered to 0.45 µm before being bottled and preserved with nitric acid, and/or having acid added to them by the lab for analysis.

- ***Fertilizers and pesticides:*** While the more harmful pesticides are controlled in Nova Scotia, the cumulative effects of "safer" pesticides can still cause harm to groundwater and wells. The use of fertilizers in residential gardens can also impact well water by increasing nutrient (nitrates, nitrites) content in groundwater. Landscaping practices, such as growing gardens to camouflage wells (particularly if bark mulch is used), can also have deleterious effects on well water quality, particularly if the annular space outside of well casings are not properly sealed.
- ***Products used during past land-use activities:*** These may include:
    - Products used and/or disposed of in past mining activities, which may include iron and/or manganese releases from old workings, as exemplified by some the water sample results in Table 20, to arsenic from mining waste dumps and tailing ponds, as well as mercury spilled in stamp mills or as condensate downwind of them, and as mercury carried into tailings ponds.
    - Chemicals used in forestry (herbicides) and from fuel spills during harvesting.
- ***Current industrial and construction activities:*** These may include:
    - Any of those used in forestry in the past.
    - Also, specific to current industrial land use and present and future construction for residential development construction:
        - Local increases in nitrates and possibly hydrocarbons from blasting,
        - Physical damage to wells from ground shake causing debris in bedrock fractures to mobilize – possibly stopping or reducing flow through some fractures, while opening up flow in others. Such damage was confirmed for a South Uniacke area well, allegedly (as evidenced by blasting ignition tubing spread about not far from the affected well) from unmonitored blasting.
        - Water quality damage to wells due to disturbances of material lodged within bedrock fractures from ground-shake, which in the Uniacke SPS study area is likely to result in increased in well water values for turbidity and various metals including iron, manganese and arsenic.
    - Improper management of the waste organic materials (branches, tree stumps and trunks, root masses and organic soils from wet area) produced while grubbing construction locations for new roads and lot development. Many times, developers will simply bury those grubbing materials on-site, which is akin to constructing landfills without any proper designed of monitoring. Such activity must never be allowed were wells are to also be constructed, whilst the low redox subsurface conditions generated from the decomposing grubbing materials are likely to cause the release dissolved metals into groundwater. Grubbing materials should instead be properly disposed of as source material at locations designed for producing compost.

Much if not all of the above will have been addressed for the part of the Uniacke SPS study area that is underlain by granodiorite bedrock (an environmentally sensitive area due to the shallow soils and propensity for fractures in this more competent rock type to have larger apertures and to extend over greater distances, frequently to surface), as it is a part of the Pockwock Lake headwaters water supply source protection area. But such may not be the case for the rest of the Uniacke SPS study area.

In addition to the above, a roughly 1,070 km2 area extending from immediately north of the Uniacke SPS study area to the Minas Basin is defined by MEH as a “Wind Energy Zone”.

There have been growing concerns and documentation made available on the effects of offshore wind farms on marine life due to construction and during operation, to the emissions in water of infrasound (ultra low frequency sound), which is caused by the harmonics created when windmill blades passing their towers. But little information can be found on the effects of infrasound on aquifers and water wells[110], except at the rural community of Dover, Chatham-Kent region, Ontario (Groundwater Canada, 2023 and earlier online news articles).

The issue there is regarding allegations by residents living near the North Kent 1 Wind Complex starting in 2017 that their well water quality was being severely impacted by the operation of the wind farm. A report from an Expert Panel (Benn et al, 2021) commissioned by the government of Ontario concluded that of the 50 to 70 tested wells located some 1.2 to 1.5 km (AECOM, 2017) from the windmills, nearly all had due to infrasound emissions from the wind farm experienced increases significant increases in turbidity and several metals relative to well-controlled baseline pre- and post-construction on- and off-site baseline well samples. These increases were all due to materials dislodging from soils and bedrock aquifer fractures by the infrasound generated by the wind farm. An additional concern regarding the damaged wells is that due to inaction by the Ontario government, in late 2024 the lead author of the Expert Panel report and members of the effected community had to launch an official request to the Ontario Provincial government to take action. As of 08 January 2025, the effective residents have heard nothing back from the Ontario government (The Chatham Voice, 2025).

A similar situation of well damage potentially could occur at the Uniacke SPS study area due to the fracture nature of the aquifer units that underlie it and the Wind Energy Zone to the north of the study area.

10.4 Maintenance practices for existing and new wells

All new wells should be properly chlorinated after drilling and/or after installing pumps in them, and tested for coliform after one to two weeks of use (meanwhile using bottled water to drink and cook) to allow the chlorine to properly dissipate to avoid false negatives.

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[110] Some concerns about the effects of infrasound emissions of operating windmills on water supply wells appear to be rising in the UK.

Wells should be regularly tested for coliform, general chemistry, and metals analysis. Again, to ensure that all debris has cleared from newly drilled wells or wells with newly installed pumps, to avoid false-positives for metals that may be associated with debris suspended in well water, sampling should be done after about two weeks of regular well use (again, using bottled water for drinking and cooking until lab results are available).

Notwithstanding the need for regular water quality testing, the above testing should be done both before (to assess baseline conditions) and following (to assess possible impacts) from any large-scale work on or near the well, including any major land-use changes and/or heavy construction and blasting.

As an extension of this, to reduce the chances for septic systems failures, which can be deleterious to on-site and neighbouring well, well owners should be encouraged to undertake proper and regular septic system management. This includes disposing of only what septic systems are designed to handle, (i.e. “flushable” products are seldom really flushable and most don’t break down in septic systems, oils and grease disrupt system functioning, and placing too many solids into septic tanks can prematurely reduce their effluent residence times for proper treatment). The general recommendation for average families of four is that septic tanks should be pumped every three years to remove floating greases and sinking solids to maintain proper effluent residence times.

10.5 Water quality issues and treatment options

The more common water quality issues that may be expected from wells drilled within the Uniacke SPS study area may include any one of more of the following:

- ***Hardness:*** Can cause soap efficiency to decrease (i.e. needing more soap for laundry), spotting of dishes in dishwashers, development of calcium films on bathroom tiles, and buildup in piping, hot water tanks, and boilers. Hardness is an aesthetic concern with no guideline, since the calcium and magnesium that cause hardness are in a form that is beneficial to health.

- ***Elevated iron and/or manganese:*** Can cause staining of plumbing fixtures, staining of laundry if bleach (a strong oxidizer) is used, or staining in dishwashers (many dishwater soaps contain bleach). They can also cause bad taste in drinking water when present in higher concentrations. While iron is an aesthetic concern (there is no evidence of dietary water-borne iron toxicity in the general population), chronic exposure to manganese may affect neurological development and behaviour.

- ***Sodium and/or chloride:*** Most likely to be issues due to road salt. Elevated sodium in well water may cause problems for people with high blood pressure, and elevated chloride values can make water more aggressive to plumbing and heating systems.

- ***Elevated TDS:*** A result of the cumulative concentration of other elements present in the water. More likely to be a problem for wells that produce water that is hard and/or high in sodium and/or chloride.

- ***Taste, colour, odour issues:*** A byproduct of either elevated iron or manganese.

- ***Arsenic:*** A naturally occurring element present in much of the Meguma Supergroup bedrock. Arsenic is colourless, odourless, and produces no taste effects; the only way to confirm its presence and the efficacy of any arsenic treatment system is to test water supplies frequently and to water samples analyzed by a certified lab. Chronic exposure to arsenic can result in lung, bladder, liver or skin cancers and cause other skin, vascular and neurological effects.

- ***Uranium:*** A naturally occurring element that is present in approximately 4% of water wells in Nova Scotia, and which is prevalent (present in approximately 21.3% of wells) within plutonic HU's (Drage and Kennedy, 2013). The health concerns are not regarding radioactivity (uranium needs to be processed and/or present in extreme concentrations, such as may be present at mine- able uranium deposits), but at the concentrations found in well water are instead related the toxicity of the metal as relates to liver cancer, Raynaud's disease[111], effects on bone, the circulatory system, thyroid, spleen, and central nervous system.

  As was noted in Section 7.4, however, uranium and its radon gas and/or lead-210 (210Pb) daughter products should not be expected to be issues of concern on-site.

The matrix in Table 21 lists these and a few other types of water quality problems that may occur and be required to be addressed for water from wells drilled on-site, along with the more common types of home water treatment methods available to treat each issue.

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[111] A disorder that causes decreased blood flow to the fingers. In some cases, it also causes less blood flow to the ears, toes, nipples, knees, or nose. Spasms of blood vessels happen in response to cold, stress, or emotional upset.

Table 21. Water quality problems that may exist for Uniacke SPS study area wells and common home treatment methods available to address them.

	Adsorptive media filtration[1]	Aeration and filtration	Anion exchange[1]	Carbon filter[1]	Continuous chlorination and filtration	Distillation	Oxidizing media filtration	Ozonation and filtration	Reverse osmosis	Ultraviolet (UV) disinfection	Water softening (cation exchange)
Arsenic	●								●		
Bacteria[2]					●	●		●	●	●	
Calcium (hardness)						●			●		●
Chloride						●			●		
Colour, taste, odour issues		●		●	●	●	●	●	●		
Hydrogen sulphide		●		●	●		●	●			
Iron	●	●		●	●	●	●	●	●		●
Magnesium (hardness)						●			●		●
Manganese	●	●		●	●	●	●	●	●		●
Sodium						●			●		
Uranium	●								●		
Viruses[2]					●	●		●	●	●	

1. The substances these technologies reduce or remove depends on the filter media or resin.
2. If using a filter, it must have the pore size needed for the bacteria or virus being removed.

Table 22 describes the treatment technologies listed in Table 21 and gives ball-park cost estimates for each. The cost estimates are based on quotes obtained in 2017 and 2021 and on research done in 2018, adjusted to 2024 in Canadian dollars; actual costs may vary. In general, the low-end cost is for a treatment unit homeowners may be able to install; the high-end cost is for treatment systems installed by water treatment professionals. Except for under-counter point-of-use units, water treatment systems should be installed by professionals.

Table 22. Summary of home water treatment options.

Treatment option	Description	Pros and cons	Point-of-use cost estimate	Point-of-entry cost estimate	Designed to fully or partially remove
Adsorptive media filtration	A charged media bed causes ions of the opposite charge to be pulled out of the water and attach to the media.	**Pros:** Produces very little wastewater. Does not require adding chemicals to the water. **Cons:** Treatment effectiveness may depend on the pH of the water.	Initial: $420 to $980 Maintenance: $420 to $700 every 6 to 12 months	Initial: $4,700 to $9,100 Maintenance: $1,400 to $1,800 per year	Depends on the type of media. The two most common are activated alumina and iron-based. Activated alumina media removes arsenic, fluoride, selenium, sulphate, uranium. Iron-based media removes arsenic. It may not be as effective at removing arsenic if there is also phosphate in the water.
Aeration and filtration	An aerator brings oxygen into the water. The oxygen helps change dissolved contaminants into solid particles large enough to be filtered out of the water. Some types of aeration cause VOCs and dissolved gases to evaporate out of the water.	**Pros:** Does not require adding chemicals to the water. **Cons:** Water with too much oxygen can be corrosive and corrode pipes; this may be a health concern if there are copper or lead pipes.	N/A	Initial: $1,500 to $8,900 Maintenance: Extra water to backwash; replacement of the filter media.	Color, taste, or odor issues Ammonia, chlorine, hydrogen sulfide, iron, manganese, methane, other dissolved gases, radon, TCE, THMs, vinyl chloride, VOCs May partially remove: arsenic (only if there is also high iron), nitrite, radium.
Anion exchange	Anion exchange removes dissolved minerals in the water. Sodium chloride or potassium chloride (salt) added to the system replaces negatively charged minerals in the water.	**Pros:** Sodium chloride and potassium chloride are safe to handle and easy to buy. **Cons:** Anion exchange may affect how corrosive water is to pipes; this may be a health concern if there are copper or lead pipes. If treatment is not maintained properly, high	N/A	Initial: $2,900 to $5,100 Maintenance: $140 to $650 per year for salt	Depends on the resin. Resins may be certified to remove arsenic, fluoride, nitrate, nitrite, selenium, sulphate, uranium.

Table 22. Summary of home water treatment options.

Treatment option	Description	Pros and cons	Point-of-use cost estimate	Point-of-entry cost estimate	Designed to fully or partially remove
		concentrations of the contaminant can be dumped back into the water. Salt use can negatively affect the environment.			
Carbon filter (Includes granular activated carbon filters – GAC)	Contaminants accumulate on the filter while water passes through.	**Pros:** Point-of-use carbon filters are inexpensive and easy to find and use. **Cons:** Harmful bacteria can grow if not regularly maintained and filters are not replaced according to instructions. If filter is not replaced according to the instructions it can become saturated and begin to release contaminants into the water.	Initial: $400 to $850 Maintenance: $30 to $220 every few months to replace the filter.	Initial: $1,120 to $6,000 Maintenance: Extra water to backwash or adding a disinfectant to kill bacterial growth. Replacement of the filter.	Color, taste, or odor issues Contaminant removal depends on the filter's pore size. Some filters are certified to remove chlorine, fluoride, hydrogen sulfide (H_2S), iron, lead, manganese, radon, TCE, THMs and other disinfection by-products, VOCs. Studies have shown that GAC filters are effective at removing PFAS. POE units may also treat pesticides and other SOCs.
Continuous chlorination and filtration	Chlorine bleach (a disinfectant that kills bacteria and viruses) is added to a holding tank. A pump feeds chlorine into the water, which oxidises and helps change dissolved contaminants into solid particles large enough to be filtered out of the water.	**Pros:** Use of chlorination helps prevent microbial growth throughout the plumbing system. **Cons:** Chlorination systems are complex, may take up a lot of space, and require frequent maintenance and monitoring. May create chemicals (by-products) in the drinking water. If the levels are high enough, by-products can cause long-term health issues. An additional carbon filter may be needed to remove chlorine taste from drinking	N/A	Initial: $1,100 to $4,900 Maintenance: Cost of bleach; extra water to backwash; replacement of the filter media.	Color, taste, or odor issues Arsenic (only if there is also high iron), bacteria, hydrogen sulfide (H_2S), iron, manganese, nitrite, viruses May partially remove: ammonia, radium.

Table 22. Summary of home water treatment options.

Treatment option	Description	Pros and cons	Point-of-use cost estimate	Point-of-entry cost estimate	Designed to fully or partially remove
		water.			
Distillation	Distillers boil water, which makes steam. The steam rises and leaves contaminants behind. The steam hits a cooling section, where it condenses back to liquid water.	**Pros:** Removes a wider variety and greater amount of contaminants than many other treatment options. Kills 100% of bacteria, viruses, and pathogens, water can still be consumed during boil water advisories or if the well becomes contaminated. **Cons:** Heating the water to create steam can be expensive. Water may taste 'flat' because oxygen and minerals are reduced.	Initial: $650 to $2,500 Cost consideration: Energy cost to boil water.	N/A	Color, taste, or odor issues Arsenic, bacteria, calcium, chloride, copper, fluoride, iron, lead, magnesium, manganese, nitrate, nitrite, ODS, some pesticides and other SOCs, radium, selenium, sodium, sulphate, uranium, viruses
Oxidizing media filtration	A media bed changes dissolved contaminants into solid particles large enough to be filtered out of the water.	**Pros:** More effective than other oxidation and filtration methods at removing iron, manganese, arsenic, and radium. Does not require a continuous chemical feed. **Cons:** Requires periodic regeneration of the media (backwashing or soaking with a chemical solution to make the media work again). Regeneration can be messy, and the chemicals can be harmful, so they must be handled and stored carefully.	N/A	Initial: $2,900 to $6,100 Maintenance: Extra water to backwash; cost for chemicals; replacement of the filter media.	Color, taste, or odor issues Arsenic (only if there is also high iron), hydrogen sulfide (H_2S), iron, manganese, radium
Ozonation and filtration	Ozone (kills bacteria and viruses) is	**Pros:** Does not require handling of chemicals. Ozone	N/A	Most are custom designed, must	Color, taste, or odor issues Arsenic (only if there is also high iron), bacteria,

Table 22. Summary of home water treatment options.

Treatment option	Description	Pros and cons	Point-of-use cost estimate	Point-of-entry cost estimate	Designed to fully or partially remove
	generated using electricity and then injected into the water. The ozone changes dissolved contaminants into solid particles large enough to be filtered out of the water.	rapidly degrades, so no ozone reaches the consumer through the drinking water. **Cons:** Uses a lot of energy.		call water treatment professional to get a quote.	hydrogen sulfide (H_2S), iron, manganese, nitrite, viruses
Reverse osmosis (RO)	RO uses energy to push water through a membrane with tiny pores. The membrane stops many contaminants while allowing water to pass through.	**Pros:** Removes a wider variety and greater amount of contaminants than many other treatment options. **Cons:** Can create a lot of wastewater. May require pretreatment to prevent the membrane from getting clogged. Systems may require storage tanks and booster pumps, which require space.	Initial: $560 to $2,900 Maintenance: $280 to $420 every 1 to 2 years	Initial: $10,700 to $22,000 Maintenance: $590 to $1,100 every 1 to 2 years	Color, taste, or odor issues Arsenic, bacteria, calcium, chloride, copper, fluoride, iron, lead, magnesium, manganese, nitrate, nitrite, other dissolved solids, pesticides and other SOCs, PFAS, radium, selenium, sodium, sulphate, other metals, TCE, THMs, uranium, vinyl chloride, viruses, VOCs
Ultraviolet (UV) disinfection	A UV lamp shines UV rays through the water to kill bacteria, viruses, and other pathogens.	**Pros:** Does not require adding chemicals to the water. UV disinfection can be more effective than chlorination. **Cons:** May require pre-filtration if water has cloudiness (turbidity > 1 NTU).	Initial: $350 to $600 Maintenance: $80 to $150 per year	Initial: $490 to $1,700 Maintenance: about $150 per year	Bacteria, viruses
Water softening (cation exchange)	Water softeners remove dissolved minerals in the water. Sodium	**Pros:** Sodium chloride and potassium chloride are safe to handle and easy to buy. Water softening	N/A	Initial: $2,900 to $5,100 Maintenance: $140 to $650 per year for	Calcium, copper, iron, magnesium, manganese, radium

Table 22. Summary of home water treatment options.

Treatment option	Description	Pros and cons	Point-of-use cost estimate	Point-of-entry cost estimate	Designed to fully or partially remove
	chloride or potassium chloride (salt) are added to system to replace positively charged minerals in the water. This makes the water softer. Water softeners are sometimes installed to treat only some water in the home. The water softener may not be connected to cold water plumbing or kitchen faucet plumbing.	is the cheapest option for removing hardness (calcium and magnesium). **Cons:** Water softening with sodium chloride adds sodium to the water, which may be a health issue for some people. Water softening may affect how corrosive your water is and can corrode pipes; this may be a health concern if there are copper or lead pipes. Salt use can negatively affect the environment.		salt	

To avoid selling scams, proper, complete lab analysis (general chemistry and metals scan) should be done of well water samples before deciding on what type of treatment system to install and/or making any system purchases.

In light of the our assessment of the limited water quality results available for this study, a water softener may be adequate to meet most household needs for wells that produce moderately to very hard water with some iron or manganese. However, for maintenance, some form of acid (citric-based) may be needed occasionally during system backwash to remove iron/manganese coatings that may form on resin beads should oxidizing conditions prevail at the well or water treatment system. There are water softener systems available recently that employ an inert material inside the resin beads that allows for more complete media regeneration and thus, reduced salt use when compared to systems using conventional resin media.

11.0 Summary, conclusions, suggested future work

11.1 Summary and conclusions

The geology at the Uniacke SPS study area – which today is mostly rural area but with a past history of gold mining – is the result of a long (over 200 Ma) history of tectonic continent and mountain building – of the aggregation of foreign land masses and of submarine sedimentary deposits many kilometres thick to form what is now Nova Scotia. The rocks of these land masses were extensively folded and fractured as a mountain chain was created that many was comparable to today’s Himalayas. A a part of this process, granitic plutons floated into the roots of those mountains, serving as the engine for hydrothermal fluids to mobilize and concentrate mineral deposits at numerous locations within and around the Uniacke SPS study area.

That period of mountain building was followed by about 200 Ma of erosion and more recent glaciations. The result is the exposure today at or just below surface of tightly folded, mostly vertically dipping and heavily fractured thick sequences of metamorphosed sediments and granitic plutons through which the only pathway for groundwater is via their fracture systems.

The bedrock folds and related cleavage in the Uniacke SPS study area strike mostly northeast-southwest, whereas the bedrock joints, fractures and faults strike sub-parallel to the folds as well as strike mostly northwest-southeast, defining the directions in which groundwater flows.

A lineament analysis done for this assignment to augment the available limited data suggests that locally, lineament-interpreted faults strike in three primary directions and four secondary directions, many of them related with each other, with the primary faults trending east-northeast with 0.5 km to 3 km spacing frequency that parallels Provincial-wide thrusts and dextral strike-slip faults (one of which can be traced in shaded relief form the northern part of the Uniacke SPS study are to over 50 km northeast, with local drag folding and block rotations between faults); and two sets that strike west-northwest and northwest at 0.2 km to 1.6 km spacing frequency that parallel the province-wide sinistral strike-slip fault system that defines topographic fabric of the eastern shore of Nova Scotia.

The bedrock aquifer units (HUs) present at he Uniacke SPS study area include the Early Cambrian age coarser-grained metasedimentary Taylors Head Formation, and the finer-grained Beaverbank Formation (largely siltstone), Cunard Formation (black slate), and Middle to Upper Devonian granodiorite bedrock HUs. All of these depend entirely on secondary permeability (fracture flow) to deliver water to wells. The Taylors Head Formation HU underlies about 76.5% of the Uniacke SPS study area.

The bedrock HUs are overlain by three Quaternary HU’s – two glacial tills that cover about 64% of the Uniacke SPS study area and each have different physical hydrogeological characteristics, and related drumlins, which all combined range from non-existent to slightly over 35 m in thickness (mean around 7 m, median of 5 m) within the Uniacke SPS study area.

The latest well log database (current to the end of 2020) contains records for 1,547 wells within the roughly 17km by 17km mapping area used for this study assignment, of which only 6 are dug wells (dug wells are grossly underrepresented in the database). Of the 1,571 drilled wells, 24 are reported to be commercial and/or for public use and one (in HRM) is municipal. However, many of these wells are poorly georeferenced, such that data from them can serve only for crude statistical analysis, and not to help characterize the individual bedrock HUs. But based on the width of the bedrock units at surface and known accuracy of their contact locations, a location accuracy threshold of 125 m for wells was deemed adequate to serve as data for more detailed evaluations. As such, of the 1,571 well log records, 781 could be used to assess individual bedrock HUs within the 17km x 17km greater study area, and 483 could serve to provide data within the Uniacke SPS study area. Of those, only two plot as being drilled into the granodiorite, an insufficient number to assess that bedrock HU.

The bulk of the data with accurate locations is from residential wells, which drillers typically advance only as deep as is required to meet domestic needs. So the database contains a mix of water yields and well depths from which it is difficult if not impossible to properly compare different bedrock HUs. So for this study, well yield data was individually normalized to the amount of open borehole (vertical distance from well bottoms to bottom of casings) for each of the 781 database records with accurate locations to obtain values of LPM/30m (litres per minute per 30 metres of exposed bedrock), a value that's akin to well specific capacity, which can be used to compare and assess different bedrock HUs and spatial aquifer capabilities. Such calculations were possible for 430 wells drilled within the Uniacke SPS study area.

Based on well data with good location accuracy, wells within the Uniacke SPS study area had slightly lower yields from all bedrock HUs combined than the average for the 17km x 17km greater study area, although none in the Uniacke SPS study area reported zero yield.

Within the Uniacke SPS study area, well yields from all bedrock HUs combined ranged from 0.5 to 97.9 L/min (average/median of 14.6/7.7 L/min), or 0.2 to 89 LPM/30m (average/median of 11.3/3.6 LPM/30m). Based on average LPM/30m values, the Cunard Formation HU appears to be the most highly productive (average/median 15.3/11.2 LPM/30m, but from only 27 data values), followed by the Taylors Head Formation HU (average/median 11.2/3.4 LPM/30m, from 348 data values), then the Beaverbank Formation HU (average/median 10.3/3.2 LPM/30m from 53 data values). The highest and lowest values were from the Taylors Head Formation HU (279.6 and 0.2 LPM.30m), followed by the Beaverbank Formation HU (139.8 and 0.3 LPM/30m), then the Cunard Formation HU (52.1 and 1.4 LPM/39m).

The higher maximum values for LPM/30m from the Taylors Head Formation HU are likely a function of the greater competence of that mostly greywacke bedrock unit, in which water-bearing fractures encountered at wells should be expected to extend greater distances from wells and have larger apertures. By comparison, water-bearing fractures encountered in wells drilled into the Beaverbank or Cunard Formation HUs, which due to their finer grained nature and thus, lower competence, would are expected to extend over shorter distances from wells and be filled with muds or clays smeared within them as material that had been ground up by the motion along fractures and fault zones.

There is publicly available pumping test data for 16 wells within the Uniacke SPS study area, and unpublished data for three wells located about 1.5 km outside the study area which we were able to access. The values for transmissivity (T) from all of these ranged from 0.03 to 8.13 m^2/day (mean 1.44 m^2/day), from which calculated safe yield (Qs_{20}) values ranged from 2.0 L/min to 88.8 L/day (mean 19.1 L/day), with values for storativity (S) from only four tests (three from outside the study area) ranging from $8.12x10^{-5}$ to $8.06x10^{-4}$ (mean $5.43x10^{-4}$), which suggest semi-confined to confining conditions for the water-bearing fractures in the wells tested.

Calculations suggest there is sufficient groundwater recharge within the Uniacke SPS study area to meet the needs of over 22,800 homes (assuming a need of 1,350 L/day/home), and sufficient aquifer water storage in the bedrock and Quaternary HUs to meet drought conditions for that number of homes for between over 9 to 37 years. However, well interference may be an issue. While there currently is insufficient data to calculate the degrees of well interference to expect across the Uniacke SPS study area, calculations done for other developments with similar bedrock geology suggest that new lots within the Uniacke SPS study area may need to be as large as 1.3 to 1.7 hectares to help avoid well interference in denser developments.

Total well depths reported within the Uniacke SPS study area range from 13.7 to 191.5 m (average 78.2 m) and casing lengths range from 2.4 m (no longer allowed, since the minimum casing length required for domestic wells under the current well drilling regulations is 6.12 m) to 28.1 m (average 11.7). Based on these numbers and from interpreted average overburden thickness, new well construction in the southwest central parts of the Uniacke SPS study area may be expected to cost $5,800 to $13,800 at lower driller price ranges, and $7,400 to $17,800 at higher driller price ranges. Due to the presence of drumlins and generally thicker overburden in the western, northern and eastern-southeastern boundary parts of the Uniacke SPS study area, new well construction in these locations may be expected to cost $13,800 to $20,700 at lower driller price ranges, and $17,800 to $26,800 at higher driller price ranges.

Overburden conditions (adequate saturation soil thickness, water depths that can be reached by excavators) appear adequate to construct dug wells over 40% of the Uniacke SPS study area.

No data is available on dug well water quality for the Uniacke SPS study area. However, dug wells should be expected to produce generally good quality water, although that water may be more corrosive to plumbing systems than water from produced from drilled wells, and dug wells are more prone to experiencing surface water contamination, or to having groundwater levels in them drop to below pump intakes, or below the bottoms of wells, than are drilled wells.

All three of the bedrock HUs for which there is water quality data is available were found to produce generally good quality, alkaline, moderately hard to hard, calcium-bicarbonate type waters with near to slightly above neutral pH. Some wells within the Uniacke SPS study area were found to produce calcium chloride type water due to contamination by road salt applications. Iron values may be elevated, but elevated manganese values appears to be a more frequent problem. Arsenic may also be expected to be elevated and require treatment. All of these metals are naturally inherent to the bedrock in the area.

That said, arsenic, iron, manganese, and perhaps mercury may arise as human-caused well water quality issues of concern at or near the former South Uniacke and Mount Uniacke Gold Districts. Also, harm may arise regarding both yields and water quality for wells located near the existing (and expanded) Mount Uniacke quarry, and also possibly in the northern-most parts of the Uniacke SPS study area, which is at the southern edge of a Wind Energy Zone – a community in Ontario is currently experiencing significant water quality problems due to infrasound emissions from windmills through their aquifer, and similar concerns appear to be rising in the UK.

11.2 Suggested future work

There is a shortage of pumping test data available within the Uniacke SPS study area from which to scientifically better understand the nature of the local bedrock fracture fracture flow systems, and to better assess the likely effects of well interference before allowing land development, in particular near existing homes and for larger development projects.

While these pumping tests may (and probably should) be requested from developers to ensure that increasing population density within the Uniacke SPS study area does not impact existing and increasing numbers of new wells, this can become a detriment to some regarding development investment, and result in a haphazard availability of proper hydrogeological information for use in terms of proper aquifer planning and monitoring.

As such, developers should be encouraged to view the need for hydrogeological testing as a benefit to them and to their land purchasing customers – and to do such testing early in the development processes, striving to exceed the bare minimum of wells to be tested as recommended by NSE (2011), and using as many observation wells as possible to enhance the quality of their testing. This should be done by developers at a minimum as a matter of exercising proper due diligence regarding their investments, and perhaps more importantly, to help assure prospective property buyers that their water supply needs are being properly addressed and cared for.

Additionally, since many new home buyers in developments within the Uniacke SPS study area are likely to be moving into the area from urban centres with central water supply, developers should be encouraged to supply easy to understand well operation and maintenance and septic system maintenance instruction manual to all new property buyers, so they can better understand how wells work, when and how to test water quality from the and for what parameters, and what land use practices to apply and to avoid to ensure the overall integrity of their well water supplies and of those across the Uniacke SPS study area – this new and growing MEH community have the potential to become a model for other jurisdictions in this regard.

Regarding the above, MEH may wish to implement a well defined, science-based and planned aquifer monitoring and well water quality and pumping test data collection program – with all relevant old and new data placed within an easy to access central data repository – to which developers should be required to contribute.

Perhaps key “special” locations could be selected within the Uniacke SPS study area for groundwater monitoring and pumping test programs, using either existing or new wells, funded either directly through MEH, by sponsoring local businesses, or by developers as a part of development agreements, for such places and things as central community buildings, recreation areas, parks, and/or along trails.

Assuming one is not already in place, a source water protection plan should be developed for the Uniacke SPS study area, and beyond. Where certain land-use related issues on privately owned lands may not always be able to be avoided, ensuring the presence of proper information and educational programs for well owners and the community at large may go a long way to giving home to the importance for community members to protect their own valuable water supplies and the water supply resources of their neighbours. The “new well owner manuals” noted above could become an important part of this process.

Finally, just as one should expect professionals to sign off on bridge designs, so should MEH seek to have any geological and/or hydrogeological study or components of larger studies, such as the Mount Uniacke environmental assessment (WSP, 2023), properly and fully evaluated, written, and signed of by experienced, licensed professional geoscientists.

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