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Project 168UD01

Level 1 groundwater assessment
Hemlock Drive – Open Space Development
Westwood Hills, St. Margarets, Nova Scotia

Report submitted to:

Marchand Homes
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Working with Nature's Science to provide credible environmental and water resource solutions...

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Executive summary

The proposed development is planned to include 20 single family residential units within a 15.86 ha. parcel of currently undeveloped forest-covered land.

The site is immediately bounded by Hemlock Drive and Parklyn Crt. and low density single family development to the west and south, and by undeveloped forest elsewhere. There is no industrial or commercial land use anywhere near the site such that besides any possible residential type incidents (i.e. heating oil leaks), there are no land uses in the general area that may present any environmental issues of concern at the site today, or which may have presented any concerns in the past.

The site is entirely underlain by Middle- to Late Devonian age (380-370 Ma.) granitic rock belonging to the Halifax Peninsula Leucomonzogranite, a coarse-grained Stage 2 pluton. The rock has no primary permeability, so well yields drilled into it will depend entirely on fracture flow (secondary permeability) for groundwater to flow into them. The overburden at the site consists of generally thin, sandy glacial till.

Based on information from the NSE well log database, 847 wells have been drilled into the Halifax Peninsula Leucomonzogranite within a roughly 6 km by 6 km area centred at the site. There are no dug wells reported to have been constructed in till overlying the Halifax Peninsula Leucomonzogranite within that area, and accurate mapping coordinates are available for only about 28% of the drilled wells, so it was necessary to relegate the review of well yields and construction details to statistical analysis of the available database records.

Short-term driller air lift yield rates for wells completed in the above-noted area and in a much more local ~0.5 km area in which 162 wells have been drilled into the Halifax Peninsula Leucomonzogranite range from from zero (those wells were abandoned and replaced by others) to 68.2 (mean 12.8) L/min from wells that are 30.49 m to 153.96 m (mean 77.86 m) deep, with 5.5 m to 34.15 m (mean 8.92 m) of casing. Of these, over 98% (some having required deepening and/or stimulation by hydraulic fracturing) meet or exceed the minimum 1,350 L/day (0.9 L/min) household need as suggested by NSE (2011).

The highest air lift yield rates reported in the NSE well log database for all wells drilled into the Halifax Peninsula Leucomonzogranite within a 6 x 6 km area centres on the site is 272.8 L/min, whereas the highest reported for the ~0.5 km area is 68.2 L/min, with those and other wells producing higher than average yields being located immediately to the south of the Marchand Homes site. These localized high well yields may be explained by bedrock faults as exemplified by topographic lineaments near- and on-site as identified using shaded relief images generated from 1 m resolution LiDAR DEM data.

Two methods were applied to assess the groundwater recharge potentially available for the wells that are proposed to be drilled on-site. Both methods allowed for the required 50% of the estimated available recharge to be reserved for stream baseflow and related ecosystem maintenance. The more (extremely) conservative method used, which assumes that groundwater recharged is limited to the site property boundaries, suggests that such recharge could, on an annual basis, provide approximately 1.8 times the minimum 1,350 L/day per lot water need suggested by NSE (2011) for single unit residential use.

The more realistic assessment method used to evaluate two differently sized possible recharge areas (which contain 111 and 182 homes, respectively, including those proposed to be constructed on-site) estimated that there should be sufficient groundwater recharge within those areas to provide water from up to 198 and 906 homes, respectively.

The amount of water that an aquifer can store will depend on average porosity and aquifer size/thickness. The porosity of the local bedrock aquifer units may be expected to range between 0.5% to 3%, and that of the much thinner surficial unit above bedrock range 25% to 35%. Considering affected aquifer areas the sizes of the two groundwater recharge areas considered for Method 2, then there may be sufficient groundwater storage within the bedrock HU to supply water to existing homes (including those proposed by Marchand Homes for the site) for an estimated 10.5 to 200 years, and from within the surficial till HU for an estimated 3.9 to 11.1 years, assuming there is no new groundwater from recharge.

While well interference effects from pumping could not be calculated based on the data available, experience at other sites with similar bedrock geology and development density suggests that pumping induced well interference should not be an issue of large concern on and immediately around the site. However, well interference could be an issue if wells are spaced too close together, or if shallow, higher yielding wells are located too close to lower yielding wells, so maintaining proper (consistent) well spacing and being aware of the possible effects that might exists between deeper and shallower wells is important.

The Halifax Peninsula Leucomonzogranite HU produces generally good quality groundwater, but there may be some issues related to hardness, iron and manganese, and arsenic and uranium may also require treatment. These can be relatively inexpensive and easy to treat. Radon gas in well water and in the air in homes may also be associated with the Leucomonzogranite. This too can be relatively easily mitigated.

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Statement of Limitations and Qualifications

This Level 1 hydrogeological assessment report was prepared by earth-water Concepts inc. (ewC) for the sole benefit of Marchand Homes for them to advance development negotiations with HRM for an Open Space Development involving a proposed 20 homes on a 15.86 ha. piece of currently forested land located east of Hemlock Drive and the intersection of High Timber Drive in the Westwood Hills subdivision at St. Margarets, Nova Scotia. This report cannot be used for any other purpose by any other person or entity without the express written consent of ewC and Marchand Homes.

The data and interpretations presented in this report are based solely on site inspections, data available for review, and site conditions present at the time the work was performed. There are levels of uncertainty inherent to all geologic/hydrogeologic assessments which are subject to change over time and/or as new or different information becomes available. All data obtained for this assessment represent conditions about a limited area surrounding the subject site and as such, the information used for this report can be expected to be variable with respect to location and time; ewC accepts no responsibility for the levels of completeness or accuracy of the information used for this report, or to update such information. This work is specific to the site, conditions and land use 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 and related hydrogeological practices by trained professional and technical staff for the purpose and use described in this statement and the report; ewC makes no other representations, or any guarantees or warranties whatsoever, whether express or implied, with respect to this report, the information presented, or any part thereof, and ewC accepts no responsibility for any events, conditions or other circumstances that may have occurred before, or which may occur subsequent to, the work that was undertaken. This report must be read as a whole and no sections thereof are to be copied or read out of such context. Should future investigations provide information which supplements or differs from the information presented in this report, we request to be notified immediately and permitted to reassess the results and interpretations provided herein. This Statement of Limitations and Qualifications forms part of the report and any use of the report is subject to the terms thereof.

Original is signed

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Sr. Hydrogeologist/Hydrologist
earth-water Concepts inc.

1.0 Introduction

earth-water Concepts inc. was commissioned by Marchand Homes to carry out a Level 1 groundwater assessment for a proposed low density 20 single family home residential development located off of Hemlock Drive in the Westwood Hills area of the Halifax Regional Municipality (HRM), Nova Scotia.

The purpose of this study is twofold, to:

1. Provide a screening level review of the proposed subdivision to help identify, from a desktop review of available data:
   - the availability of, and ability for the site to supply the volumes of well water needed to support the proposed subdivision,
   - well construction and water quality issues of possible concern,
   - potential issues that may arise from an increase in groundwater resource demand on existing neighbouring groundwater users.
2. Assist the developer in the moving forward an application for development to HRM under the development agreement process.

1.1 Study guidance

This Level 1 groundwater assessment was done solely for the subject site in accordance with the Nova Scotia Environment Guide to Groundwater Assessments for Subdivisions Serviced by Private Wells (NSE, July 2011).

1.2 Map coordinates and accuracy

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 compass and chain, which coordinates may be approximate. All ground elevations are in reference to vertical datum GCVD2013.

2.0 Site description

2.1 Definition of the study area

For the purpose of this report, the "site" comprises the proposed Marchand Homes Hemlock Drive subdivision area specifically, as described in Sections 2.2 and 2.3 below. However, by necessity, the study encompasses a much larger area, as required to properly assess and

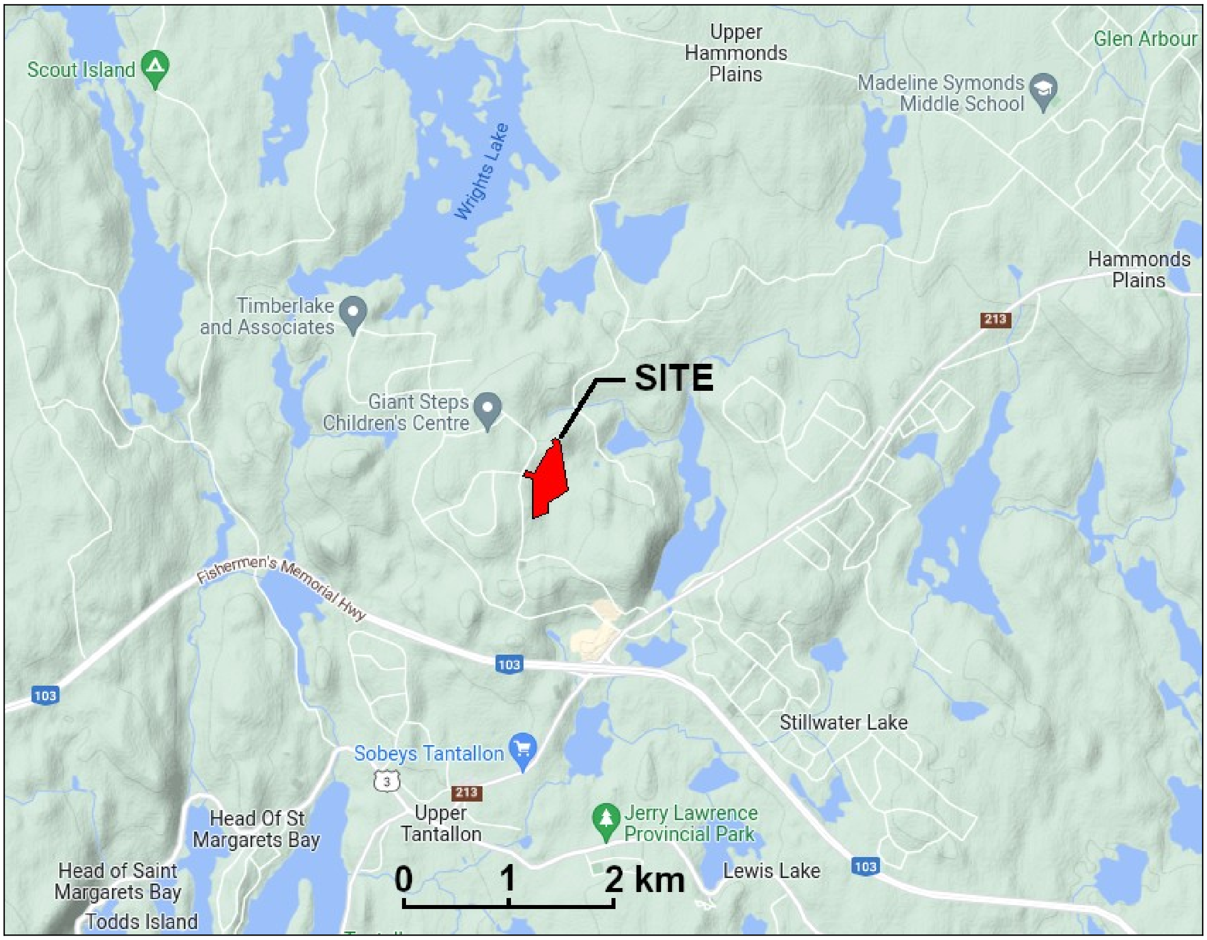

Figure 1. Site location.

describe the site's geology and hydrogeology, and other related natural and anthropogenic features and land uses as may pertain to groundwater quantity and quality characteristics at the site.

2.2 Site location and access

The site (land parcel PID 41180779) is located in the St. Margaret's Westwood Hills area, immediately east of Hemlock Drive where it intersects with High Timber Drive, in HRM, Nova Scotia. The site is in the north-central part of NTS map sheet 11D/12C (within parts of Tract 78/F, K, L, O and P), and is centred at approximately UTM 431520E/4951940N.

Figure 1 shows the site location relative to major roads and communities. Figure 2 shows the site location and more immediate local geographic features in greater detail.

Access to the site from the Hammonds Plans Road via either Winslow Drive or Westwood Blvd. to Hemlock Drive, then north along Hemlock Drive to the intersection of High Timber Drive.

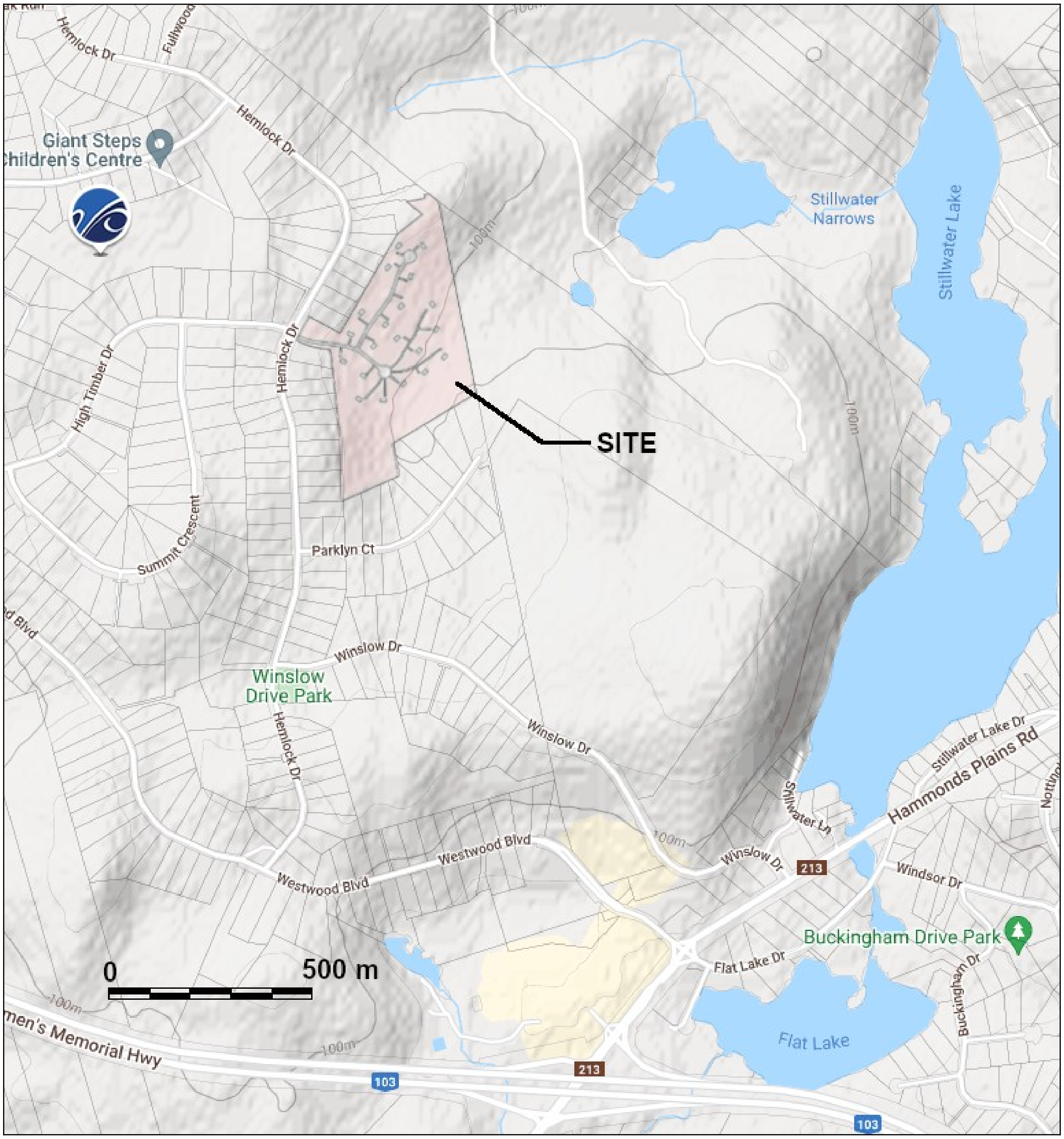

Figure 2. Site location close-up and plan showing preliminary road and lot layout.

There is currently no access onto the site from Hemlock Drive or anywhere else around the property. However, there what appears to be an abandoned trail, which based on historic air photos (more later) was constructed some time between 1992 and 2003 (perhaps when High Timber and Hemlock Drives were built). It is visible in the latest air photos, but not included in any NSCRS (2021) maps or GIS data. Once past heavy bush adjacent to Hemlock Drive, that trail may allow foot travel due east about ¾ into the Marchand Homes property, ending roughly at UTM 431605E/4952020N.

2.3 Development description

The site land parcel totals about 15.86 ha. The site layout has not yet been firmed up, but the development is anticipated to include 20 lots with layout approximately as shown in Figure 2 with some minor adjustments. The lots are to be serviced by individual on-site wells and septic systems, and about 820 m of new road and shared driveway.

3.0 Assessment procedure

3.1 Scope

Level 1 assessments are done to characterize the regional and local geology/hydrogeology to define the availability of, and possible issues related to, water supply for new subdivisions that are to be serviced by private wells. The overall objectives are to minimize:

- the risk of potable water quality and natural and land-use quantity problems in new residential subdivisions; and
- potential for impacts of subdivision development on existing groundwater users and the environment near the proposed development.

Level 1 groundwater assessments generally consist of a site visit and desktop reviews, using available information, to characterize and describe the geology, hydrogeology, and other regional and local natural and man-made features that may be of significance to a site's groundwater resources.

Level 2 assessments are similar to a Level 1 assessment, except they include doing field work that typically includes the drilling on test wells on the proposed development site, and carrying out pumping tests and water quality testing on those wells.

The scope of this assignment is to carry out a Level 1 assessment of the subject site.

3.2 General methodology

This Level 1 assessment involved completing desktop reviews of published and unpublished reports and one site visit, which was done on 24 February 2022. The data that was reviewed included geologic and hydrogeologic maps, water well log database, mineral exploration drillhole and other data, historic air photos, LiDAR[1] DEM[2] data, and hydrologic and geologic interpretations made from that data.

1. LiDAR (an acronym for Light Detection and Ranging) is a remote sensing method that uses a pulsed laser beam that is scanned from an aircraft to measure distances, based laser pulse reflection return time, to the tops of trees, and to bare earth as can be seen by the laser beam through vegetation.

4.0 Site characterization

4.1 Area land use and cover

The site consists of mostly softwood forest. The property is bordered immediately to the south and west by residential properties (single homes) along Parklyn Court and Hemlock Drive, respectively, and to the north and east by undeveloped forest land.

Farther out, the areas south, west and north-northwest are occupied by low density rural development. The areas directly north, east, and southeast comprise undeveloped forest to Anderson Lake and beyond in the north, and Stillwater Lake in the east.

4.1.1 Local municipal zoning

The site and lands immediately surrounding and over 1 km from it to the south, west and northwest are zoned R-A1 (general residential), and those immediately surrounding to the north, northeast, and east for over 1 km in those directions are zoned MU-1 (mixed use 1) (HRM, 2021a, 2021b, 2021c). The 82.9 ha. parcel of land located immediately to the east and southeast of the site, east of Winslow Drive to Stillwater Lake, is Crown owned.

4.1.2 Area domestic-type land use

All of the R-A1 lands noted above have been developed – there appears to be only open-space residential land use in those areas. Everything east of the site is undeveloped forest.

4.1.3 Area industrial land use

There is commercial/retail land-use (grocery stores, restaurants, service stations) just east of the intersection of Route 213 (Hammonds Plains Road) and Westwood Blvd., and community land use (community centre with arena) across Westwood Blvd. There is what appears to be an abandoned gravel borrow pit east of Westwood Blvd. just north of where it intersects with Hemlock Drive, approximately 1 km southwest of the southern-most corner of the Marchand Homes property. There is another older (nearly fully treed over) borrow pit about ⅓ the size of the first that is located due south of and about 550 m from the southern-most corner of the site (southeast of the Hemlock and Winslow Drive intersection). There are no other known industrial or commercial land uses within a couple of kilometres of the site.

2. DEM (Digital Elevation Model) data is bare earth elevation data (as compared to DSM, or Digital Surface Model data, which represents to tops of trees and other vegetation) that's collected from air photos, LiDAR, or other means, as a square grid across the land. The DEM used for this study had a horizontal resolution of 1 m and a vertical accuracy of approximately 15 cm.

4.1.4 Site land cover

The site land cover consists primarily of softwood, with mixed wood ground cover generally below the site entrance to Hemlock Drive and within the southwest portion of the site. Table 1 summarizes the current leading forest species and species distribution long with general forest height on the Marchand Homes property.

Table 1. Leading forest species on the site (NSDNR, 2021a, 2021b).

General part of the site	Approx. mean forest height (m)	Primary species	
		Species	% distribution
Southwest corner	13	Red spruce	50
		Red maple	40
		Balsam fir	10
Southeast corner	10	Red spruce	70
		Balsam fir	20
		Eastern larch	10
Centre to eastern boundary	12	Red spruce	50
		Balsam fir	30
		White pine	10
		Red maple	10
Western boundary, site entrance, wrapping around to site centre and northeast boundary	16	Mixed red and black spruce	70
		Eastern hemlock	20
		White pine	10
Centre of site from entrance to north-northwest boundary	12	Red spruce	50
		Red maple	30
		Balsam fir	20

The forest within the northwestern part of the property is classed as mature, with multi-aged and old forest growth present along the southern edge to southern eastern edge of the site. The parts from the site entrance at Hemlock Drive to the centre and eastern boundary of the site are considered to be the most merchantable (NSDNR, 2021a)

There are no wetland areas shown on-site by NSDNR (2021a); the only wetland present nearby is situated off site about 230 m east of the site's eastern boundary – about ⅔ of the way between the site and Patient Ross Lake located about ½ km east of the site.

One stream is shown to be present within the southern boundary at the centre of the site, to the very southern-most part of the site's eastern boundary.

4.1.5 Registered wetland and special species designations

The wet areas mapping model produced by UNB in 2007 (made available by NSDNR (2012 and 2021a)) suggests based on topographic indexes that the western ⅔ of property should be rapid to moderately well draining, with moderate to poor drainage from approximately the entrance of the site at Hemlock Drive and to the stream situated at the southeast corner of the site. A culvert present under Hemlock Drive that starts at the ditches at the northwest corner of the High Timber and Hemlock Drives intersection discharges water from ditches along High Timber Drive and the west side Hemlock Drive onto the site. However, there are no wetlands or related species at risk registered with the Province within the site property boundaries.

4.1.6 Historic land use

Air photos flown in the summers of 2017, 2003, 1992, 1981, 1977, 1974, 1966, and 1964 were reviewed to help assess the recent historic land use of the Marchand property and surrounding areas. That review identified the following general site conditions and changes going back over the past 56 years:

- In the 1964 and 1966 air photos, the property and the entire roughly 2 km area around it was forest. There were no well developed (foot trails only, perhaps) roads present, except the Hammonds Plans Road, and the power right of way near it. Highway 103 had not yet been built. There is evidence of past clear cutting having taken place prior to 1964 in a small area due south of Bull Pond north of where Highway 103 is today, and perhaps earlier yet (more apparent regrowth) also in a small area located about mid way between Patient Ross and Wright's Lakes.
- The 1974 air photos show a number of new forest trails or gravel roads east of the property, which appear to originate 4 or 5 km or more to the east, from around the Taylor Lake area. This trail system extends north/south from Anderson Lake to Stillwater Lake, with the western limit of the trail system present along a northwest line about 150 m west of Patient Ross Lake (about 400 m east of the property's eastern border. Highway 103 is present, but the area at least 2 km west of the site remains forested. The 1977 and 1981 photos show no change in the immediate area.
- The 1992 air photos show a new forest road originating from the north that branches east and west around where the Westwood Blvd. and Wyndham Drive intersection is today, with both branches extending as far south as about the centre of the green space between Wyndham and High Timer Drives. The area at the end of the west branch, what is now developed area between the west end of High Timber Drive and Westwood Blvd. had been clear-cut. There is no other development apparent south of these roads to Highway 103, and the new forest roads that were identified to the east of the property in the 1977 air photos have become heavily overgrown.

- The 2003 air photos show new development within the Westwood Hills district from the south up to and including High Timber Drive. There are no road connections yet between the forest trails noted above (except a forest trail) and Westwood Blvd. and Hemlock Drive (there is only a short spur of it beyond High Timber Drive). The on-site foot trail noted in Section 2.2 of this report is present in 2003 air photos.
- The 2017 air photos show the Westwood Hills district developed pretty much as it is today, with on-site trail heavily overgrown and only just barely visible in the photos.

Older air photos may have been flown at smaller but still reasonable scales during the 1930's to the 1950's, but were not available for review for this assessment. However, the earlier photos available for this review suggest that the areas discussed above would contained mostly undisturbed forest prior to the 1960's.

4.2 Topography, surface hydrology

Figure 3 shows the site location relative to Nova Scotia's primary watersheds. The larger scale map in Figure 4 shows the regional land surface topography, lakes, streams and rivers, roads, buildings, other geographic features, and the local tertiary sub-basins.

4.2.1 Area topography

Ground surface elevations within the Figure 4 map area range from sea level to 174.3 m and average 87.4 m. Ground surface elevations on-site range from 121.6 m at the entrance right at Hemlock Drive, to 123.3 m at the property's northern tip, 120.1 m at the southern tip, to 107.8 m at the easternmost tip. The ground surface elevations along the property's eastern edge (the lowest parts of the site) range to about 95 m.

4.2.1 Surface water hydrology

The site is situated near the east edge of the East/Indian River primary watershed (Figure 4). More specifically, the site is located at the western edge of the East River secondary watershed 1EH-1 (which forms the very eastern edge of the East/Indian River primary watershed), and more precisely, at the western edge of tertiary sub-watershed 1EH-1-E (Figure 5), which constitutes the uppermost part of the East River secondary watershed.

The East/Indian River watershed is large, having a total area of 777,636,283 m^2 (NSE, 2021a). However, the East River secondary watershed is much smaller, but still reasonably sized, with an area of 36,809,689 m^2. Tertiary sub-watershed 1EH-1E encompasses nearly 60% of that, with area of 21,880,716 m^2. The Marchand Homes property is located roughly ⅓ of the way up the tertiary sub-watershed.

Figure 3. Site location relative to Nova Scotia's primary watersheds.

The streams (NSGC, 2021a) and watershed boundaries (NSE, 2021a) in Figure 4 were mapped and defined from 1:10,000 scale data, for which the elevations in the DEM were not as accurate (within 1 to 2 m accuracy only) as can be obtained today from LiDAR data. As such, Figure 4 cannot show watersheds as accurately as needed to properly define the drainage patterns and smaller sub-basins at and around the site. Therefore, recently flown 1 m resolution LiDAR DEM data (NSGC, 2021b) with vertical accuracy around 15 cm was used to redefine the boundaries of East River secondary watershed 1EH-1 and its sub-basins.

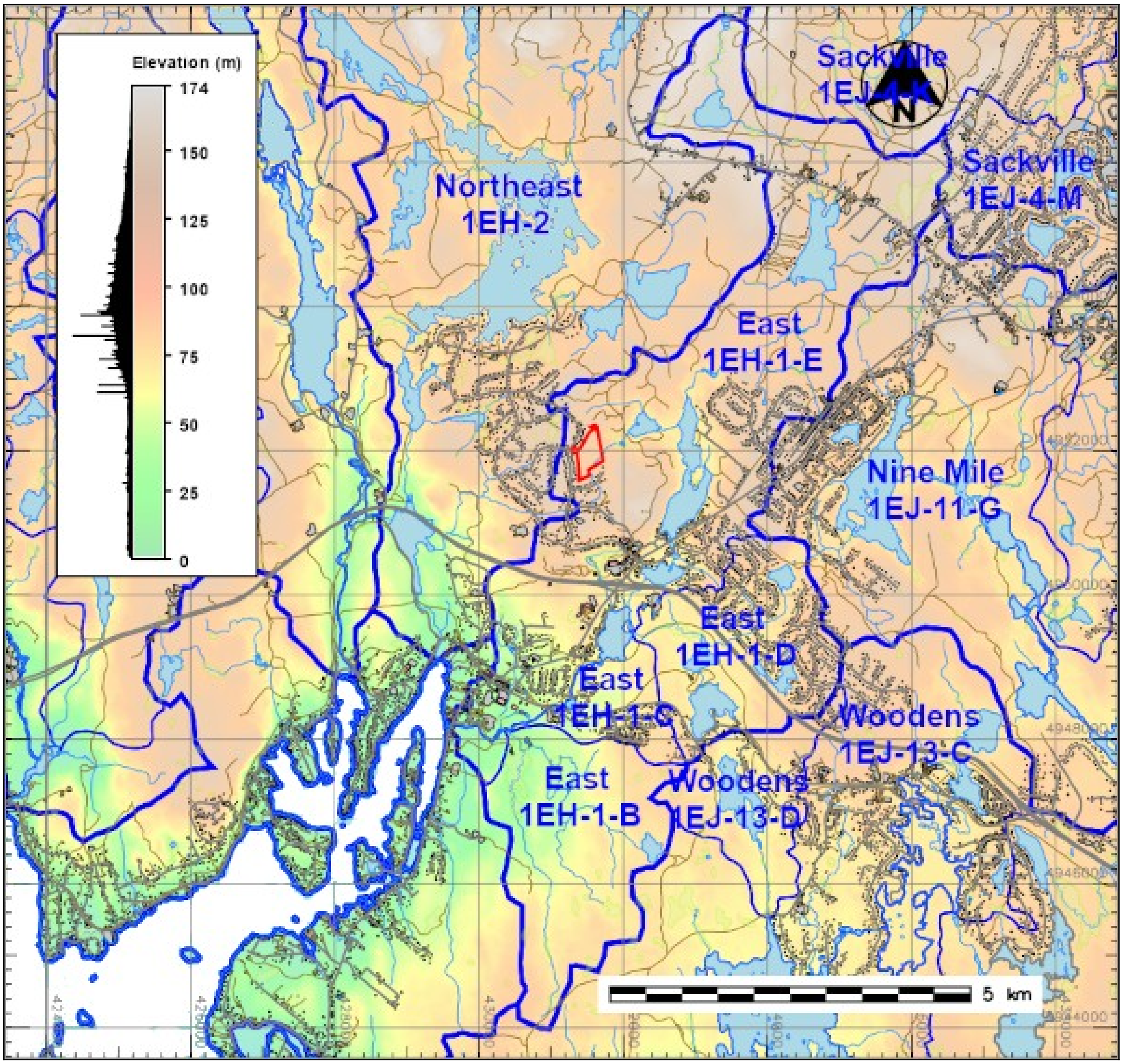

Figure 4. Regional ground surface topography (NSGC, 2021b) and local secondary (thick dark blue lines) and tertiary (thin dark blue lines) sub-watershed boundaries (NSE, 2021a). Basemap from NSGC (2021a). Rivers and lakes = light blue, paved roads = dark grey, trails = light brown, Marchand Homes property boundary = red lines.

To do that, the LiDAR DEM was first hydraulically corrected by carving "channels" of appropriate depths (based on road centre vs. ditch elevations) into it where NSPW (2021) and NSGC (2021a) show bridges and/or culverts to be present under roadways, and elsewhere where streams identified from photogrammetry in 1:10,000 scale mapping (NSE, 2021a; NSGC, 2021a) are shown to cross roads and trails. The carved DEM was then further corrected by filling any no-flow areas that may have been inadvertently created by the carving. Using that corrected DEM, the hydrologic modelling modules that are built into GRASS GIS (2021) were run, using a flow initiation threshold of 500 m^2 (0.05 ha.) from

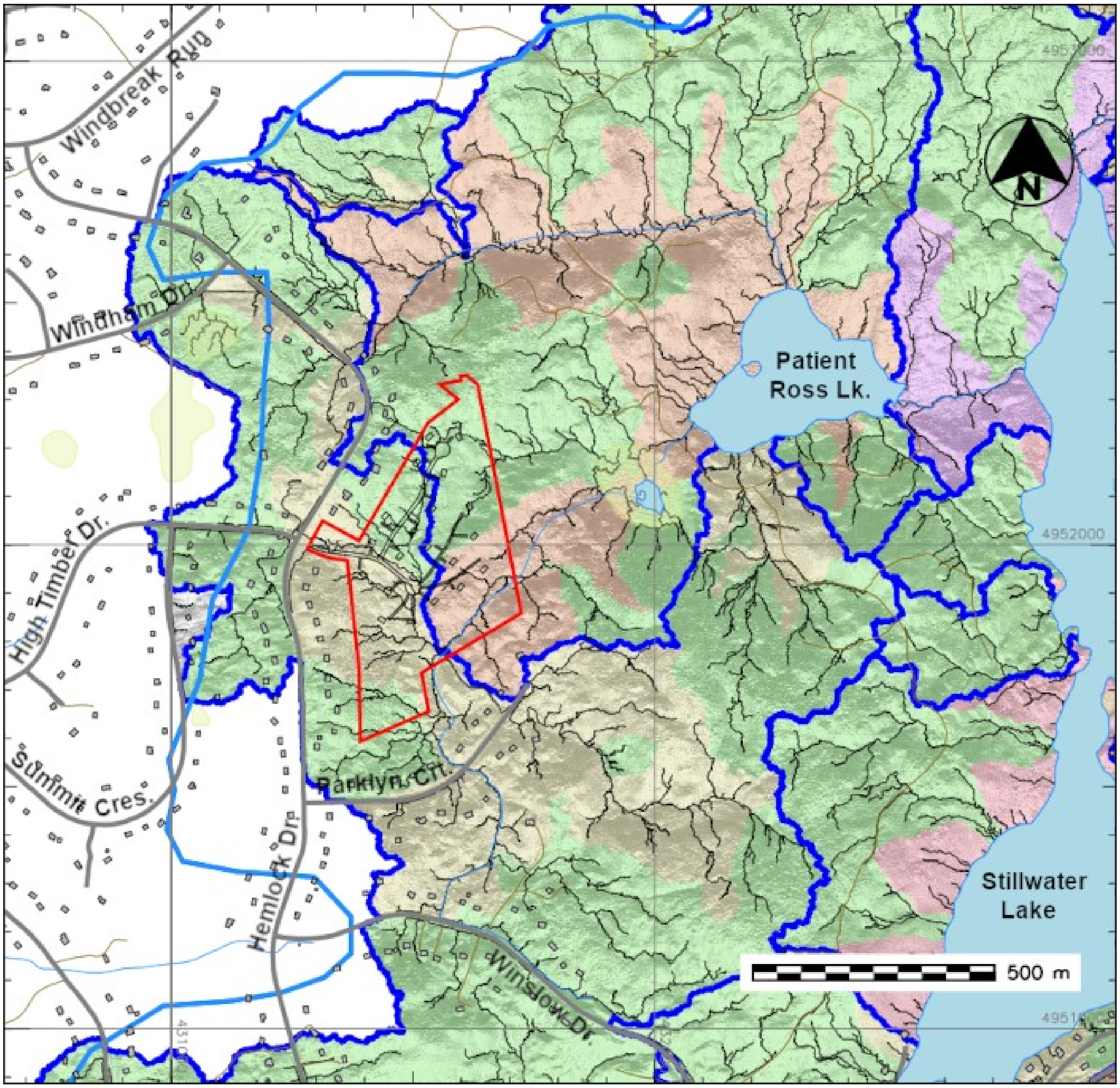

Figure 5. Local drainage patterns and related surface water capture sub-basins as defined for 1st to 9th Strahler (1952, 1957) order channels as defined for an East River outlet at the head of St. Margarets Bay. The site borders are red. The dark-blue lines show the boundaries for basins that drain 6th and 7th order and greater channels. Basins draining via 4th to 8th, 5th to 8th order channels are colour-shaded. The black lines show drainage down to 2nd order (with 2nd and 3rd order flows unlikely to channelize). The thin light-blue lines are streams as shown from 1:10,000 scale mapping (as in Figure 4), which represent 5th order flow off-site and 6th order flow on and below the site. The thick light-blue line is part of the east 1EH-1-E basin boundary (NSE, 2021a) shown in Figure 4. The hill shade topographic relief was created with the sun due south and 30 degrees above the horizon. Basemap, NSGC (2021a).

which to initiate surface flow within the DEM domain, to define channel flow directions, stream orders (Hack, 1957; Horton, 1945; Shreve, 1966; Strahler, 1952, 1957), and channel segment lengths, slopes, and other stream statistics. This resolved the East River secondary watershed 1EH-1 to 9 orders of streams, per the Stahler (1952, 1957) stream order method, from the smallest channels likely to initiate only as minor streamlets during major rain events, to where the East River discharges into the ocean at the head of St. Margarets Bay south of Upper Tantallon.

Figure 5 shows the local drainage patterns down to the 2nd Strahler order and related catchment sub-basins. The 5th (off-site and from the culvert under Hemlock Drive) and 6th (on- and below-site) order channel flows (shown also at light blue lines in Figure 5 and also in Figure 4) are expected to be perennial. There are only three short 4th order channel sections on-site which may be expected to be ephemeral, but only during extreme of rain events. Flows below 4th order are likely to manifest only as surface sheet flow, with perhaps rare, occasional 3rd order channelized occurring under natural (pre-development) conditions.

Local on- and off-site flow patterns are driven by complex topography that is entirely derived from bedrock below (see more in Section 5 of this report). Surface drainage on-site is via two 5th to 6th order drainage basins, which common boundary runs north-south though about the middle of the site. Site drainage is ultimately to Stillwater Lake via Patient Ross Lake.

In the east half of the site, surface drainage is via 3rd and lower order flow in the north (shaded green in Figure 5), then 4th order flow off-site (also shaded green). In the southeast part of the site, drainage is via 3rd and lower order flow (shaded tan in Figure 5) directly into a 6th order perennial stream (located at the far south-eastern corner of the site), then off-site into the wetland and small pond west of (and which discharges into) Patient Ross Lake.

In the west half of the site, drainage originates as mostly 3rd order flow, with minor 4th order flow from outside of the property via ditches on the west side of Hemlock Drive and a culvert that originates at the north side of High Timber Drive and discharges around where the proposed (preliminary) entrance road to to the site is shown in Figure 5. Outfall from that culvert exists as 5th order eastward then southerly flow at the centre of the site, to join another 5th order channel that originates off-site (the stream that passes under Parklyn Court) to form the 6th order perennial stream noted in the paragraph above.

In the west half of and within the site, drainage is via three sub-basins:

- from the north (shaded green in Figure 5) via mostly 3rd and lower order flow and minor 4th order flow into the channel that originates from the culvert,
- from the southwest/central part of the site (shaded yellow in Figure 5) via 3rd and lower order flow directly (on-site and partly across the site boundary) into the channel that originated from the culvert, and
- from the very southern corner of the site via 3rd and lower order flow, then 4th order flow into the channel that originated from the culvert.

5.0 Area bedrock geology

Figures 6 and 7 show the area bedrock geology and stratigraphy. The site and surrounding area are underlain by Middle to Upper Devonian age (395 to 360 Ma) granitic bedrock that intruded into folded Cambrian to Early Ordovician age (540 to 470 Ma) sediments, which altogether form the Meguma Supergroup.

5.1 The Meguma Supergroup

The Meguma Terrane (Meguma Supergroup) is Canada's east-most tectonic terrane[3] (see Figure 8). 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.

5.1.1 Meguma Supergroup components

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[4] 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 comprising over one quarter of the Meguma Supergroup.

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

3. A tectonostratigraphic terrane is a crust fragment that is formed on a tectonic plate that is accreted or "sutured" to crust lying on another plate. The crustal block preserves its own distinctive geologic history, which is different from that of the surrounding areas. The suture zone between a terrane and the crust it attaches to is usually identifiable as a fault.

4. 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.

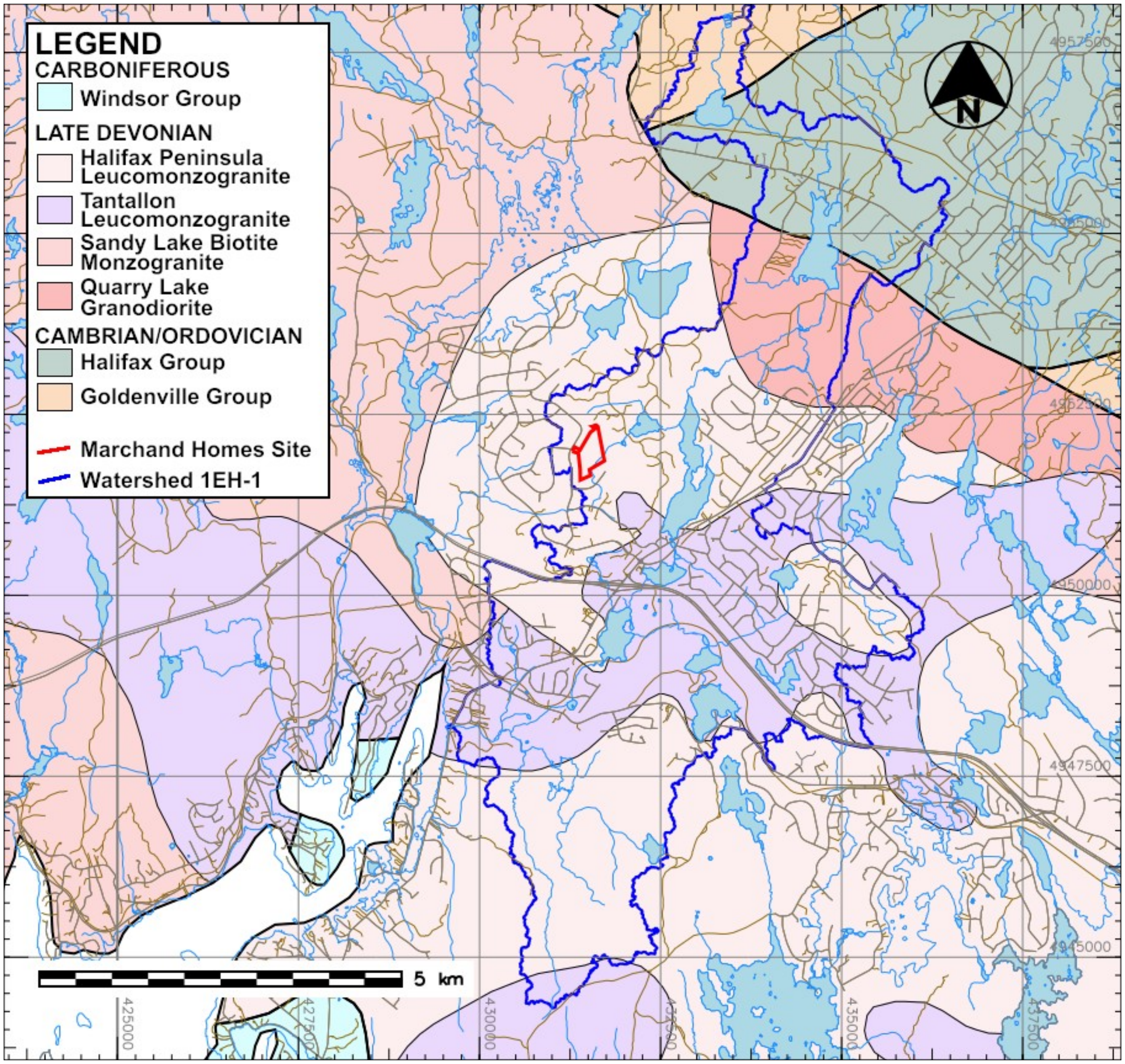

Figure 6. Area bedrock geology (Keppie, 2000; White et al, 2014).

system. This now metamorphosed fold belt was then intruded by mostly Middle Devonian to Mississippian age (395 to 360 Ma) granitic plutons, followed by additional regional and localized deformation and rapid exhumation, the whole of which is referred to today as the Meguma Supergroup.

5.1.2 Origin of the Meguma Terrane

The traditional thinking is that the Meguma sediments were deposited in a passive continental shelf type environment on the west coast of Gondwana and subsequently compressed onto the Avalon Terrane.

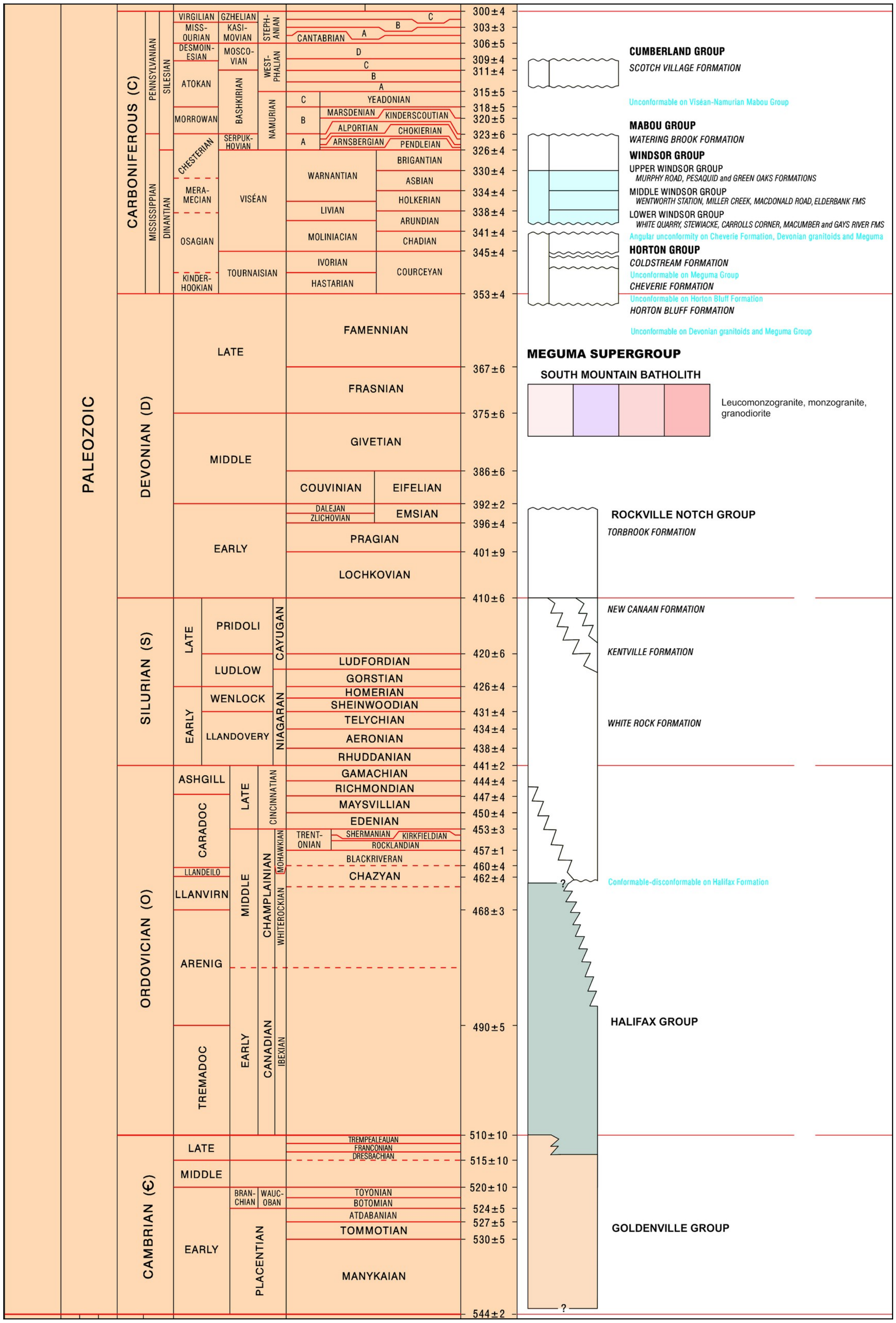

Figure 7. Local Cambrian to Carboniferous stratigraphy showing the bedrock units (coloured) present in the area in Figure 6 (from Keppie, 2020; Pothier et al, 2015).

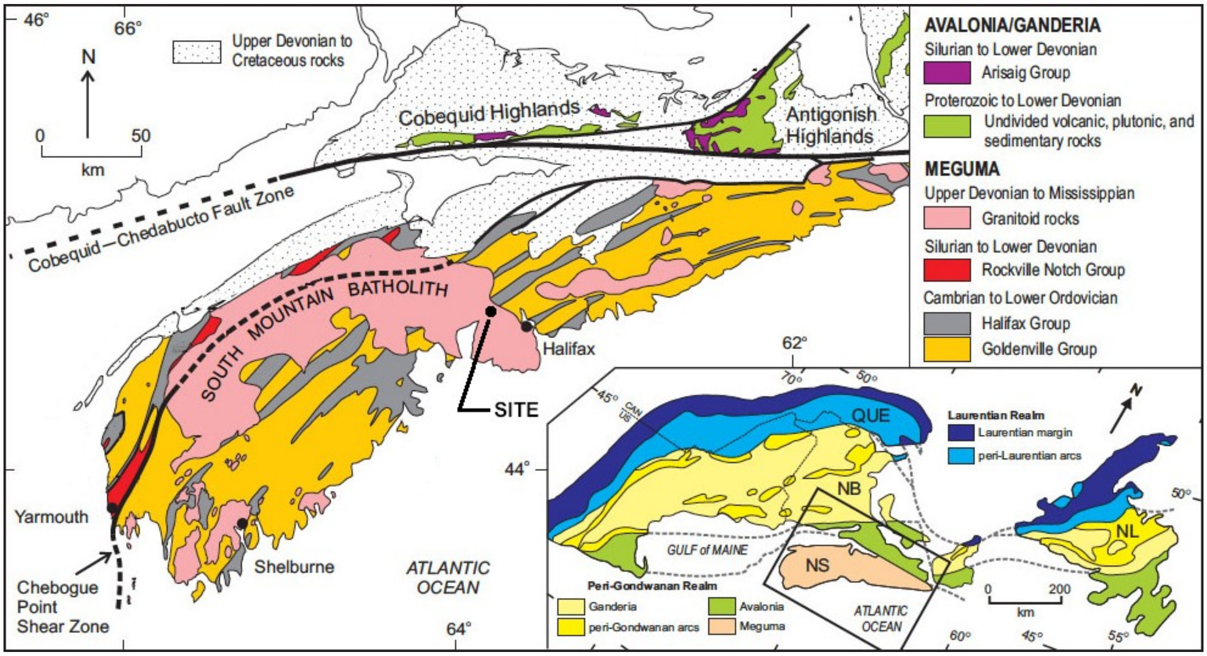

Figure 8. The Meguma Terrane in relation to the Laurentia (early North America) and other eastern Canada tectonic Terranes (after White and Barr, 2017).

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.

Figures 9 and 10 probably best illustrate those tectonic processes. In Figure 9:

(a) The Ganderia, Avalonia, and Meguma terranes are reconstructed to surround the South America craton around 510 Ma following the breaking up of Pannotia.

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

(c) Closure of Iapetus sea and continuous spreading of Rheic ocean bring Ganderia, Avalonia, Eastern Avalonia terrane 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

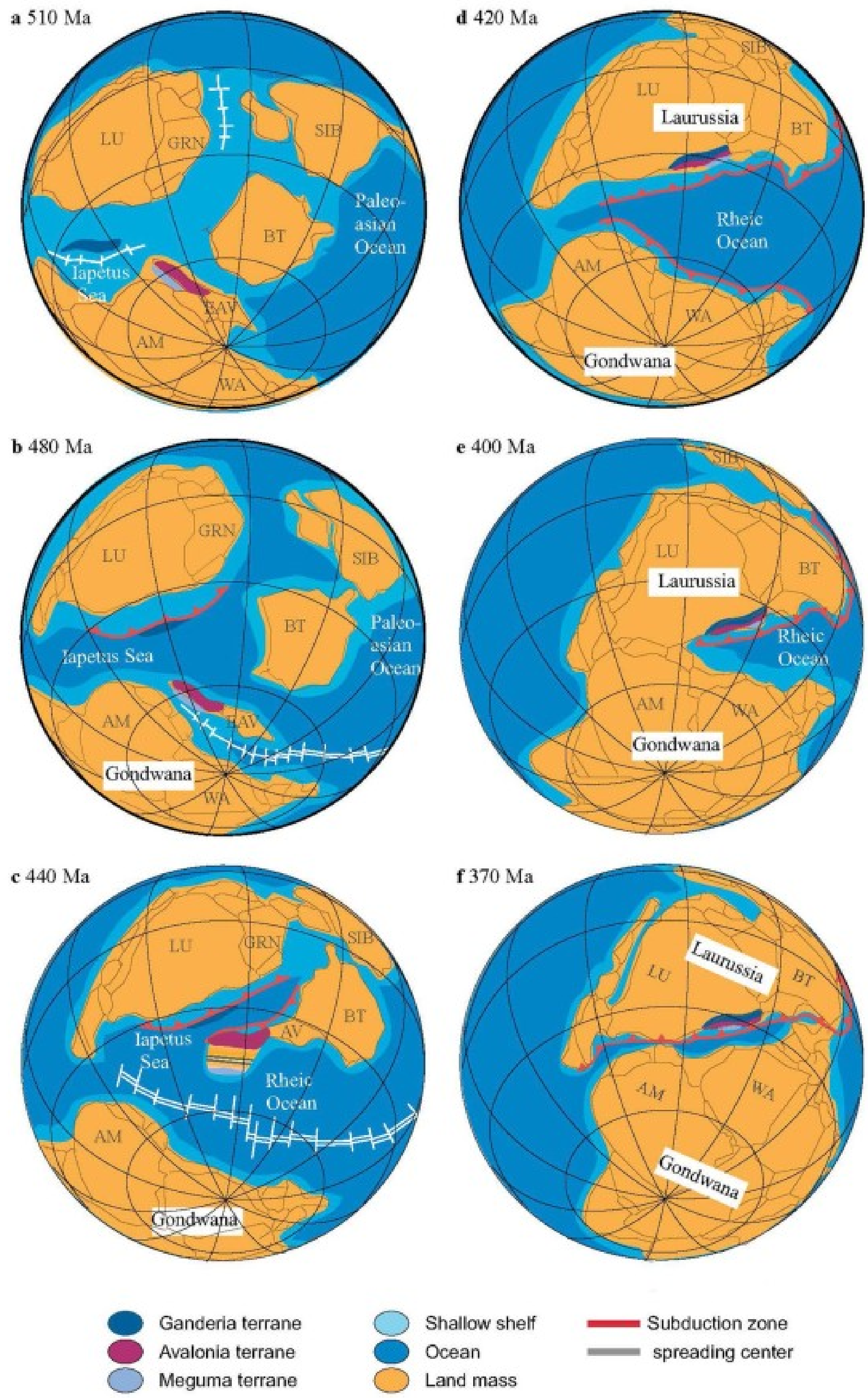

Figure 9. Palinspastic reconstructions during the Early Paleozoic time (510-370 Ma) period (from Shellnutt et al, 2019). AM = Amazon, AV = Avalonia, BT = Baltica, EAV = Eastern Avalonia, LU = Laurentia, GRN = Greenland, SIB = Siberia, WA = West Africa.

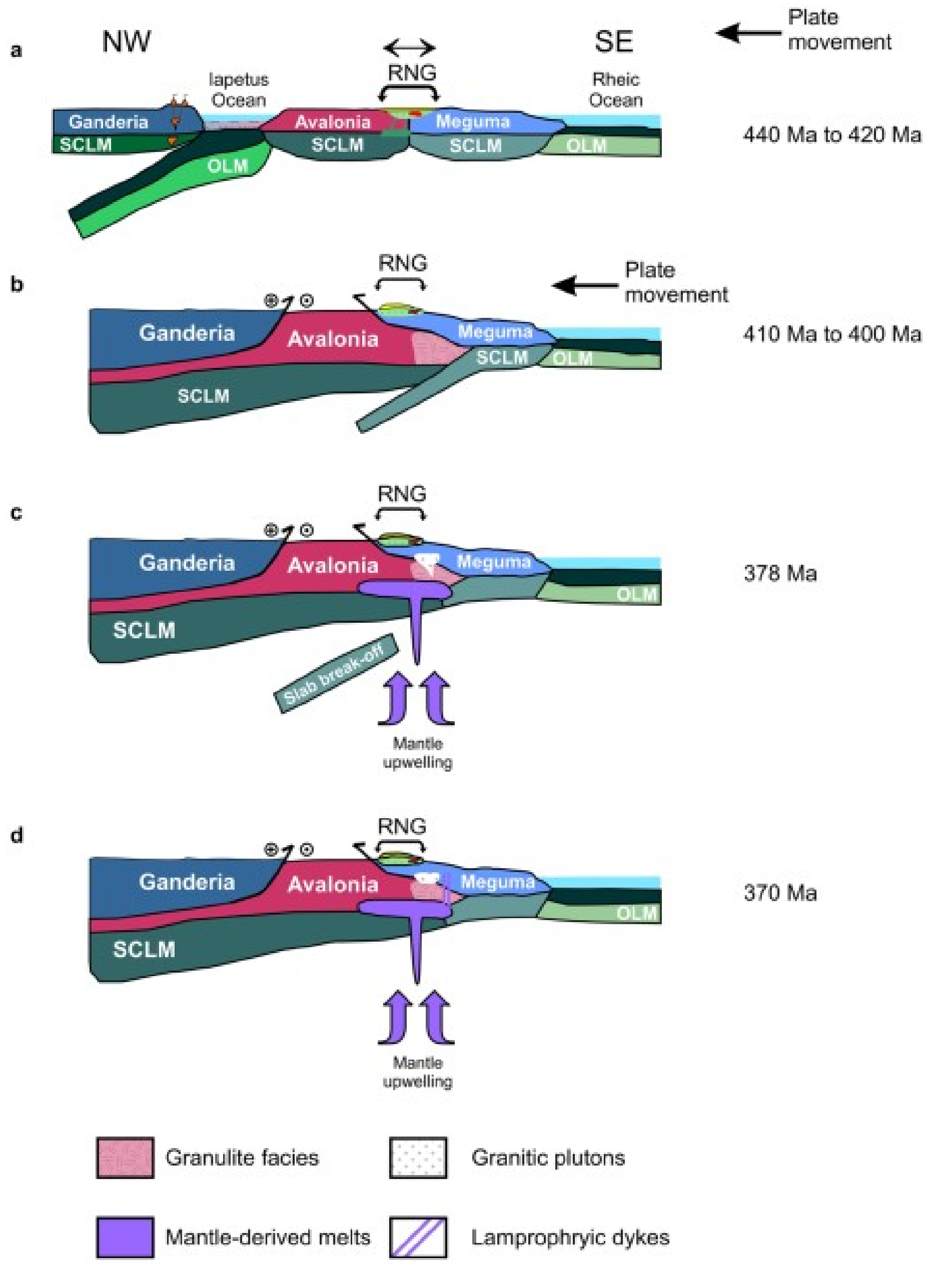

Figure 10.Tectonic evolution showing the possible relationship between Avalonia and Meguma during the Late Silurian to Late Devonian. (a) Late Silurian emplacement of the Rockville Notch Group. (b) Initial stages of the Acadian Orogeny and peak granulite facies metamorphism in the underlying Avalonia rocks. (c) Middle Devonian silicic magmatism and high temperature deformation episode. (d) Late Devonian dyke emplacement and entrainment of the granulite xenoliths. SCLM = subcontinental lithospheric mantle. OLM = oceanic lithospheric mantle. RNG = Rockville Notch Group.

over Avalonia. Brittle faulting of the Meguma, granitic magmatism triggered by mantle detachment from folding, related hydrothermal gold mineralization in folds and shear zones.

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

5.2 Structure and metamorphism of the Meguma Supergroup

5.2.1 Folding

The main period of folding is thought by many to be ductile deformation of 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.

5.2.2 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 with a distinctive northwest orientation that typically show a sinistral (counterclockwise) strike-slip[5] separation (over 20 km for some). They may also exhibit a certain amount of normal and/or reverse[6] (depending on location) displacement. These northwest striking faults define the overall structural fabric of the Meguma Terrane, and are responsible for the development of nearly all of the harbours along Nova Scotia's Eastern Shore.

5. Lateral, or horizontal displacement.

6. 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 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.

Also, also many northeast dextral strike-slip, thrust[7], and tension faults cut the province that cover 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).

5.2.3 Metamorphism

The regional metamorphism[8] associated with tectonic compression during the Acadian Orogeny varies across the Meguma Terrane from amphibolite facies[9] (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 encompasses nearly one third of the Meguma – see Figure 8) that intruded 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 in width 0.5 to 2.5 km around plutons (Taylor and Schiller, 1966).

5.3 Cambrian and Ordovician Meguma lithostratigraphy

Parts of the Goldenville Group and the Halifax Group are represented within the northeast mapping area of Figure 6. While they are located at best 3.5 km from the Marchand Homes site, they are located topographically upgradient of the site and underlie the upper reaches of the East River tertiary sub-watershed 1EH-1-E. As such, they may have a weak influence on groundwater quality at the site, and on the quality of surface water flowing near the site and possibly available as groundwater recharge. Therefore, they are described below.

Over a dozen formations are recognized in the Goldenville Group (Pothier et al, 2014). The group is dominated by thickly bedded to massive grey to greenish grey, generally poorly sorted quartzose and feldspathic psammite (metasandstone) with chlorite-rich matrix,

7. 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.
8. 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.
9. 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.

interbedded with minor grey to black pelitic rocks (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[10], 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-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 6 map 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. 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.

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.

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 Goldenville, has been intruded by Upper Paleozoic granitic plutons. It is unconformably

10. The Beaverbank and Moshers Island Formations have been ascribed by some to the Halifax Group (White et al, 2007; White, 2010), but others have more recently ascribed them to the Goldenville Group (White et al, 2014; Pothier et al, 2014).

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 Bluestone Formation (upper age not defined along Nova Scotia's Eastern and Southern Shores) are the two Halifax Group bedrock units present within the Figure 6 map area. The former is characterized by black to rust-brown slate with thin beds and lenses of minor black metasiltstone. The Cunard Formation also contains medium-bedded, fine-grained, cross-laminated metasandstone. Sulphide ;minerals are common and prone to generating acid rock drainage. The Bluestone Formation is characterized by light grey to blue-grey slate that is rhythmically inter-layered with laminated to thin-bedded, fine-grained metasandstone. The Bluestone Formation contains trace fossils and bioturbated beds are common.

5.4 The South Mountain Batholith

The Marchand Homes property is directly underlain by the Halifax Leucomonzogranite (see Figure 6), which is situated at the very eastern edge (see Figure 8) of the South Mountain Batholith (SMB) and which is one of many of its Stage 2 plutonic diapirs.

The following sections briefly describe what a pluton is, how the SMB evolved, and details on the general petrographic (mineralogical composition), chemical, and radiometric characteristics of the plutonic bedrock units that are shown in Figure 6.

5.4.1 A quick primer on the geology of plutonic rocks

Plutonic rocks are igneous[11] rocks that have solidified from a melt (or partial melts, since some plutons originate as not quite liquid, plastic masses) at great depth. This is what differentiates them from volcanic rocks, which are melts, often with same or very similar chemical makeup, that have found their way to and cooled and solidified at the surface.

Plutonic rocks force their way upward through older rock (often referred to as country rock) as a function of materials present in the melt (or partial melt) being less dense than the country rock they rise through[12]. As such, they float up through country rock, usually as diapirs (much like the lighter density fluid in lava lamps rises through the less dense fluid).

11. 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 (the Meguma Terrane was a major mountain chain that back in Pangea's time rivalled the Himalaya mountains of today) are significant in that they make up 90-95% of the top (16 km) of the earth's crust by volume.

12. The chemicals and minerals that make up the SMB are in general less dense (have lower weight by volume) than the clastic materials within the Meguma Supergroup metasediments through which they rose.

Because they cool deep underground, plutonic melts do so slowly – over tens of thousands of years or longer – which allows individual crystals within the melts 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, and the plutonic rocks present at their roots to form the SMB, was later exposed by erosion[13]. A large body of this type of rock is called a *pluton*. Hundreds of kilometres of plutonic rock are referred to as *batholiths*.

There are many major types of plutonic rocks, the classifications and names of which depends on the mix of minerals present in the rock[14].

To begin, there are four primary classes of igneous rocks: ultramafic, mafic intermediate, and felsic. Ultramafic and mafic[15] rocks are made up of more magnesium and ferric minerals with lower silica content (generally 45-55%). Felsic[16] and intermediate rocks are made up of more aluminum-silicate minerals with higher silica content (70-85%) that are also rich in other elements like oxygen, potassium and sodium, and usually more quartz is also present in the rock. Except for minor intrusive sills and dykes, the SMB is chiefly composed of felsic rocks, with those in Figure 6 listed in order of increasing mafic mineral content.

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) and many others have used to classify the rocks of the SMB.

13. The material that was eroded from the Pangea Meguma mountains today makes up the greater than 10 km thickness of sediments in the Maritimes Sedimentary Basin and Nova Scotia’s offshore continental shelf.

14. It is important to know what the difference is between a mineral and a rock. A mineral is defined as 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, the two are considered as different minerals because their crystalline structures are very different – one having a sheet-like structure (thus graphite being among one of the softest minerals, with a slippery feel), the other having a rigid 3-D interlocking structure (thus diamond being the hardest natural material on earth). Rocks, on the other hand, are 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.

15. 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.

16. Felsic rocks are generally found in lighter shades of grey, ping, 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).

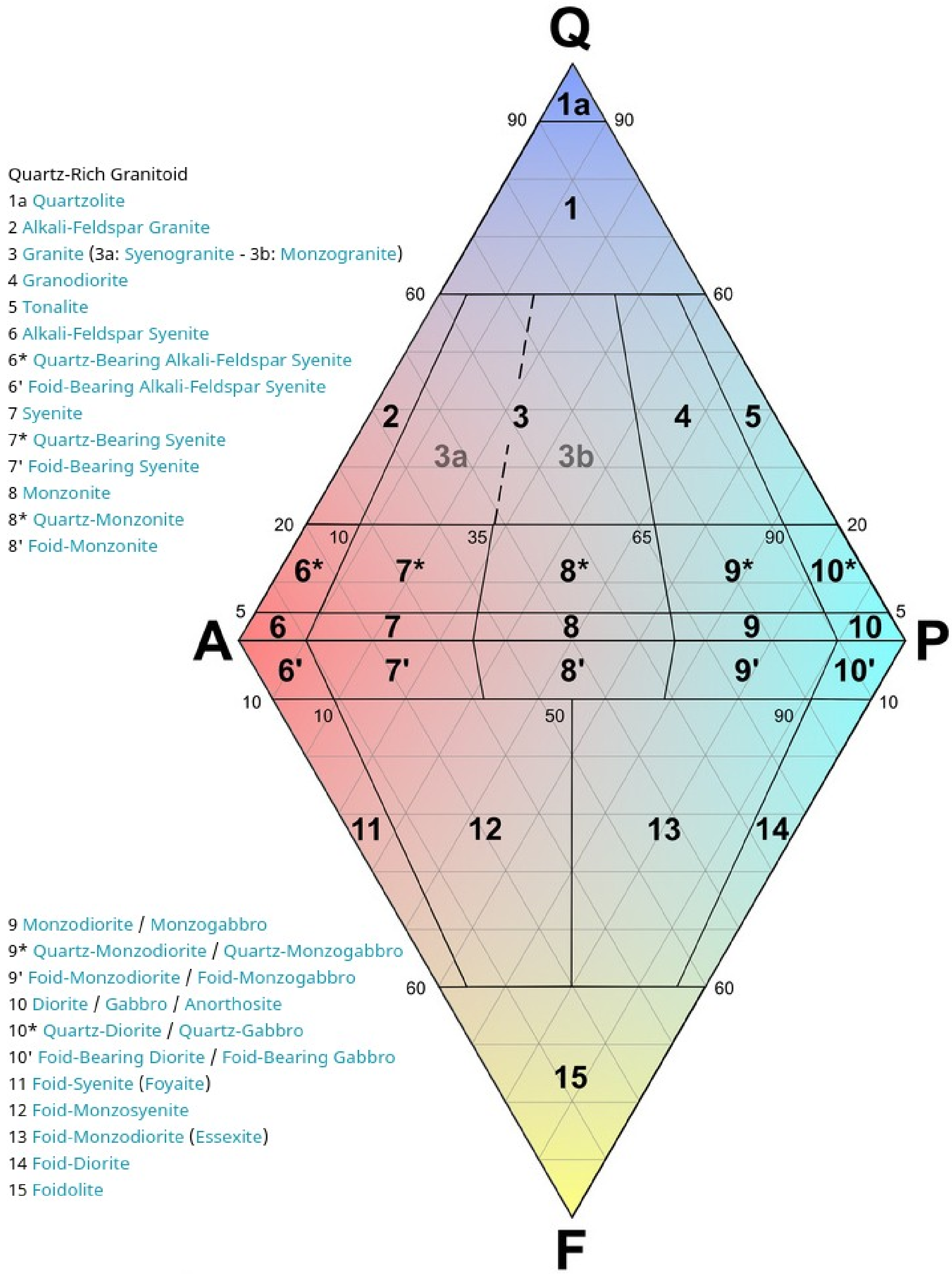

Figure 11. QAPF classification diagram describing rocks of the SMB in Figure 6.

Figure 11 is one such diagram, which the International Union of Geological Sciences (IUGS) proposes[17] and is now the generally accepted scheme (and also used by MacDonald (2001),

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

White et al (2014), and others for for the SMB) for classifying plutonic rocks by their modal composition. The classification diagram in Figure 6 is for felsic plutonic rocks with less than 90 vol-% mafic minerals[18], 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[19], or foids for short (F).

The QAPF diagram in Figure 6 incorporates two ternary diagrams[20] that encompass all of the rocks of the SMB, including the plutons that form the bulk of it, and its less major final stage intrusive sills, dykes, and pegmatites[21].

5.4.2 General description and genesis of the South Mountain Batholith

The SMB is one of the largest granitoid complexes in the Appalachian orogen, representing over 7,000 km^2 of the bedrock geology in southern Nova Scotia. It is made up of two penecontemporaneous suites of plutons; an earlier granodioritic to monzogranitic suite (stage 1 plutons), and a slightly later monzogranitic to leucogranitic suite (stage 2 plutons), emplaced at around 380–370 Ma. during the Acadian Orogeny.

Gravity models reveal the 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) further state that from maps and Schmidt projections of the magnetic fabric data, in the Stage 1 plutons foliation[22] 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 (more in Section 5.6 of this report) and perpendicular to regional Acadian shortening. The magnetic lineations are also perpendicular

18. Rocks that contain more than 90 vol-% mafic minerals are called ultramafic and are classified in an independent scheme.

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

20. 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.

21. 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.

22. 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.

to late aplitic[23] and pegmatitic[24] 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 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 (1000) 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.

The very narrow deformation aureole within the country rocks suggests lateral spreading of the plutons was not the main space creation mechanism during emplacement; space was mostly created by vertical displacements of country rocks.

5.4.3 Local bedrock petrology, chemical and radiometric characteristics

Leucomonzogranite is generally composed of alkali feldspar, plagioclase feldspar (Na,Ca) $[(Si,Al)AlSi_2]O_8$ and quartz (SiO_2) as the essential minerals, with muscovite $KAl_2(AlSi_3O_{10})(OH)_2$ typically present as the non-essential, or accessory mineral.

The Halifax Peninsula Leucomonzogranite in Figure 6 (a Stage 2 pluton represented by area 3b in Figure 11) is described by MacDonald et al (1994) as buff, orange, white, pink and red, medium- to coarse-grained and minor fine-grained, megacrystic[25] or seriate[26], containing 2-7% biotite and 4-8% muscovite as accessory minerals, with traces to 5% cordierite[27] and zero to traces of andalusite[28]. Metasedimentary xenoliths[29] are rare.

MacDonald et al (1994) describe the Tantallon Leucomonzogranite in Figure 6 (also a Stage 2 pluton, and again represented by area 3b in Figure 11) as buff, orange, pink, red, and white,

23. Having a fine- to medium-grained sugary texture.

24. A texture in which mineral grains are exceptionally large.

25. Where some grains or crystals are considerably larger than the encircling matrix.

26. Where grain size is gradual and essentially continuous.

27. Cordierite is a magnesium iron aluminum cyclosilicate mineral in which the relative amounts of magnesium and iron can vary with a series formula $(Mg,Fe)_2Al_3(Si_5AlO_{18})$ to $(Fe,Mg)_2Al_3(Si_5AlO_{18})$

28. Andalusite is a low pressure, high temperature metamorphic aluminum nesosilicate mineral with the chemical formula Al_2SiO_5.

29. A xenolith is a piece of rock trapped in another type of rock. In plutons, xenoliths may include other granitics which may have fallen through the melt from the pluton ceiling, or country rock experiencing a similar fate.

predominantly fine- to medium-grained with minor coarse-grained, variably porphyritic[30] and equigranular, and minor pegmatitic, with 3-13% muscovite and 2-7% biotite as the accessory minerals and zero to traces cordierite and andalusite. Metasedimentary xenoliths are rare.

Monzogranite typically has the same composition as leucomonzogranite, but with hornblende (a dark green to black mineral from the amphibole family), biotite $K(Fe^{2+}/Mg)_2(Al/Fe^{3+}/Mg/Ti)([Si/Al/Fe]_2Si_2O_{10})(OH/F)_2$, or when expressed in a simplified form, $K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$, and muscovite $KAl_2(AlSi_3O_{10})(OH)_2$ as the accessory minerals.

MacDonald et al (1994) describe the Sandy Lake Monzogranite in Figure 6 (also a Stage 2 pluton, which again is represented by area 3b in Figure 11) a light to medium grey, predominantly medium- to coarse-grained, megacrystic or seriate, with 10-17% biotite and a trace to 1% muscovite as accessory minerals and a trace to 1% cordierite. Metasedimentary xenoliths are common to abundant.

Monzogranite and leucomonzogranite are considered to be the final fractionation products of a cooling magma.

Granodiorite is a coarse-grained igneous rock with less than 90% mafics that is composed of quartz, potassium-feldspar (alkali-feldspar), and plagioclase $(Na,Ca)[(Si,Al)AlSi_2]O_8$, with 20-60% quartz, and plagioclase being 65-90% of the total feldspar on the QAPF diagram. Accessory minerals often include andesine and oligoclase (both $(Na,Ca)[Al(Si,Al)Si_2O_8$ feldspars), and subordinate potassium feldspar, with biotite and/or hornblende, or, more rarely, pyroxene, as the mafic components. Associate minerals often include azurite $Cu_3(CO_3)_2(OH)_2$, microcline $K(AlSi_3O_8)$, cerussite $PbCO_3$, and sphalerite ZnS.

MacDonald et al (1994) describe the Sandy Lake Monzogranite in Figure 6 (a Stage 1 pluton that plots in area 4 or Figure 11) as light to medium grey, predominantly medium- to coarse-grained and minor fine-grained, with equigranular to slightly megacrystic texture, containing 15-25% biotite and traces of muscovite as accessory minerals, and traces of cordierite. Metasedimentary xenoliths are abundant.

Figure 12 is a copy from part of a table from MacDonald (2001) that summarizes the chemical composition of 104 rock samples collected from numerous locations across the Halifax Peninsula Leucomonzogranite.

Note that many rock types are represented in Figure 12. While the bedrock underlying the Marchand Homes site is defined as a leucomonzogranite, rock composition can vary from place to place across plutons, depending on where within the melt those rocks are from, and

30. Displaying minerals in two distinct size populations, where one of more minerals are consistently larger than the rest of the rock matrix.

Pluton	Halifax (HP)			Halifax (HP) Cont.	
Rock Type	BGD	BMG	MBMG	CGLMG	FGLMG
% of Pluton	4.1	12.6	33.3	37.6	12.3
Samples	10	18	25	24	27
SIO2	67.79	70.24	71.07	72.85	74.29
AL2O3	15.55	14.88	14.63	14.35	14.20
FE2O3	4.10	3.13	2.83	2.04	1.59
CAO	1.75	1.20	1.03	0.68	0.42
MGO	1.67	1.39	1.23	0.88	0.73
NA2O	3.67	3.44	3.56	3.46	3.47
K2O	3.98	4.51	4.47	4.64	4.38
TIO2	0.58	0.41	0.39	0.20	0.13
P2O5	0.19	0.18	0.25	0.22	0.24
MNO	0.09	0.07	0.06	0.06	0.05
H2O	0.67	0.62	0.65	0.57	0.72
Ba	588	469	360	199	101
Rb	164	198	242	278	329
Sr	171	122	92	55	28
Zr	177	140	132	84	59
Nb	12	11	14	11	11
V	44	29	26	11	7
Y	32	30	24	23	19
Ga	22	21	22	22	21
Cu	1	2	3	0	1
Zn	71	66	65	51	47
Hf	6	4	4	3	2
Ta	1.1	1.2	1.7	1.9	2.4
Sc	9.4	6.7	5.8	4.0	3.2
La	34	27	24	15	8
Th	12.3	11.6	11.2	8.2	5.1
U	3.0	3.6	4.3	5.8	8.8
Li	76	88	93	95	108
F	646	638	710	763	759
As	4.6	2.3	2.9	3.7	5.5
Sn	5	7	9	12	20
W	1	1	1	2	6

Figure 12. Chemical composition of rocks from the Halifax Peninsula Leucomonzogranite pluton (copied from MacDonald, 2001). The major elements (top half of the figure) presented as weight percent. The trace elements (lower part of the figure) are presented as ppm. The rock types represented by the sample groupings are BGD = biotite granodiorite, BMG = biotite monzogranite, MBMG = muscovite-biotite monzogranite, CGLMG = coarse-grained leucomonzogranite, FGLMG = fine-grained leucomonzogranite.

associated fractionation effects resulting from differential cooling within and across the pluton. The different rock types listed in Figure 12 are a reflection of that variability.

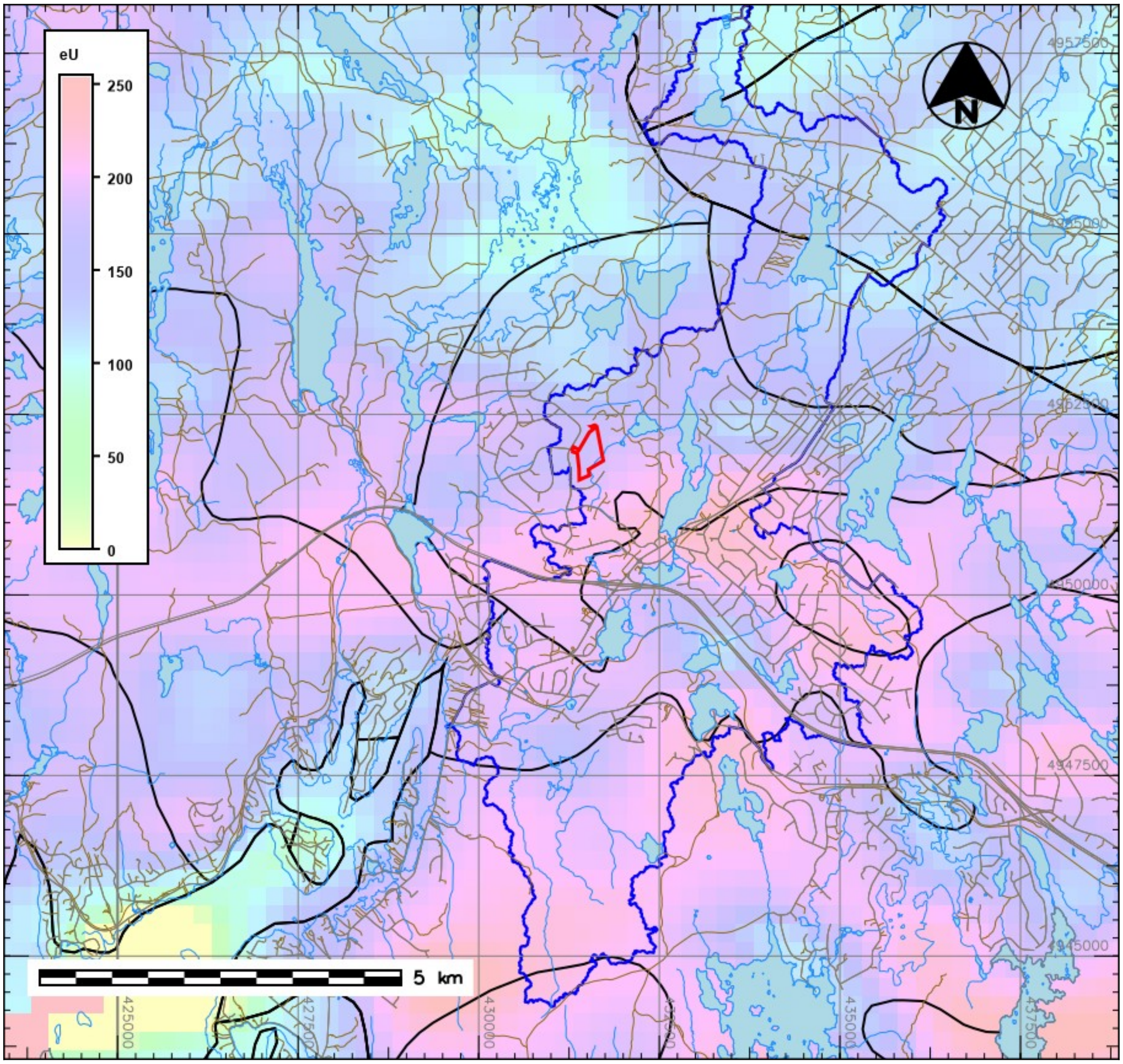

Figure 13. eU distribution within the Figure 6 area. Bedrock boundaries from Figure 6 are shown in black, watershed 1EH-1 boundaries in blue, and the site boundaries in red.

Figure 13 shows the area equivalent uranium (eU) distribution (NSDNR, 2006) presented at 200 x 200 m resolution and obtained from airborne radiometric surveys[31] flown between 1976 and 1990 by the Geologic Survey of Canada at 250 x 250 m resolution. At a glance, the eU distribution appears to correlate approximately with the uranium values for coarse- versus

31. 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.

fine-grained leucomonzogranite samples in Figure 12. The data presented in Figure 13 is also the basis from which Nova Scotia as developed its radon risk maps (O'Reilly et al, 2013), and as such, Figure 13 also represents the potential for the risk of radon to be present in buildings or in groundwater.

5.5 Carboniferous geology

Figure 6 shows a few outliers of Middle Carboniferous age (340-330 Ma.) Windsor Group sediments. These comprise small parts of larger limestone, dolostone, gypsum, sandstone, shale and conglomerate deposits what were eroded elsewhere, but preserved at parts of the South Shore.

5.6 Local structural geology

Having recorded the attitude of prominent joints and faults at approximately two thousand outcrop locations, Horne et al (1992) appear to have the most complete publicly available treatise on the structural geology of the SMB. Much of the following is taken from them.

Structures in the SMB include primary flow features, northeast-trending faults[32] (at 045°) and joints[33] (at 040° and 062°), and northwest-trending faults and joints (at 315°, 325° and 335°). Joint trends are regional in nature, showing no relationship to intrusive features. Granite-related dykes, veins, alteration and mineralization in the faults and joints indicate a primary-regional status for these structures. The northeast-trending joints and fractures are associated with dextral displacement on the northeast-trending faults, whereas the northwest-trending

32. 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.

33. 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. A prime example of this type of joint is displayed as fractured hexagonal column in the basalt on North Mountain between the Annapolis Valley and the Bay of Fundy.

joints are interpreted as tension joints and attending conjugate shear joints of small dihedral angle reflecting northwest transpression during pluton intrusion. Repetitive joint and fault development continued into the Permian (around 100 Ma. following pluton emplacement), implying a fixed regional stress throughout this time interval.

5.6.1 Joints

Northwest-directed compressional stress existed during the creation of Pangea and granite intrusion, which resulted in syn- and post-emplacement deformation and joint development.

Five regionally significant, steeply dipping joint trends have been recognized within the SMB. Ordered in a clockwise manner these are referred to by Horne et al (1992) as: trend 1 at 040°, trend 2 at 062°, trend 3 at 315°, trend 4 at 325°, and trend 5 at 335°. The form a roughly orthogonal pattern.

The northwest-trending joints are characterized by straight, continuous, planar surfaces and regular spacing, and form the dominant joint set in most outcrops within the SMB. These joints commonly dominate the topographic grain, forming long, continuous, narrow ridges. They commonly host greisenization[34], quartz ± greisen veins, and granitic dykes.

The northeast-trending joints are typically poorly developed, curviplanar, discontinuous and irregularly spaced. Locally, they can be closely spaced and form zones of fracture cleavage. Northeast-trending joints are generally not pronounced and commonly their presence is only obvious due to weathering (especially in zones of altered fracture cleavage). These joints are typically strongly hematitized and (or) chloritized, and locally control uranium and manganese oxide mineralization. Dykes and veins with this orientation are rare.

5.6.2 Faults

As was noted earlier, there are two orientations of faults within the SMB; northeast-trending faults at 045°, and northwest-trending faults at 315°, 325° and 335°. The faults in the SMB can be loosely divided into two groups on the basis of their dominant deformational style: (i) brittle faults, and (ii) shear zones.

Brittle faults typically display heterogeneous deformation, with narrow (metre scale) zones of intense deformation, characterized by breccia[35], microbreccia and cataclasite, within a broader (tens to hundreds of metres) zone of moderate deformation, which is characterized mainly by abundant shear (slickensided[36]) fractures.

34. Highly altered granitic rock or pegmatite, formed by endogenous alteration of granite during cooling.

35. Broken fragments of rock.

Intense hematization and (or) chloritization is pervasive throughout all brittle fault zones, and narrow, chloritic, pseudotachylite dykes are commonly associated with brittle faults.

Shear zones are characterized by variably penetrative brittle-ductile to ductile deformational textures, including C-S fabrics[37], mylonite[38], blastomylonite, ultramylonite and rare rodded mylonite gneiss. Minor brittle deformation associated with these faults is generally restricted to deformation of earlier ductile structures and commonly associated with a silicification event. Hematization and chloritization, which are ubiquitous in brittle faults, are conspicuously lacking or related to late brittle deformation in shear zones.

The apparent lack of offset of mapped bedrock units implies that horizontal displacement may not be substantial along either fault style. However, the character and orientation of regional northeast-trending joint trends in the SMB (trend 1 at 040° and trend 2 at 062°) are consistent with R ’ and P shears (Riedel shear geometry) associated with dextral displacement along northeast-trending faults. Dextral strike-slip displacement on these faults is also consistent with regional, Appalachian-parallel faulting during the Upper Paleozoic.

The prevailing structural fabric of Nova Scotia is northwest because of the direction of the collision between Gondwana and Laurasia. That pattern is more difficult to identify in the SMB, but Horne et al (1992), MacDonald et al (1994), White et al (2014), and others have identified two major northwest-trending faults in the SMB, namely the Herring Cove fault and Roxbury Brook fault. These faults roughly parallel several other faults in the eastern portion of the Meguma Terrane.

Apparent sinistral displacement on the Herring Cove fault is suggested by the relative offset of map units in the Halifax area, but a similar relative offset may be explained by a component of dip-slip movement. Although the relationship between northwest- and northeast-trending faults is unknown, the relative orientation and sense of displacement of the northwest-trending faults is consistent with expected conjugate shear faults associated with dextral displacement on the northeast-trending faults.

5.6.3 Taking local structural considerations beyond the published work

MacDonald et al (1994) and White et al (2014) show the Herring Cove fault, which defines the straight shoreline of Portugese Cove, to extend inland to Frasers Lake. However, a northwest-trending lineament[39] that is defined by shaded relief topography in White et al (2014) and by Maple Lake, the south shore of Coxs Lake, and a part of Stillwater Lake,

36. A smoothly polished surface caused by frictional movement between rocks along two sides of a fault, which is often striated in the direction of motion.

37. A metamorphic fabric formed by the intersection of shear surfaces. The foliation that develops in a shear zone is usually thought to trace the XY-plane of the strain causing the displacement.

38. Fine-grained, compact metamorphic rock produced by dynamic recrystallization of constituent minerals.

suggest that the Herring Cove fault likely extends as far as the north end of Stillwater Lake, and about 1.3 km due east of the Marchand Homes property. The shaded relief suggests a possible parallel fault at the south end of Stillwater Lake.

There are many more similar, well defined, parallel northwest-trending lineaments throughout the Chebucto Peninsula that suggest the presence of many more faults, for example: from Stiff Lake to Peters Lakes just south of Harrietsfield; from West Dover to Moser Hill Lake; and numerous others at the southwest corner of the peninsula. Farther west, fault-related lineaments define both shores of and many streams within the Aspotogan Penninsula (ewC, 2005)

Figure 14 shows the results of a shaded relief lineament analysis[40] done for this study over about a 2 km radius area around the Marchand Homes site. The rose diagram in Figure 15 shows the azimuth frequency at 10° intervals for the 48 lineaments identified locally within the Figure 14 area. The analysis clearly the northeast and northwest faults described above (Horne et al, 1992), as wells as two other minor lineament (possible fault) sets that likely represent conjugate shears that are related to the two primary fault sets.

5.7 Local economic geology

Searches were carried out of the designated land use database (NSGC, 2021a), the Nova Scotia mineral occurrence database (O'Reilly et al, 2016), the abandoned mine openings database (Hennick and Poole, 2020), drillhole database (O'Neill and Poole, 2016) 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 greater Marchand Homes property area. Those searches identified the following within approximately a 5 km radius are of the Marchand Homes site:

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39. 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.

40. The lineaments in Figure 14 were identified using shaded relief images created from 1 m resolution LiDAR based DEM. Using GIS, eight shaded relief (hill shade) 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 20x vertical exaggeration applied to enhance the shadows produced. Linear shadow and related (watercourse) trends were manually picked by carefully study of each shaded relief image, and the lineaments identified were digitized as one separate vector data layer. The orientations (azimuth) of the lineaments were then extracted from that data layer to produce Figure 15.

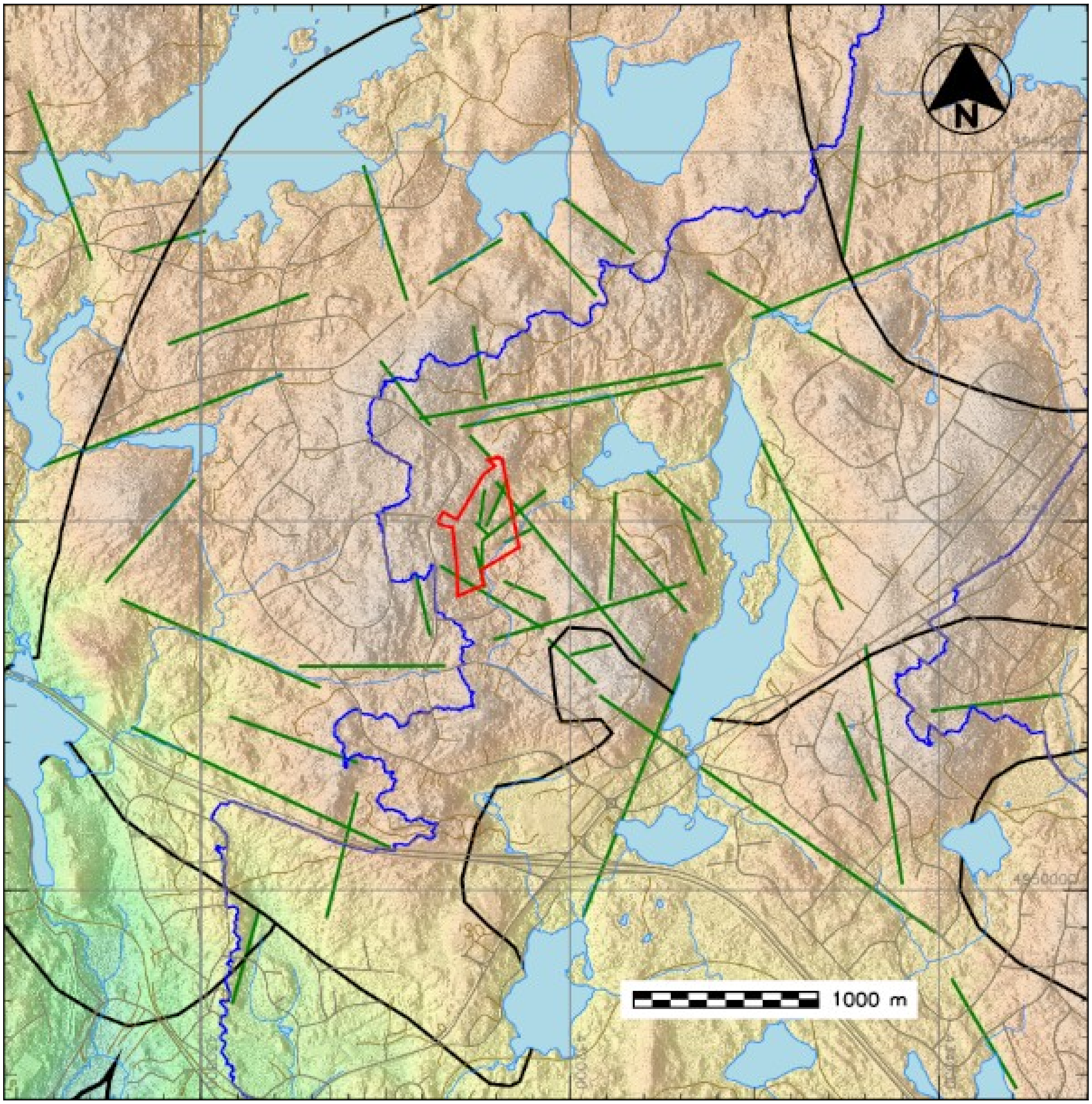

Figure 14. Lineaments identified from shaded relief lineament analysis. Elevation legend same as for 4. The Marchand Home site boundaries are in red, sub-watershed 1EH-1-E (also from Figure 4) in blue, and bedrock unit contacts (from Figure 6) in black.

- Recorded mineral occurrences:
  - gold, situated where the SMB contacts with Goldenville Group metasediments and located approximately 4 km due north of the site property boundary,
  - arsenic, situated approximately 4.25 km due west of site property boundary,
  - copper and iron, situated approximately 4.5 km west-southwest of site boundary,

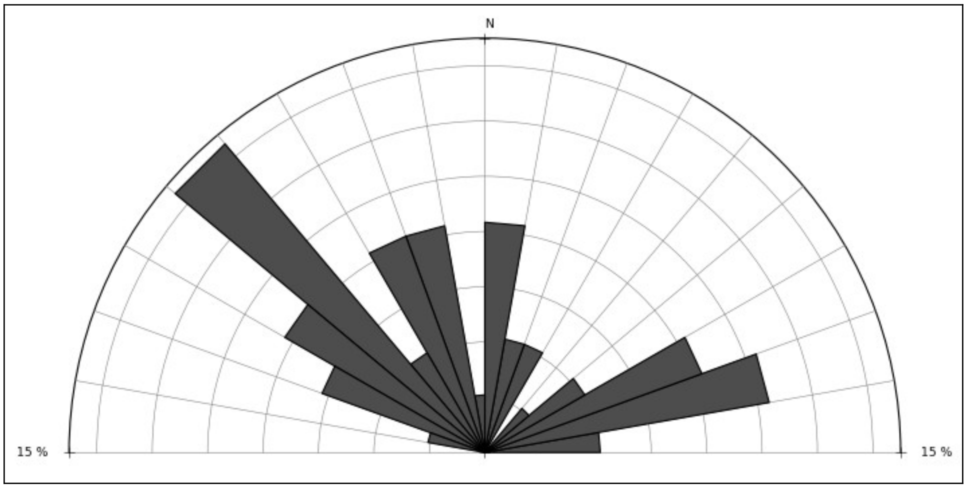

Figure 15. Rose diagram for lineaments in Figure 14.

- ◦ copper, iron, and molybdenum, situated near Highway 103 and approximately 2 km west-southwest of the site property boundary,
- ◦ tungsten, molybdenum, and iron, situated near Highway 103 and approximately 1.7 km southwest of the site boundary,
- ◦ fluoride, situated near Highway 103 and approximately 1.4 km south of the site property boundary, and
- ◦ lead and gold, situated just southeast of Duck Pond, south of the St. Margarets Bay Road, and approximately 2.5 km due south of the site property boundary, and
- ◦ arsenic, iron, and molybdenum, situated near Highway 103 and approximately 5.2 km southeast of site property boundary.

- Mines – only the following from the above have been developed and/or mined:
  - the gold occurrences located about 4 km north of the site, and
  - the lead deposit located near Duck Pond south of the St Margarets Bay Road.
- Construction soil borrow pits – there are 30 to 40 construction soil borrow pits within about a 5 km radius of the Marchand Homes property, the nearest of which are:
  - north of Highway 103: approximately 1 km southwest, 560 m due south, and 1.1 km southeast of the site property boundary, and
  - south of Highway 103: approximately 2.2 km southwest and 1.9 km southeast of site south of 103.

None of the above-noted mineral occurrences, mines, or soil borrow pits are located upstream of the site within sub-watershed 1EH-1-E, or within the estimated groundwater recharge area for wells to be located on-site (see Section 7.4 of this report).

5.7.1 Environmental considerations related to local mineral occurrences and the local bedrock geology

Because of their locations and distance from the Marchand Homes site, none of the mineral occurrences, mines, or soil borrow pits above-noted are anticipated to present any surface water, groundwater, potential groundwater recharge, or other environmental concerns relating the water supply wells that are to be drilled on-site. However, the presence of copper, iron, tungsten, molybdenum, and fluoride within the Halifax Peninsula Leucomonzogranite pluton near Highway 103 suggests that similar occurrences may also be present at other locations within the pluton, which is present could perhaps cause natural well water quality concerns.

Additionally, the radiometric signatures in Figure 13 suggest that uranium may be a concern in some well waters, as could radon possibly be a concern to air quality inside homes, as gas entering homes directly through foundations, or via well water supplies should radon concentrations be elevated enough in groundwater.

6.0 Quaternary geology

6.1 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 and 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) is preserved.

The Wisconsin glaciation started about 75,000 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, 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 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.

These 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 16 shows their distribution at and around the site.

6.2 Till ground cover and drumlins

All but about 15% of the area is underlain by granite till (Stea and Fowler, 1981; Stea et al, 1992), which is generally thin with many areas of exposed bedrock, and associated drumlins. Quartzite till is present within the remaining 15% of the Figure 16 area.

The granite till is described by Stea and Fowler (1981) and Finck and Graves (1987) as a sandy, loose to moderately compact, moderate yellowish brown to reddish orange and greyish orange to dark yellowish brown angular till with cobble sized clasts. The matrix is 80-90% sand, 10-20% silt and clay. The matrix to clast ratio is variable. Washed sandy zones

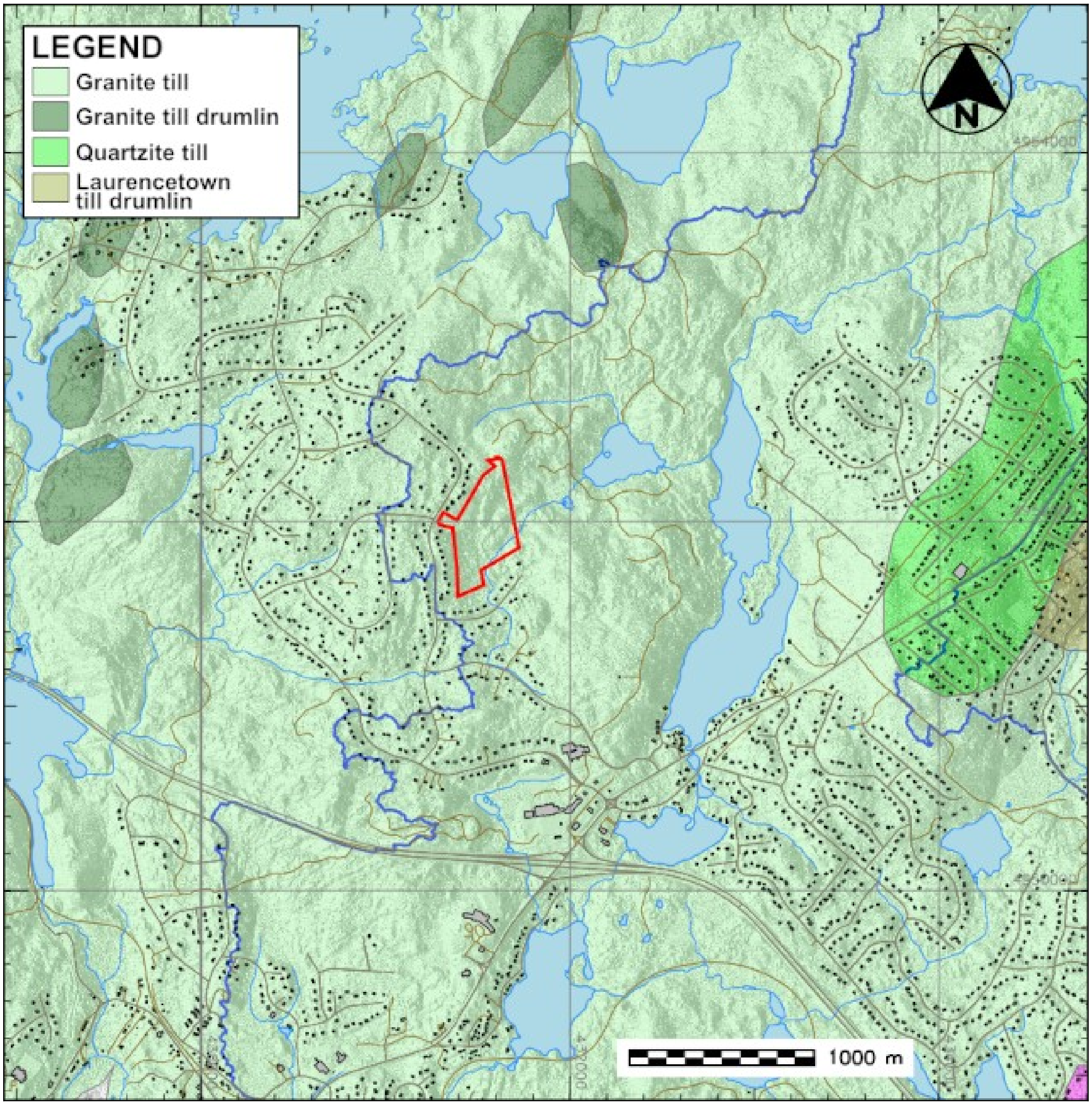

Figure 16. Quaternary (surficial) geology (from Stea et al, 1992)

around boulders and clay skins on pebbles are common. It is an oligomictic[41] till sheet (clasts dominated by a single granite type and commonly minor second granite type) that contains up to 95% locally derived clasts (1-4 km transport). The till is flat to rolling, with many surface boulders. It may range in thickness from 1 to 10 m (3 m average). The drumlin facies, which oblong, tear-drop features, can range in thickness from 2-20 m, are generally of the same colour as the till, in some cases more compacted with finer matrix, and locally enriched in allochtonous clasts (10-70 km transport).

41. Containing a small number of dominant minerals or rock types.

The quartzite till is described as a light bluish grey, loose, with angular clasts that are largely cobble sized, with a siltier matrix. The drumlins associated with it (present in only a small area at the eastern edge of Figure 16) is of the Lawrencetown till series (Stea and Fowler, 1981), which is described as reddish brown, moderately compact noncalcareous, fissile and massive, with a bimodal clast fabric in sandy clays that are dominated by kaolinite.

6.3 Holocene deposits

There is little to no readily available published information on the alluvial, lacustrine, or organic deposits present within the Figure 16 map area. However, they constitute only a relatively small part of the post-glacial deposits in the area.

Sitting above the tills described in Section 6.2 are the A and B soil horizons. They encompass the top soil and the subsoil layers – generally those that are cultivated. Although not shown in Figure 16, the map area is about 85% covered by Gebraltar Series soil, with only about 7% of the area (area encompassing the quartzite till) covered by Wolfville Series soil, and the rest of the area (about 8%) immediately north of Anderson and Cooper Lakes covered by Halifax Series soil.

MacDougall et al (1963) describe the Gebraltar Series soil as a brown sandy loam over strong-brown sandy loam, which is derived from pale-brown coarse sandy loam till derived from granite. It has good to excessive drainage. They describe the Wolfville Series soil as dark red-brown loam to sandy clay loam over strong-brown loam to sandy clay loam, which is derived from the till below. It has good drainage. The Halifax Series soil is described as a brown sandy loam over yellowish sandy loam that is derived from olive to yellowish-brown stony sandy loam till derived from quartzite bedrock. It has good to excessive drainage.

7.0 General hydrogeology

Domestic groundwater supplies may be obtained from dug wells constructed in till or other surficial deposits, or from wells drilled through surficial material into bedrock. Dug and drilled wells will each have their own water quality and yield characteristics, depending on the type of soil or rock they are constructed in.

7.1 Data availability and quality

Figure 17 shows the point-locations of the various data sources that were used to carry out this part of the assessment. These data sources included the most recent available well log database files (NSE, 2019; NSDNR, 2020), and the latest available well water quality (NSDNR, 2016a, 2018) and pumping test (NSDNR, 2016b; Drage, 2018) GIS database files.

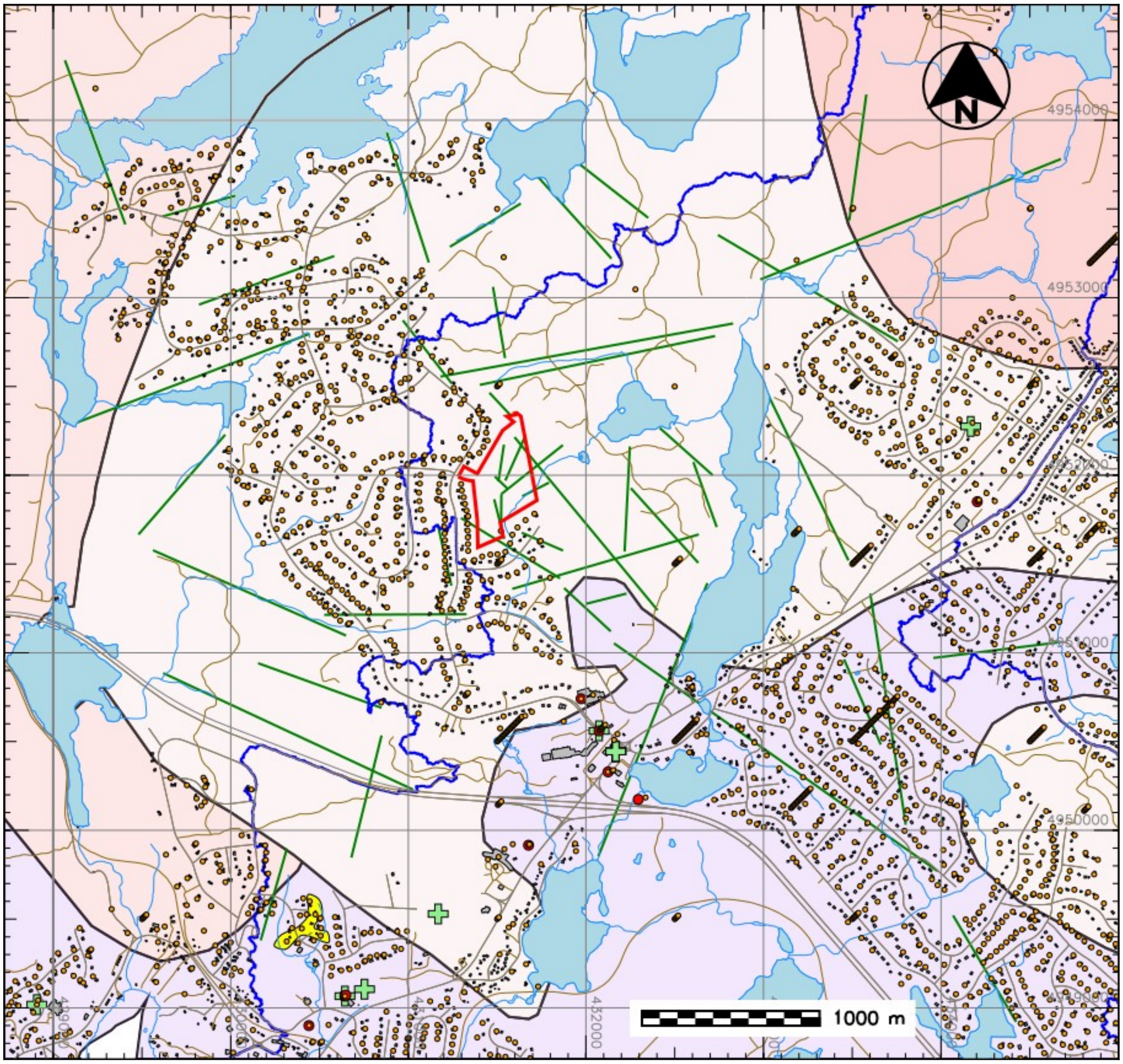

Figure 17. Sources and locations of data used for this assessment. Orange dots = wells; red dots = wells with pumping test information; green crosses = wells with water quality data. The geology legend is as in Figure 6, with the watershed 1EH-1-E boundary in dark blue and lineaments from Figure 14 in green. The Marchand Homes site boundary is red.

Where the data above permits, the well data that is summarized and statistically evaluated as the means to characterize the aquifer units for this assessment is done at three scales:

- it looks at the available well data within the entire Figure 17 area, since granitic bedrock is present within all of that mapping area,
- it looks at the available data for only those wells that have been drilled into the Halifax Peninsula Leucomonzogranite area is shown in Figure 17, and
- it looks at the local hydrogeology in greater detail, within the are that is immediately

around and within the estimated groundwater recharge area for wells that are to be drilled on the Marchand Homes development site.

The Nova Scotia well log database is poorly georeferenced[42] for wells that were constructed prior to mid-2016. This can present difficulties for proper hydrogeological assessments, particularly where several wells that plotting at one location within the database may have been constructed within an area with different types of geology – thus requiring that certain data be removed to avoid biasing interpretations across geologic units.

The NS well log database contains records for 1,885 drilled wells and 7 dug wells[43] within the Figure 17 area. And 917 of those drilled wells (there are no dug wells) plot within the leucomonzogranite bedrock unit area in Figure 17. Of the 1,885 drilled well records in the Figure 17 area, only 20.64% of the records give UTM coordinate locations that are accurate to within 50 m (class 1 accuracy), 74.16% give UTM locations that are accurate to only within 800 m (class 2 accuracy), and 5.20% give UTM locations that are accurate to within 1,500 to 8,000 m (class 3 and 4 accuracy). Of the 917 wells that in GIS plot as being drilled into leucomonzogranite in Figure 7, only 27.92% of the records are tagged with class 1 location accuracy (within 50 m), 69.25% are tagged as having class 2 location accuracy, and 2.84% give UTM tagged as having locations accurate to within 1,500 to 8,000 m.

This having been said, many of the wells that are tagged as having class 2 location accuracy (to within 800 m) in the well log database appear to plot very near the residences they seem to belong to. This appears to be true especially within the Westwood Hills subdivision, and for streets right around the Marchand Homes property. However, many records for wells tagged with class 2 location accuracy also plot as the stacked series of dots centred at the middle of the UTM grids southeast of the subdivision at UTM 431500E/4950500N, 432500E/4950500N, 433500E/4951500N, 434500E/4950500N, and 434500E/4951500N.

Within the Figure 17 map area, pumping test data is available for only 9 wells (only one plots within the leucomonzogranite) and water quality data is available for only 11 wells (only two plot within the leucomonzogranite).

42. 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.

Withn 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 17 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 those to report well locations, but most phone GPS are accurate to only about 100 m.

43. Dug wells are significantly underrepresented in Nova Scotia because well differs frequently fail to submit records on the wells they construct to NS Environment for inclusion into the well log database.

Notwithstanding the poor georeferencing, data is available with “generally good enough” location accuracy to obtain summary well characteristics, such as well depths, casing lengths, driller air lift yield rate test results, and depths to water-bearing fractures (to help characterize aquifer bearing capacity in 3-D) within the Figure 17 map area. Tables 2, 3 and 4 summarize those characteristics for the total Figure 17 and the different bedrock units discussed above.

Table 2. Key aquifer and well construction characteristics for wells within the Figure 17 area.

	N (data records)	Max.	Min.	Mean	1st Quartile	Median	3rd Quartile
Yield rate (L/min)	1,835	518.2	0.0	18.9	4.5	9.1	20.5
Yield rate per 30 m[44] (L/min)	1,832	1363.8	0.0	15.8	1.9	5.5	14.9
Static water level (m)	1,223	120.43	0.00	6.88	3.66	6.10	6.71
Bedrock depth (m)	1,720	47.87	0.00	4.80	2.44	3.66	5.49
Well depth (m)	1,878	184.45	12.20	74.16	50.30	73.17	91.46
Fracture 1 (m)	1,611	176.83	0.61	39.59	19.82	35.06	53.35
Fracture 2 (m)	1,010	167.68	0.18	57.52	39.63	54.88	72.18
Fracture 3 (m)	72	108.23	13.72	56.36	38.19	52.29	73.17
Fracture 4 (m)	15	114.33	32.32	65.49	46.95	62.50	80.34
Fracture 5 (m)	4	105.18	52.74	72.48	55.49	66.01	83.00
Casing depth (m)	1,794	56.71	0.61	9.23	6.10	7.32	12.20

Table 3. Key aquifer and well construction characteristics for wells plotting as having been drilled into the Halifax Peninsula Leucomonzogranite within the Figure 17 map area.

	N (data records)	Max.	Min.	Mean	1st Quartile	Median	3rd Quartile
Yield rate (L/min)	895	518.2	0.0	18.7	4.5	9.1	20.5
Yield rate per 30 m (L/min)	894	464.9	0.0	13.5	1.5	4.1	12.7
Static water level (m)	657	115.85	0.61	7.03	4.27	6.10	7.32
Bedrock depth (m)	848	39.63	0.00	4.92	2.44	3.66	5.49
Well depth (m)	915	184.45	12.20	81.76	57.47	76.22	103.66
Fracture 1 (m)	779	176.83	3.66	41.22	21.34	36.28	54.88
Fracture 2 (m)	483	167.68	10.06	60.39	38.11	57.93	79.27
Fracture 3 (m)	50	108.23	13.72	58.21	36.59	54.27	75.84
Fracture 4 (m)	10	114.33	32.32	71.01	49.39	73.48	91.84
Fracture 5 (m)	2	105.18	56.40	80.79	68.60	80.79	92.99
Casing depth (m)	866	42.68	0.61	9.86	6.10	9.15	12.20

44. Because of the way that residential wells are drilled (typically deep enough only to yield sufficient water for single residential needs, as opposed to drilling to depths to optimize yields, such as would be done for commercial wells), database reported well yields and depths can vary significantly over small distances, making it difficult to characterize aquifers. To help do spatial aquifer analysis, we have normalized yield against well depths in our GIS by calculating reported yield per 30 m (100 feet) of open borehole (vertical distance from the casing bottom to well bottom) to obtain values that are akin to well specific capacity.

Table 4. Key aquifer and well construction characteristics for wells plotting as having been drilled into bedrock other than the Halifax Peninsula Leucomonzogranite within the Figure 17 map area.

	N (data records)	Max.	Min.	Mean	1st Quartile	Median	3rd Quartile
Yield rate (L/min)	847	272.8	0.0	18.9	5.8	11.4	19.8
Yield rate per 30 m (L/min)	845	1363.8	0.0	18.1	2.6	6.2	16.5
Static water level (m)	494	120.43	0.00	6.90	3.35	5.49	6.71
Bedrock depth (m)	789	47.87	0.00	4.76	2.44	3.66	5.79
Well depth (m)	870	160.06	12.20	67.75	46.65	62.50	86.89
Fracture 1 (m)	749	152.44	0.61	38.66	19.51	33.54	53.35
Fracture 2 (m)	469	146.34	0.18	55.95	39.63	54.88	68.60
Fracture 3 (m)	21	96.04	21.95	53.09	39.63	48.78	63.11
Fracture 4 (m)	5	70.43	42.68	54.45	47.87	48.78	62.50
Fracture 5 (m)	2	75.61	52.74	64.18	58.46	64.18	69.89
Casing depth (m)	837	56.71	3.66	8.73	6.10	6.71	10.67

Due to the small number of dug wells in the database for the Figure 17 area, there is not sufficient data to properly characterize the surficial hydrostratigraphic unit[45] (HU) of the area. Therefore, the discussion below on the surficial HU (and bedrock HU's to a certain degree) must be based on a general understanding of the area topography, land use, geology (i.e. the medium through which groundwater flow), and the effects that those aquifer materials might impose upon the regional, nearby, and on-site hydrogeology and hydrogeochemistry.

7.2 The area surficial (till) hydrostratigraphic unit

Till generally has low permeability and thus, any wells constructed in this HU are expected to provide sustained yield rates that are just large enough to meet average single residential needs. However, due to the generally sandier nature of the tills overlying granitic terranes, 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 over the granitic rock.

Dug wells are known to produce generally good quality water. However, since tills are usually unconfined[46], wells constructed in them are prone to contamination from surface

45. 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 flow and the quality of groundwater. The surficial (soil) HU, Carboniferous (Windsor Group) rocks, and plutonic rock units in Figure 17 are each expected to have potentially very different groundwater flow characteristics and water quality, so they must each be considered as separate HU's.

46. A confined aquifer (or HU) is an aquifer below the land surface that is saturated with water. Layers of impermeable material are both above and below the aquifer, causing it to be under pressure so that when the aquifer is penetrated by a well, the water will rise above the top of the aquifer (i.e. flowing wells).

A water-table--or unconfined--aquifer or HU is an aquifer whose upper water surface (water table) is at atmospheric pressure, and thus is able to rise and fall. Water-table aquifers are usually closer to the Earth's surface than confined aquifers are and do not have impermeable layers above them. As such the are impacted by drought conditions sooner and are more prone to surface contamination than confined aquifers.

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 shorter travel times, and thus shorter natural soil filtration distances, available for the water 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 upon 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 can vary significantly in surficial deposits.

In many cases, particularly where till permeability is lowest, the piezometric (water table) surface will follow general ground surface elevations (more details on this in Section 7.4.1 of this report). That is why in the Wet Areas Mapping model provided by NSDNR (2012), very shallow groundwater levels (near surface) are anticipated in till near the stream present in the southeast part of the Marchand Homes site, whereas pending till depth, piezometric levels would be expected to be deeper at the higher surface elevations of the site.

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.

7.3 Physical characteristics of the area pluton bedrock HU's

The rocks of the Halifax Peninsula and Tantallon Leucomonzogranite units are impermeable – they are tight crystalline structures with no primary permeability[47], so secondary type permeability (fracture flow) along joint sets, fault planes, and shear zones, is the only way that surface water can percolate into and groundwater can flow through these two bedrock units. Consequently, the yields for wells drilled into them will depend entirely upon the how many water-bearing fractures wellbores can intercept. So depending on the fracture orientation, location, and degree of bedrock fracturing present, well yields (and water quality, depending on mineralization present along those fractures) can be expected to vary significantly over very short distances within the Figure 17 mapping area.

47. The term "primary permeability" describes groundwater flow within the spaces between sand grains of non-indurated and indurated sedimentary deposits, which values depend the size of the spaces, amount of bonding cement present (clay minerals, calcite, quartz), and thus the interconnection of the interstices and overall levels of flow tortuosity within the aquifer. Secondary permeability is flow through bedrock joints (small cracks) or fractures in faults and shear zones, or through solution channels or caves such as may be present in areas with limestone.

The Halifax Peninsula and the Tantallon Leucomonzogranite bedrock units will in general be addressed as one HU in the discussions below. This is because both bedrock units are anticipated to have a generally similar mineralogical and chemical make-up (both are leucomonzogranite, and both are Stage 2 plutons, likely originating from the same magma feedstock). However, due to their micro-scale crystalline grain-size differences, the two units may be expected to have experienced slightly different rheological responses to the internal stresses of emplacement and to the pre- to post-emplacement Acadian Orogen tectonic stresses, and thus slightly different physical hydrogeologic (fracture) characteristics.

The numbers in Tables 3 and 4 clearly illustrate these differences, where yields per 30 m for wells drilled into the Halifax Peninsula Leucomonzogranite are typically much lower than those for wells drilled into the Tantallon Leucomonzogranite, notwithstanding thinner tills (shallower depths to bedrock) bedrock fractures are generally deeper, and thus wells need to be drilled deeper to obtain sufficient yields to meet residential needs.

However, the generally slightly deeper casings for wells drilled into the Halifax Peninsula Leucomonzogranite (again, notwithstanding thinner till) suggests that the upper surfaces of the bedrock within the Halifax Peninsula unit is in general more highly weathered. Based on Israeli and Emmanuel (2018) and Nie et al (2018), larger grain size of the Halifax Peninsula Leucomonzogranite may be related to this greater degree of near-surface bedrock weathering, but is not likely to result in the development of smaller weathered bedrock fragments (Hoskin and Sundeen, 1985).

7.3.1 Pumping test data

Table 5 summarizes the pumping test data (NSDNR, 2016b; Drage, 2018) available for the nine wells shown as red dots in Figure 17.

Pumping test Hal-150 appears to have been done for an assessment similar to this one. All of the pumping tests were done on wells that were constructed for schools, shopping centres, nursing homes, or other businesses.

It is apparent from the pump setting depths and associated values listed in Table 5 for available drawdown that none of the safe yield interpretations summarized in the table were done with consideration of the impacts possible resulting from dewatering major water-bearing fractures[48] in the wells being tested, which can affect well sustainability for wells under continuous long-term production. This having been said, the well for pumping test

48. Pumping causes the groundwater level at and around the pumping well to be lowered. It is generally good practice to avoid dewatering wells for extended periods of time to below the depths of major water-bearing fractures, since doing so can result in those previously saturated fractures becoming dried up, inducing air into them, and thus (in a process similar to air locking a hydronic heating system) decreasing the fracture's hydraulic conductivity, thus also decreasing well yield.

Hal-62 was significantly under-stressed[49], which can also result in overestimation of well sustainability.

Table 5. Data summary from pumping test database (Drage, 2018) for wells in Figure 17 area.

PumpTest_ID	HAL-150	HAL-31	HAL-74	HAL-133	HAL-136	HAL-106	HAL-62	HAL-173	HAL-51
Easting	430440	430643	430648	431677	431973	432074	432125	432295	434204
Northing	4948900	4949066	4949071	4949916	4950741	4950560	4950329	4950174	4951851
NSE Well Number	110081	700630	700630	40295	881977	930469	752759	921780	742261
Well depth (m)	121.92	91.44	91.44	91.44	90	76.2	85.34	76.81	131.06
Casing depth (m)	12.19	3.66	3.66	18.29	6.1	6.1	7.32	7.32	12.8
Test Year	2011	1971	1977	2004	2004	1993	1975	1993	1975
Test duration (hours)	72	72	72	72.6	132	72	72	72	72
Ave. pumping rate (m^3/d)	19.33	42.08	44	47.01	19.58	28.8	163.64	23.14	39.27
Tot. vol. pumped (m^3)	58.01	126.24	132	142.2		86.4	490.91	69.43	117.82
Static water level (m)	1.74	2.23	5.79	10.56	13.43	7.04	2.59	1.8	14.33
Pump setting depth (m)	114	88.39	88.39	60	--	68.58	79.25	68.58	106.68
Avail. drawdown[50] for test (m)	112.31	86.11	79.25	49.45	--	61.57	73.76	66.78	88.39
Max. drawdown in test (m)	60.65	73.99	57.79	7.06	37.3	15.06	2.84	49.87	49.99
% of avail. drawdown used	54	85.93	72.92	14.28	--	24.46	3.86	74.67	56.55
Drawdown stable?	Y	N	N	N	N	Y	Y	N	Y
Tot. recovery (m)	60.58	73.76	--	5.58	31.13	14.97	--	49.51	--
Recovery minutes	1440	640	--	2760	90	120	--	120	--
% recov. of max. drawdown	99.88	99.69	--	78.95	83.47	99.39	--	99.3	--
Calc. Transmissivity (T)[51] **(m^2/d)**	0.3	0.16	0.47	5.18	0.3	0.68	9.29	0.27	0.52
Specific capacity ($m^3/d/m$)	0.32	0.57	0.76	6.62	--	1.91	57.52	0.38	0.79
Hydraulic cond. (K) (m.d)	0.003	0.00184	0.00552	0.0743	0.00401	0.00968	0.308	--	0.0045
Avail. long-term drawdown (m)	--	86.11	--	50	75	--	--	64.01	106.68
Long-term yield (Q_{20})[52] (m^3/d)	--	7.72	19.64	123.38	15.33	28.8	163.64	11.77	26.18
Long-term yield (Q_{20}) (L/min)	--	5.4	13.6	85.68	10.65	20	113.6	8.17	18.2
Short-term yield[53] (Q_{short}) (m^3/d)	--	16.36	32.73	--	--	--	222.55	17	36
No. of observation wells	--	--	--	1	--	1	--	--	--
Aquifer T (m^2/d)	--	--	--	3.88	--	--	--	--	--
Aquifer Storativity[54] (S)	--	--	--	0.000075	--	--	--	--	--

49. For pumping test purposes, in order to adequately stress the aquifer being tested, the amount of water level lowering sought-after is typically 75% of the available drawdown. Also, recoveries greater than 80% of total drawdown experienced are usually sought to ensure there is enough recovery data for interpretations

50. The available drawdown serves as a multiplier in the equation used to calculate Q_{20} and other yield values. As such, there is a linear relation between available drawdown and long-term sustainable yield.

51. The coefficient of Transmissivity (T) defines the ability for water to flow through an aquifer and, thus, of the capability of the aquifer to deliver water to wells. It is the rate at which water flows through a strip of aquifer as defined by aquifer hydraulic conductivity multiplied by aquifer saturated thickness penetrated by the wells under consideration.

52. 20 years is used as the standard duration for the assessment of sustainable yield. This number assumes a number of things about the aquifer being tested, one of which is that there is no groundwater recharge during the 20 year periods used for assessment.

53. These are typically based on 3 to 4 month terms to approximately include possible recharge effects.

54. Storativity (S), or the coefficient of storage, represents the volume of water released per unit of aquifer storage area per unit change in 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 (percentage of the void space available between sediment grains or in bedrock fractures for water to be stored in) of the aquifer.

The upper values for Qs_{20} in Table 5 are quite a bit lower than those presented in Tables 2 through 4. However, it should be noted that the air lift yield test results reported by drillers are usually based on crude visual estimates of water flow rates coming from the tops of well casings during well development after drilling completion. Also, since well development is typically done with the drilling bit sitting at the very bottoms of wells, thus blowing all water from wells, and usually for only a period of about one hour, then driller air lift yield tests cannot be used to represent long-term or sustainable yields for wells that are intended to be pumped continuously. And such, the air lift well test yield results must be viewed as non-conservative approximations only of what wells might be able to produce.

Depending on well depth and the depths of fractures encountered in drilled wells, as well as hydrogeologic conditions at and around the wells, driller air lift yield test results may represent at best only 75% to 50% of the actual, long-term sustainable well yields for wells in which water-bearing fractures are located deeper down nearer the bottoms of wells. In Wells where water-bearing fractures are encountered higher up at shallower depths, actual sustainable long-term pumping rates may be as low as 30-40% of the driller air lift yield test results or lower. Pumping tests of sufficient duration are needed to be able to identify proper, long-term sustainable well yield values.

7.3.2 Area aquifer confinement

In light of the somewhat sandy nature and good drainage of the area tills, the Halifax Peninsula Leucomonzogranite HU would typically not be considered to be confined, particularly where water-bearing bedrock fractures may be present at shallow depths. However, where water-bearing fractures are found deeper in wells, pending static water levels relative to water-bearing fracture depths, those fracture systems may experience confined type conditions if they represent long groundwater travel flow paths from the recharge areas to the wells.

This having been said, the single value for aquifer Storativity (S) of 7.5×10^{-5} presented Table 5 for the pumping test Hal-133 (at Sir John A. MacDonald High School) is clearly within the range for confined aquifers (Freeze and Cherry, 1979). The water-bearing fractures in that well are reported to have been encountered at depths of 18.9 and 77.75 m, each also reported by the driller to have yielded 27.3 and 22.7 L/min, respectively.

7.3.3 Static groundwater depths and groundwater level fluctuations

Table 2 through 4 show the static[55] water depths for drilled wells within the Figure 17 area. While the static water depths are shown to vary broadly, the extreme low static groundwater may be a function of drillers not waiting long enough for wells to recover after drilling – the

55. Non-pumping, natural groundwater level.

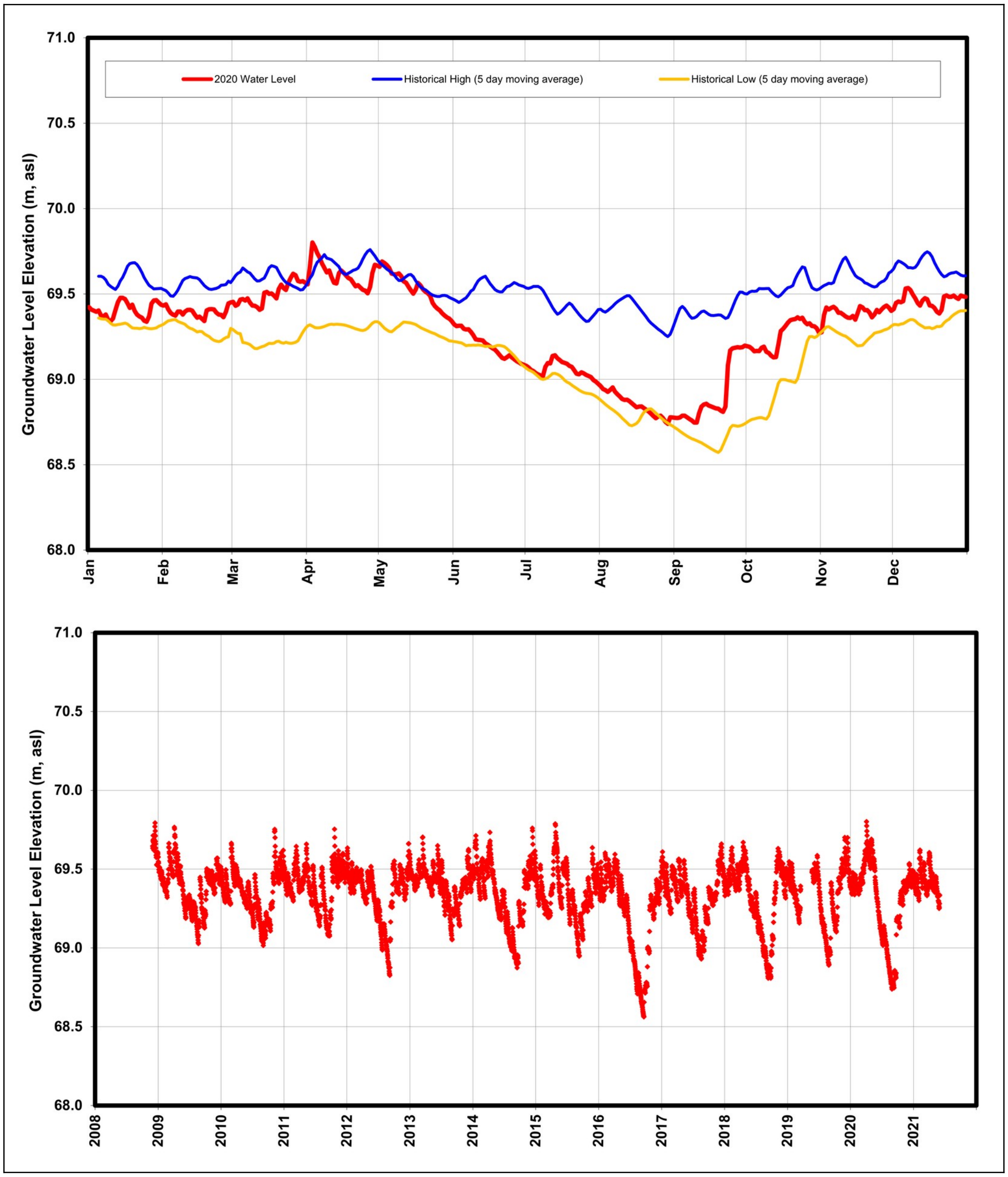

Figure 18. Groundwater levels at the NSE (2021b) Lewis Lake network observation well. Top: complete year 2020 data (red) overlain onto maximum (blue) and minimum (yellow) historic (to 2008) levels. Bottom: daily average water levels from the end of 2008 to mid 2021.

mean static water depths are in the 6 to 7 m range. Static water levels may be expected to vary, by significant amounts at times, depending on local topography, aquifer depth, and other causes. Static groundwater levels at individual wells can also vary and fluctuate naturally both seasonally, and year to year, depending on the amounts of precipitation received, how much of that precipitation becomes groundwater as recharge during any particular water year, and during in antecedent years over greater periods of time.

To define what those seasonal and annual groundwater fluctuations are, Nova Scotia Environment has reinstated its groundwater elevation observation well network (NSE, 2021b), and nearly continuous recent data plus some historic data are available from most of their network system wells. Their nearest network observation wells completed in granite is located at Lewis Lake (network well 079) located only a few kilometres southwest of the site. Figure 18 shows the historic high and low groundwater levels and daily static groundwater elevations from it from early 2009 to mid 2021.

The Lewis Lake observation well shows a 0.45 m to 0.8 m annual water level fluctuation, with a nearly 1.15 overall maximum to minimum historic range over time. Similar static water level fluctuations may be expected at wells on or near the Marchand Homes property.

7.3.4 The local Halifax Peninsula Leucomonzogranite HU characteristics

The larger scale site close-up in Figure 19 (zoomed in from Figure 17) illustrates very clearly how the fracture flow for wells that are drilled into the Halifax Peninsula Leucomonzogranite can result driller air lift yield results and required well depths can vary significantly over very short distances. Table 6 summarizes the key aquifer and well construction characteristics for wells plotting as having been drilled only into the Halifax Peninsula Leucomonzogranite within a 500 m radius of the Marchand Homes property boundaries.

Table 6. Key aquifer and well construction characteristics for wells drilled within the Halifax Peninsula Leucomonzogranite and within 500 m of the Marchand Homes property boundaries.

	N (data records)	Max.	Min.	Mean	1st Quartile	Median	3rd Quartile
Yield rate (L/min)	162	68.2	0.0	12.8	4.5	8.0	18.2
Yield rate per 30 m (L/min)	162	62.7	0.0	8.8	1.5	3.6	11.1
Static water level (m)	133	33.54	0.61	6.45	3.05	5.49	7.62
Bedrock depth (m)	147	18.29	0.00	3.54	2.13	3.05	4.57
Well depth (m)	162	153.96	30.49	77.86	57.93	76.22	94.13
Fracture 1 (m)	143	144.82	6.71	37.69	17.68	32.01	50.61
Fracture 2 (m)	99	125.00	12.20	56.62	38.11	53.35	76.98
Fracture 3 (m)	7	108.23	28.96	59.19	33.54	51.83	79.12
Casing depth (m)	150	34.15	5.49	8.92	6.10	8.54	9.76

The forth and fifth fractures are not reported in the database records for wells drilled within 500 m of the site boundaries. A comparison of the data for 894 wells in Table 3 to the 162 wells represented in Table 6 shows that within local site area, driller air lift yield test results are generally quite a bit lower than within the rest of Halifax Peninsula Leucomonzogranite area in Figure 17, as are the normalized yields per 30 m of open bedrock within wells, and well depths and casing lengths are greater, although bedrock is slightly shallower.

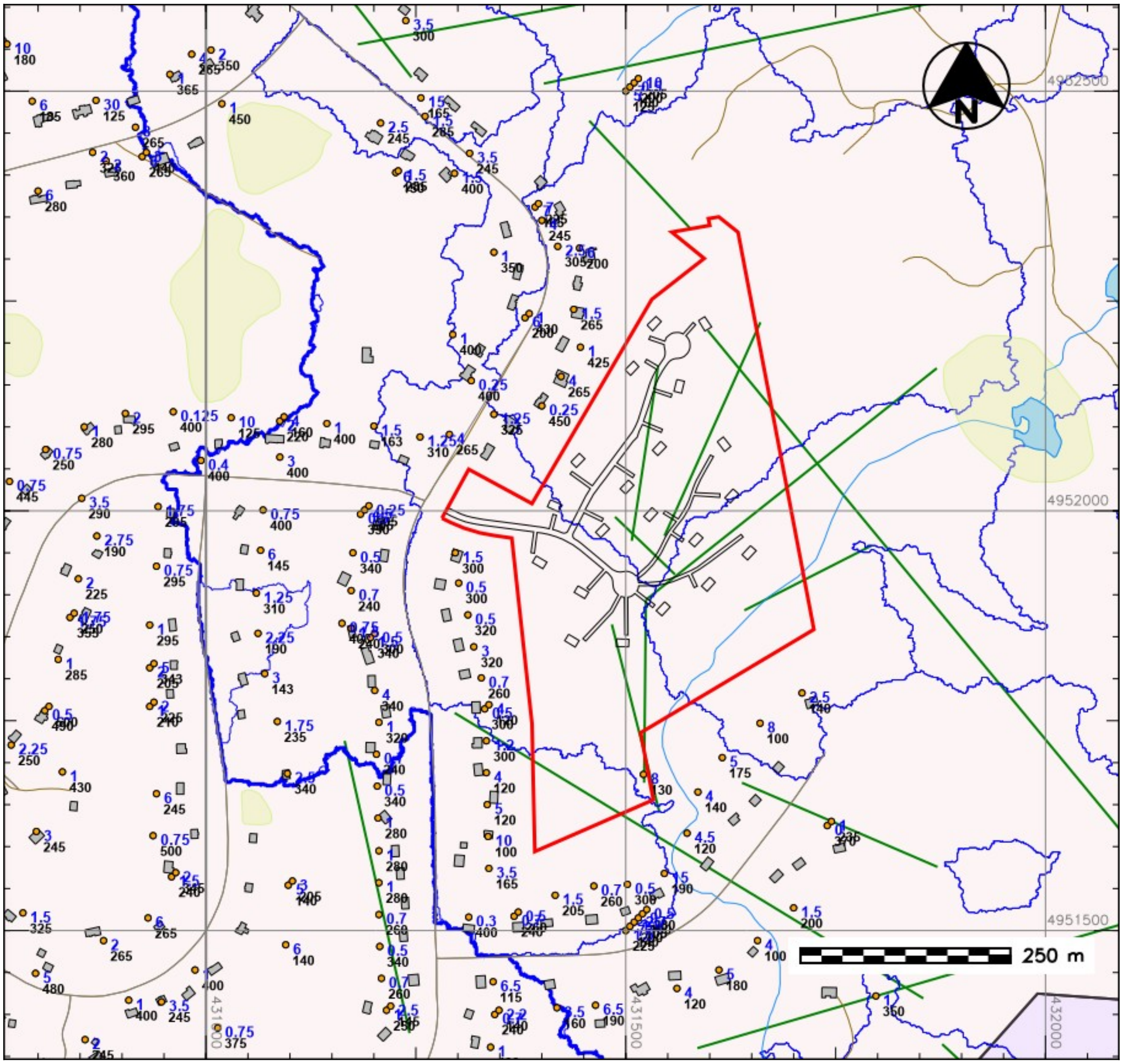

Figure 19. Close-up from Figure 17 of the local site (boundaries are in red) area wells (orange dots), with driller air lift yield test results (igpm) shown blue, and well depths (feet) shown below in black. The thicker dark blue line is the western boundary of sub-watershed 1EH-1-E, and the thinner dark blue lines are its 4th order stream drainage sub-basins. The geology legend is the same as in Figure 6, with lineaments from Figure 14 in green. The pale green area are wetland areas per NSGC (2021a).

Among the 162 wells summarized in Table 6, one well was abandoned (likely the one with zero yield), two wells (1.2%) are reported to have required stimulation (hydraulic fracturing, with yields after stimulation of 1.1 and 11.4 L/min), and eight wells (4.9%) are reported to have been deepened 5 to 68 m after initial drilling (to new depths of 68.6 to 153.96 m), with yields after deepening ranging from 1.1 L/min (153.96 m deep) to 20.5 L/min (also 153.96 m deep), with an average yield of 9.4 L/min for those wells after deepening.

Based on data from nearby wells drilled within 200 m of the site boundaries along Hemlock Drive and Parklyn Crt., wells drilled on-site may be expected to anywhere from 1.4 to 68.2 L/min (average 13.2 L/min) from wells drilled to depths of 30.5[56] to 154 m (average 77.3 m), yielding 0.45 to 56 L/min (average 9.6 L/min) per 30 m of open borehole. Depths to bedrock ranged from surface to 6.7 m, with casing lengths ranging from 6.1 (the minimum per well construction regulations for domestic wells) to 17.4 m.

Among these wells, 2 (at 316 and 365 Hemlock Drive) required stimulation (hydraulic fracturing) after drilling, and 2 wells (at 185 and 347 Hemlock Drive had to be re-drilled deeper to improve yields. One well (at 143 Parklyn Crt.) produced no water, was abandoned at 112.8 m, and a second well drilled on that property 5 m away. It was drilled to a depth of 71.7 m and was air lift tested at 4.5 L/min. And at 2 High Timber Drive, it appears that a first well drilled in November 2020 may have failed, was replaced by another located about 5 m away, which then required stimulation (blasting, which is not a recommended form of well stimulation, since blasting can effect other nearby wells).

Based on the immediately surrounding existing wells, drilling success may be expected to be generally greater within the southern part of the site, due no doubt to greater fracture flow, notwithstanding the issues noted above at the end of Parklyn Crt., as possibly exemplified by the northwest-trending lineaments identified in that part of the site. However, the lineament analysis that was done for this assignment suggests that there may be north-south conjugate faults to these, as well as a couple of northeast-trending lineaments (possible faults) in the north parts of the site, which are not apparent elsewhere farther west off-site.

NSE (2011) recommends a minimum daily water usage rate of 1,350 L/day per single family dwelling (which, for today's homes with multiple bathrooms, may not be conservative enough). So assuming there is sufficient well bore cold-water storage in wells[57], a well should be able to produce a at least 1 L/min to meed that criteria. Of the 895 wells represented by Table 3, about 1.64% do not meet that 1,350 L/day criteria (3.2% of the wells produce under 2,025 L/day, or 1.5 times the NSE recommended criteria) and 1.23% of the 162 wells represented by Table 6 do not meet the 1,350 L/day criteria (3.7% of the wells produce under 2,025 L/day) based on the driller air lift yield test results reported for wells drilled into the Halifax Peninsula Leucomonzogranite within those two respective mapping areas.

The difficulties in obtaining water supplies at a few nearby lots illustrate very clearly, and this cannot be over-stressed, that wells drilled in the Halifax Peninsula Leucomonzogranite

56. Wells this shallow are generally not recommended, for reasons of possible impacts from well interference (see Section 7.6 of this report) in areas with high well spacial densities and where other nearby wells may be considerably deeper.

57. That wells are deep enough to have the necessary combined yield and storage capacity per 24 hour period to meet domestic demand.

will depend entirely on fracture flow to be able to produce any reasonable amount of water. Since wells are typically vertical, as are bedrock faults and fractures in many instances (which, in the area, are expected to be steeply dipping), then the opportunity for wells to intercept a sufficient number of bedrock fractures may be difficult at some lots.

7.4 Groundwater quality

Table 7 summarizes the water quality data available in public GIS files for wells drilled into Leucomonzogranite and represented by the green crosses in Figure 17.

Table 7. Well water quality data available from the public domain GIS files for wells completed in Leucomonzogranite within the Figure 17 map area (NSDNR, 2016a, 2018).

Parameter/Sample ID	Ptest404	Reg2232	Ptest373	Ptest374	Reg2216	Ptest396	Reg3321	Reg1569	Guide[1]
Year sampled	1975	2005	1993	1993	2005	1975	2012	2004	
Alkalinity (mg/L as $CaCO_3$)	105	24	21	22	15	54	12	17	
Bicarbonate (mg/L)	--	23.9	21	22	15.1	--	12	17	
Carbonate (mg/L)	--	0.5	0.5	0.01	0.5	--	5	--	
Sodium (mg/L)	12	47	54.7	19.3	190	6.7	154	43	200 a
Potassium (mg/L)	1.3	3	1.9	2.3	3.7	1	2.5	2.1	
Calcium (mg/L)	50	20	41.2	16.1	60	16	62.1	35	
Magnesium (mg/L)	4.2	3.3	8.6	2.6	15	2.1	16.4	3.7	
Fluoride (mg/L)	0.2	1	--	--	0.3	1.2	0.05	0.2	1.5 h
Sulphate (mg/L)	10	7.9	4	7	23	4	27	--	500 a
Chloride (mg/L)	27	88	160	46.7	430	4.2	335	130	250 a
Hardness (mg/L as $CaCO_3$)	142	62	138	50.9	210	49	223	100	
Tot. Dissolved Solids (mg/L)	240	215	303	140	757	108	607	242	500 a
pH	7.2	7.08	6.1	6.8	6.2	7.2	6.3	6.22	
Nitrate/nitrite (mg/L as N)	0.2	0.025	0.62	0.025	0.62	0.05	0.34	0.41	10/1 h
Arsenic (µg/L)	--	30	2	--	3.4	--	4	2	10 h
Uranium (µg/L)	--	0.9	4.7	--	7.7	--	6.2	1.3	20 h
Iron (µg/L)	50	3600	20	1050	25	50	25	--	300 a
Manganese (µg/L)	25	360	20	310	1000	25	445	3	120/20 h/a
Notes:	1. Health Canada, 2020. a = aesthetic objective, h = health objective.								

Except for a few parameters, based on the data presented in Table 7 and experience, wells drilled into leucomonzogranite may be expected to produce generally good quality water, but which can vary locally depending on well location and construction, local area land use, and specific local bedrock and soil lithology. The wells completed in leucomonzogranite have been seen to produce calcium-bicarbonate type waters inland, to sodium-chloride type waters nearer the ocean or 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 (7). Iron and manganese can both exceed their respective Health

Canada (2020)[58] aesthetic objective values of 0.3 and 0.02[59] mg/L[60], respectively, and health objective of 0.120 mg/L for manganese. This is due largely to the hematization[61] 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 rock, so values in water from wells drilled drilled into granitic bedrock may 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[62] 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[63] 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.

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58. While in 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.

59. The health guideline for manganese is new as of a few years ago, as is its new aesthetic guideline, which was reduced from 50 µg/L to 20 µg/L; the lower of which can be difficult to treat.

60. 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.

61. 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.

62. 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.

63. 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 1.64×10^{-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.

In regards to the data presented in Table 7, samples Reg2216 and Reg3321 show what appears to be road salt effect impacts, thus accounting for their elevated values of sodium, chloride, and total dissolved solids (TDS).

7.5 Groundwater recharge

Understanding the amount of groundwater recharge available is necessary to determine the number of homes that may be supported and the sustainability of the available on-site water supply resources for new developments.

Groundwater recharge estimates can be done by many approaches, the two most used for these types of Level 1 assessments being:

1) the ultra-conservative per-lot based water balance approach, as presented in Appendix B of NSE (2011), or
2) a more realistic aquifer-based balance approach that includes larger areas around development sites, groundwater flow gradients, which also accounts for other groundwater users outside of the subject development sites.

The information needed to assess possible water availability to aquifers by either method (or for any other type of water supply and/or well field development 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), 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.

7.5.1 Groundwater flow, potential water 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) – with flow between each being possible without distinct boundaries.

Regional flow involves recharge at the top of the province and deep, long-distance flow toward the ocean with long residence times. Regional flow in reference to the site (which is located nearer to the ocean, see Figure 3) would be mostly south-southwesterly from the St.Croix/Indian River watershed boundary toward the Chebucto Peninsula and the St. Margaret's Bay.

Intermediate flow would closely parallel the regional flow and probably include some recharge from some of the lower parts of the Sackville River watershed and from the Northeast River sub-watershed 1EH-2 from around 6 km north of the site, with discharge likely in a more southerly direction, but still with a strong south-southwesterly component, beneath East River sub-basin 1EH-1-E and eventually into the St. Margarets Bay.

As was suggested above, the groundwater-sheds for both regional and intermediate flows can and often do transcend surface watersheds. Which is why wells drilled on the Marchand Homes property would very likely be receiving groundwater from both sub-basins 1EH-1-E and 1EH-2 – particularly from the part of sub-watershed 1EH-2 that is directly to the north of the site, plus likely a little bit from the west.

Local-scale groundwater flow typically includes recharge at local knolls and discharge in nearby valleys. Local-scale groundwater flow surfaces usually parallel surface topography in a subdued manner.

At the site, this would include flow vectors directly from the north and northwest from sub-watershed 1EH-2, as wells as from the same sub-basin directly from the west (from perhaps as far as where High Timber Drive turns south), with net eastward, southeastward and southerly outflow toward Stillwater Lake and Winslow Drive.

Where there is no empirical data, the concept above and ground surface elevations may be used to make rough estimates of groundwater flow directions and define approximate local groundwater recharge areas.

The above-noted regional, intermediate, and local groundwater flows would all contribute to supply water to wells drilled on-site. This would include an area that extends perhaps as far as 1 to 1.5 km north of the site, and due to the drawdown effects of pumping wells on and around the site, perhaps around 0.5 km west of the site, narrowing to 0.25 to 0.5 km from the site at its eastern- and southern-most boundaries. For simplicity, using GIS capability to draw buffers around objects, areas encompassing buffer zones of 250 and 500 m were drawn around the site boundaries to represent the above (see Figure 20). These constitute a likely but conservative recharge area for wells to be drilled on-site of 842,777 m^2 to 1,901,793 m^2.

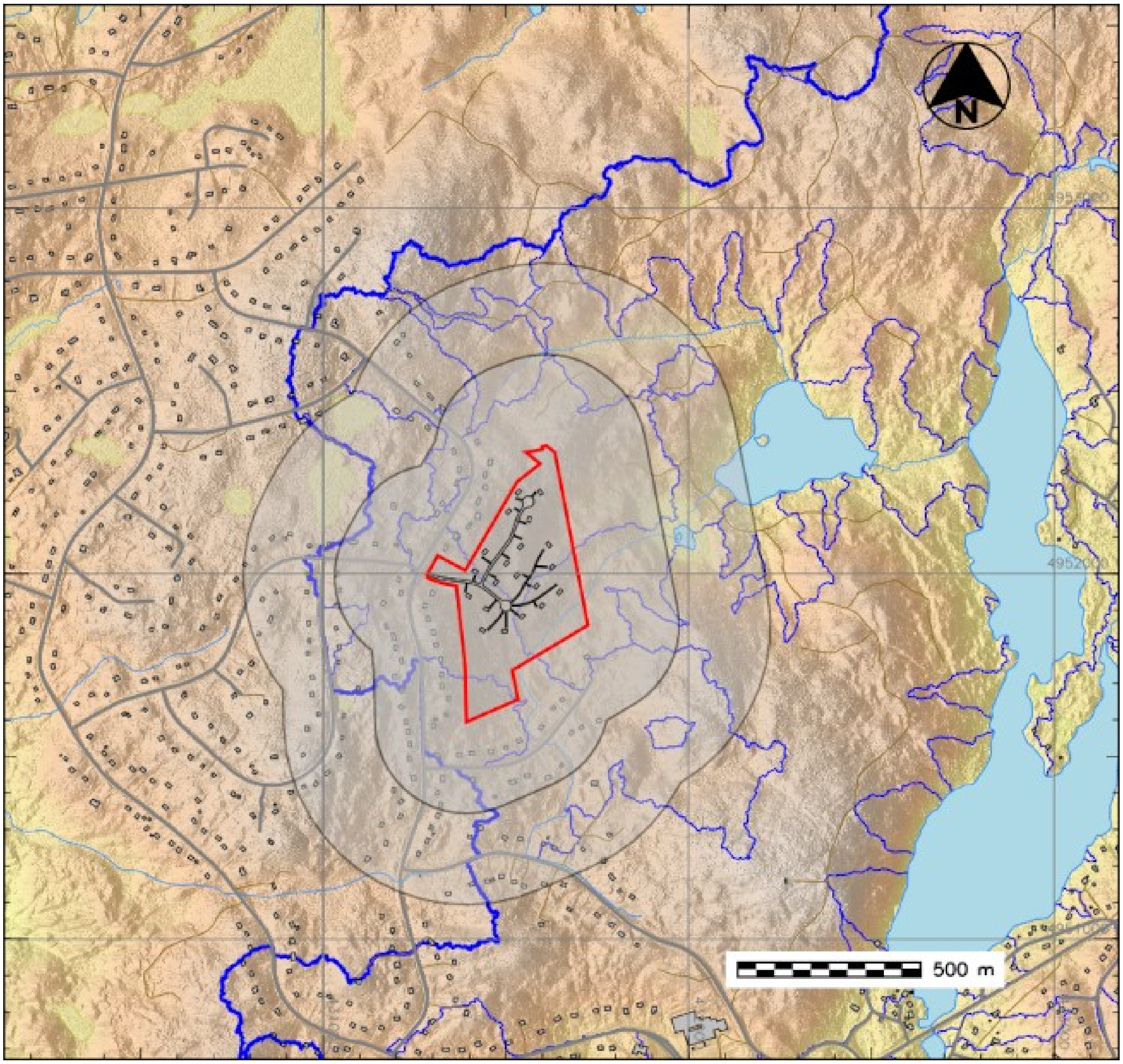

Figure 20. Likely but conservative natural estimated groundwater recharge areas (shaded 250 and 500 m buffer areas) for wells that are proposed to be drilled on-site. The thick dark blue line is the western boundary for sub-watershed 1EH-1-E, the thin dark blue lines are the boundaries for the local 4th order stream drainage sub-basins. The site boundary is in red.

7.5.2 Precipitation

Precipitation at the site 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.

The two climate station closest to the Marchand Homes property with 30-year temperature and precipitation norms are located at Pockwock Lake (6.2 km away) and Halifax Citadel

(17.9 km). The next two nearest stations are at the Shearwater Airport 29.7 km away, and at Bridgewater over 55 km away. The 30 year norms for total annual precipitation reported from those four climate stations are 1,513.2 mm, 1,468.1 mm, 1,422.6 mm, and 1,535. 7 mm, respectively, which represent a nearly 8% spread from lowest to highest.

The nearest climate station at Pockwock Lake is missing a large amounts of data, where there is data for 78% of the 30 years covered (as such, that station is not UN World Meteorological Organization (WHO) compliant). Further, the Pockwock Lake at climate station is located within the "wind shadow" a power generating windmill which, although its date of construction unknown, can significantly affect both temperature and precipitation readings.

In light of this issue arising for other projects, to help offset apparent data discrepancies, and to determine which data is best to use to accommodate Nova Scotia's ocean-affected climate peculiarities, a few years ago ewC developed a precipitation model[64] 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 8 summarizes the total monthly and annual precipitation amounts obtained from that model for a spot at the centre of the Marchand Homes site, which monthly and annual values are between those from the Pockwock Lake and Bridgewater climate stations.

Table 8. 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	148.1
February	124.7
March	140.2
April	120.4
May	129.4
June	103.5
July	101.5
August	89.3
September	117.4
October	137.3
November	158.2
December	146.0
Annual	1,516.2

64. The model 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, zero smoothing) in GRASS GIS (2021). 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.

7.5.3 Recharge coefficients

Kennedy et al (2010) have published values for groundwater recharge coefficients for the entire province. They have ascribed a value 0.16 for the Indian River primary watershed.

7.5.4 Other groundwater users

Table 9 summarizes number and of homes located within the potential groundwater recharge capture areas described in Section 7.4.1 of this report.

Table 9. Number of homes[1] within the potential groundwater recharge capture areas likely to supply water to wells proposed to be drilled on-site.

Potential groundwater recharge area		
Site area ($158,561 \ m^2$)	Smaller area ($842,777 \ m^2$)	Larger area ($1,901,793 \ m^2$)
20	111	182
Note: 1. Includes the homes that are proposed to be built on the Marchand Homes property.		

7.5.5 Estimated groundwater recharge

NSE (2011) suggests applying a daily water usage rate of 1,350 L/day per single family dwelling. Using method 1), total daily well water supply availability is calculated by:

$$Q_{lot} = \frac{I \bullet A_{lot} \bullet E_{use}}{365 \text{ days}} \qquad \text{(eq. 1)}$$

Where:

Q_{lot} = Available groundwater from each lot (L/day)

I = Groundwater recharge rate (mm/yr)

A_{lot} = Area of the lot that contributes to recharge (m^2)

E_{use} = Percentage of recharge reserved for baseflow and ecological use

Using method 2), total annual groundwater recharge available for use as well water supply is calculated by:

$$Q_{rech} = A_{rech} \bullet P \bullet I \bullet E \qquad \text{(eq. 2)}$$

Where:

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

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

P = Annual precipitation (m/yr)

I = Groundwater recharge coefficient

E = Percentage of recharge reserved for baseflow and ecological use

Using equation 1, assuming the total unpaved area[65] of the subdivision site (around 148,821 m^2) is divided by the number of lots, then assuming 20 lots, the amount of groundwater available per lot would be approximately 2,468 L/day per lot.

The number from equation 1 exceeds the NSE suggested 1,350 L/day per dwelling requirement by a factor of approximately 1.8 times.

Table 10 summarizes the estimated volumes of groundwater recharge available and the approximate total number of homes, including existing homes, that may be served by applying equation 2 and the two unpaved[66] recharge capture areas noted in Section 7.4.1.

Table 10. Estimates of groundwater recharge and number of homes (or equivalent) that could be served within the potential recharge areas described in Section 7.4.1 of this report.

Unpaved (porous) Groundwater recharge area (m^2)	Possible recharge[1] (m^3/yr)	Possible allocation[2] (m^3/yr)	No. of homes[3] served
807,977	195,621	97,810	198
1,844,393	446,550	223,275	906

1. Assuming 1,513.2 mm/yr precipitation and a groundwater recharge coefficient of 0.16.
2. Half the value in column 2, as required by NSE for ecological support.
3. Proportion of total allocation based on 1,350 L/day per home (or equivalent), 365 days/year.

7.5.6 Land use effects on water quality in groundwater recharge areas

The land uses in the potential groundwater recharge capture areas described above that could have an effect on surface water and thus, groundwater recharge quality, include:

- possible vehicle fuel leaks, home heating oil leaks, or heating oil delivery truck leaks,
- winter road maintenance salt or sand (which may contain 5-10% salt) use, and
- home fertilizer and pesticide use.

65. Subtracting home areas (10 homes x 10m x 20m) and road areas (820m x 7m) from the site area.

66. Subtracting home areas (111 homes x 10m x 20m) and road areas (1,800m x 7m) for the smaller area in Table 8, and home areas (182 homes x 10m x 20m) and road areas (3,000m x 7 m) for the larger area.

7.6 Aquifer water storage

The bedrock HU that underlies the site and the groundwater recharge areas noted above depend entirely on bedrock fractures and joints for water to flow through them. Those fractures also serve to store groundwater within those HU's.

As was noted earlier, fracture density (thus aquifer groundwater storage) may be expected to vary considerably from one place to another. Also, how the fracture systems behave to store groundwater will depend on the degree of aquifer unit confinement present.

There is only one Storativity values in Table 3 for the area; it suggests confining conditions at that well location. If the aquifer is indeed unconfined (at that location, in any case), then a possible specific storage value about around 0.1% would likely apply.

For unconfined bedrock aquifer materials, Freeze and Cherry (1979) suggest porosity values of 0-10% for shale and fractured crystalline rock, and 0-5% for dense crystalline rock. So should the Halifax Peninsula Leucomonzogranite HU be unconfined in at least some of the local areas (which is expected), in light of the apparent bedrock fracturing present in the area (i.e. the faults and lineaments shown in Figure 14 and others, then conservatively, porosity values of 0.5% to 3% might be assumed for the local fractured granitic rock.

Assuming conservatively also that there is about 160 m (maximum depth of area wells in Table 3) of fractured, saturated bedrock aquifer material within the area Halifax Peninsula Leucomonzogranite HU, then for the smaller and larger 842,77 m^2 and 1,901,793 m^3 groundwater recharge area described in section 7.4.1, the estimated volume of groundwater in storage potentially within the local bedrock HU's may be between 674,222 m^3 and 9,1218,606 m^3. Based on the existing plus proposed 111 and 182 groundwater users within each of the smaller and larger catchment areas, that represents 10.5 to over 200 years of water storage assuming no new water is introduced from precipitation.

There is no data available for static groundwater depths in the local surficial (till) HU, and the static water level data in Table 6 cannot be used to estimate static groundwater levels within the till HU, since those groundwater levels are reflective of water levels within bedrock within and to which the well casings should be sealed. However, knowing from Table 6 that local till thickness varies from zero to 18 m and averages 3.5 m, then one might assume a 1.0 to 1.5 saturated thickness for the area till. This is water that would be held in storage above and slow supplying water to the bedrock UH.

Assuming conservatively that the local till has a porosity of 25% to 35% (Freeze and Cherry, 1979), then in consideration of the two groundwater recharge areas discussed in Section 7.4.1 of this report, the volumes of groundwater that may be in storage within the surficial HU is estimated to be between 210,694 m^3 and 442,458 m^3 within the smaller recharge area, and between 475,448 m^3 and 998,441 m^3 within the larger recharge area. This would be sufficient water storage for 3.9 to 11.1 years water supply at 1,350 L/day per home for the numbers of homes (including those of the Marchand Homes development) within the above-noted recharge areas, assuming no new groundwater from recharge.

7.7 Well interference

In any development with many closely-spaced wells, there is a potential for pumping induced well interference[67] problems – namely, the cumulative pumping effects from all wells, which can result in the lowering of the water table and of groundwater levels in wells. This can affect both wells within a new subdivision, and wells outside that are in close proximity to new subdivisions.

NSE (2011) recommends the use of the Theis (1935) equation and their spreadsheet as one means to assess well interference in the absence of more complicated and costly computer aquifer modelling (which also employ the Theis equation). However, their criterion to determine whether the calculated interference is acceptable is arbitrary, may not be suitable for all sites, and all methods require having aquifer Storativity (S) data, which is available for only one well located off-site (see Table 5), and which may or may not represent the bedrock aquifer on-site.

Therefore, is is not possible at this time to assess the potential for, or the extent of, potential well interference on- or off-site resulting from the drilling of new wells on-site. However, unless there is direct fracture communication between very closely spaced low-yielding wells, past studies at more densely developed locales with similar groundwater recharge and bedrock aquifer settings suggest that well interference should not be too a large concern at or around the site. The necessary values for S can only be obtained through the collection of water level data at observation wells during pumping tests, and those observation wells must experience positive responses to pumping at the test production well, which depending on the levels and nature of bedrock aquifer fractures, may or may not be available.

67. 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 aquifer fracture patterns.

8.0 Discussion

8.1 Well yield considerations

Drilling for water into the Halifax Peninsula Leucomonzogranite HU is likely to be met with a wide range of yield outcomes – from wells that can only barely meet single dwelling residential demand with simulation, to (based on reports for wells immediately south, and one north of the Marchand Homes site) wells that could supply water for the entire new proposed subdivision.

That said, the data summarized in Tables 4 and 6 points to over 97% of wells (some with well simulation) in the Figures 17 and 19 map areas as being able to meet the minimum 1,350 L/day well output that is suggested by NSE (2011), with the lowest quartile being able to meet 6 and 4 times that minimum need regionally and locally, respectively.

Table 11. Examples of wells yields and depths that may be able to meet a water supply target of 1,350 L/day (NSE, 2011).

1 Well depth (m)	2 Well yield (L/min)	3 Well bore storage (L)[3]	4 2 hr well yield (L)	5 24 hr well yield (L)	6 Total volume from columns 3 + 4 (L)[4]
20	10.6	88	1266	15192	1354
40	9.1	265	1092	13104	1357
60	7.6	442	912	10944	1354
80	6.1	618	732	8784	1350
100	4.6	795	558	6696	1353

Notes:

1) The target water supply volume of 1,350 L/day assumes each water well serves a four bedroom home.

2) It is assumed that the entire target water supply volume of 1,350 L/day will need to be supplied during a 2 hour period to meet peak demand. Further, the well yield must be able to replenish this volume within 24 hours, on an ongoing daily basis. To satisfy these requirements, columns 5 and 6 must both meet or exceed the target volume of 1,350 L/day.

3) The column 3 calculation assumes: a) 150 mm diameter well; b) available drawdown in the well equal to well depth minus 10 m (i.e., assumes a static water level of 5 m and the pump is placed 5 m above the bottom of the well with a 5 m allowance to keep the pump submerged); c) the available drawdown is reduced by 50% to allow for cumulative well interference effects from other wells in the subdivision.

4) "Total Volume Available from Well Storage and 2 Hour Yield" is calculated as follows (Equation B.3): Total available water (L) = 500π (D/2000) 2 H A + 120Q 20; where D is well diameter (mm), H A is available head (m) and Q 20 is the 20 year safe pumping rate (L/min)

Drillers should be requested to take care to accurately note well yields with respect to bedrock fracture locations and ensure that there is sufficient combined yield and well bore cold-water storage to meet domestic needs. Table 11, which is directly from NSE (2011), may be used as a guide for that.

Where low yield wells are unable to meet these general criteria, then if done properly (focusing on deeper fractures), well stimulation by hydraulic fracturing may be able to successfully increase well yields. Well stimulation by blasting is **not** recommended.

Should wells not be able to supply all of the water needed for some lots, then mitigation options may include augmenting water supplies with roof water collection, or the use of communal water supply wells to meet those needs.

8.2 Groundwater recharge and well sustainability

The size of the contributing groundwater recharge capture areas, the proposed site lot density plus other existing well water users in those areas, and the recharge analysis done using equations 1) and 2) in Section 7.4, all point to there being more than enough groundwater recharge available to supply water to the wells that are proposed to be drilled on-site.

The sustainability of any individual household water supply will be subject to being able to drill wells successfully on each lot. As can be seen from the summary data in Tables 2, 3, 4, and 6, and from the considerable variability in the data locally presented in Figure 19, that can vary. However, in light of the local lineaments identified on- and near-site, and the higher well yields (due entirely to bedrock fracturing) reported for wells located just south of the site, decent wells yields, although still quite variable, should be expected generally from wells drilled within the southern parts of the site. Lineaments suggest that this might also extend to other parts of the site farther north.

Notwithstanding, as was noted before, for lots with lower yielding wells, hydraulic fracturing deep fractures, water preservation measures, and roof rainwater collection for irrigation, etc., may serve to mitigate water supply quantity issues.

8.3 Well interference

Notwithstanding the somewhat arbitrary nature of the calculations suggested by NSE (2011), because values for Storativity (S) are not available for the site, it was not possible to do the any of calculations to assess theoretical well interference on-site.

That said, unless there is direct hydraulic communication between low-yielding wells along specific bedrock fractures (in which case well yields should also be expected to be higher), then based on similar theoretic and empirical assessments done elsewhere with similar aquifer and lot density characteristics, pumping-caused well interference is not anticipated to be an issue of big concern at or around the site.

Where pumping-caused well interference is most likely to occur is where two or more wells are located very close together. The problem can be amplified where two wells with drastically different depths are located close together. In those kinds of situations, the well that is drilled to [68]only 30 m because it encounters a fracture that from air lift testing appears able to deliver water at a rate of 45 L/min, may be caused to “run out of water” if those fractures are somehow hydraulically connected to the deeper well, and it is pumped to bring the the water level in it to below 30 m. Therefore, while maintaining proper septic system and other setback distances, efforts should be made also to keep wells spaced as evenly and as far apart as possible, and to drill them to roughly similar depths.

8.4 Groundwater quality

8.4.1 Natural water quality

Groundwater quality from the Halifax Peninsula Leucomonzogranite HU is generally satisfactory in most situations, requiring treatment generally only for iron, manganese, hardness in some places, and perhaps arsenic and uranium – due mostly to natural composition of the magma responsible for the plutonic aquifer.

8.4.2 Anthropogenic water quality issues

Not included in any of the data available and only briefly mentioned, but of equal concern to natural water quality, are the possible human effects on groundwater quality in both rural and rural-urban (open space design) settings. These may include:

- ***Winter maintenance road salt:*** NSTIR and HRM have 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 results in just as much salt being applied on roads. Somehow, however, that math does seem not make sense, so sand (even if it contains 5% to 10% salt) should be applied to the roads on-site if possible to help avoid damage to subdivision wells.
- ***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 and thus, may not offer much protection to groundwater – 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.
- ***Vehicular spills:*** Although these may involve few events and smaller volumes and 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

68. The very short-term duration of air lift tests can very easily present false impressions of a well’s capability should the water-bearing fractures yielding those short-term results not be very widely distributed (i.e. contain very little groundwater storage, or be interconnected with other fractures receiving recharge).

that underground, are more difficult to deal with.

- ***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.

8.4.3 Well maintenance practices

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.

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 and following any large-scale work on or near the well, including any major land-use changes or heavy construction and blasting.

8.4.4 Potential water treatment options

The more common water quality issues that may be expected from wells drilled on-site may include 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 afect 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[69], effects on bone, the circulatory system, thyroid, spleen, and central nervous system.

  Drage and Kennedy (2013) have identified that uranium concentrations in well water can be strongly related to high pH values, and its mobility was related to oxidizing, alkaline conditions, as well as the formation of complexes of phosphate, calcium-carbonate compounds, silicate and fluoride. In their study, radium was commonly detected, but only 1% of the wells exceeded the drinking water guideline. Approximately 40% of the wells had radon levels above 370 Bq/L (10,000 pCi/L), although there is currently no Canadian drinking water guideline for radon.

  In 2002, lead-210 (^{210}Pb) was identified in well water at a public school in Nova Scotia. ^{210}Pb Lead-210 is a daughter product of uranium, which was not previously tested for in the province. As a result, another province-wide radionuclide testing program was initiated, which results indicated that both uranium and ^{210}Pb commonly exceeded drinking water guidelines. Subsequent work revealed those results were due to testing methods not not providing realistic indications of ^{210}Pb levels because radon gas was rapidly decaying (radon's half-life is 3.8 days) to ^{210}Pb while the samples were in transit and being analyzed at the laboratory.

69. 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.

> The sampling protocol was modified to eliminate the radon decay effects and further testing indicated that ^{210}Pb was not a common problem in groundwater in Nova Scotia (Drage at al. 2005). However, more recent work by ewC (2021) revealed that ^{210}Pb accumulating in a central water supply well and distribution piping system as a function of radon gas decay was the source for ^{210}PB (present as lead-carbonate minerals) values that did exceed the Health Canada (2020) lead health guideline.

The matrix in Table 12 lists the types of water quality problems that may need to be addressed for water from wells drilled on-site, along with the more common home water treatment methods available to treat each issue.

Table 11. Water quality problems that may exist for on-site wells and common home treatment methods available to address them.

	Adsorptive media filtration[1]	Aeration and filtration	Anion exchange[1]	Carbon filter[1]	filtrationContinuous chlorination and	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	●	●		●	●	●	●	●	●		●
Lead (including ^{210}Pb)	●								●		
Magnesium (hardness)						●			●		●
Manganese	●	●		●	●	●	●	●	●		●
Radon[3]		●		●							
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.
3. Filtration is likely unnecessary, but aeration must be done to atmosphere, thus requiring system re-pressurization in the home. Breakthrough is possible with activated carbon.

9.0 Conclusions and recommendations

9.1 Conclusions

The proposed development is planned to include 20 single family residential units within a 15.86 ha. parcel of currently undeveloped forest-covered land.

The site is immediately bounded by Hemlock Drive and Parklyn Crt. and low density single family development to the west and south, and by undeveloped forest elsewhere. There is no industrial or commercial land use anywhere near the site such that besides any possible residential type incidents (i.e. heating oil leaks), there are no land uses in the general area that may present any environmental issues of concern at the site today, or which may have presented any concerns in the past.

The site is entirely underlain by Middle- to Late Devonian age (380-370 Ma.) granitic rock belonging to the Halifax Peninsula Leucomonzogranite, a coarse-grained Stage 2 pluton. The rock has no primary permeability, so well yields drilled into it will depend entirely on fracture flow (secondary permeability) for groundwater to flow into them. The overburden at the site consists of generally thin, sandy glacial till.

Based on information from the NSE well log database, 847 wells have been drilled into the Halifax Peninsula Leucomonzogranite within a roughly 6 km by 6 km area centred at the site. There are no dug wells reported to have been constructed in till overlying the Halifax Peninsula Leucomonzogranite within that area, and accurate mapping coordinates are available for only about 28% of the drilled wells, so it was necessary to relegate the review of well yields and construction details to statistical analysis of the available database records.

Short-term driller air lift yield rates for wells completed in the above-noted area and in a much more local ~0.5 km area in which 162 wells have been drilled into the Halifax Peninsula Leucomonzogranite range from from zero (those wells were abandoned and replaced by others) to 68.2 (mean 12.8) L/min from well that are 30.49 m to 153.96 m (mean 77.86 m) deep, with 5.5 m to 34.15 m (mean 8.92 m) of casing. Of these, over 98% (some having required deepening and/or stimulation by hydraulic fracturing) meet or exceed the minimum 1,350 L/day (0.9 L/min) household need as suggested by NSE (2011).

The highest air lift yield rates reported in the NSE well log database for all wells drilled into the Halifax Peninsula Leucomonzogranite within a 6 x 6 km area centres on the site is 272.8 L/min, whereas the highest reported for the ~0.5 km area is 68.2 L/min, with those and other wells producing higher than average yields being located immediately to the south of the Marchand Homes site. These localized high well yields may be explained by bedrock faults as exemplified by topographic lineaments near- and on-site as identified using shaded relief images generated from 1 m resolution LiDAR DEM data.

Two methods were applied to assess the groundwater recharge potentially available for the wells that are proposed to be drilled on-site. Both methods allowed for the required 50% of the estimated available recharge to be reserved for stream baseflow and related ecosystem maintenance. The more (extremely) conservative method used, which assumes that groundwater recharged is limited to the site property boundaries, suggests that such recharge could, on an annual basis, provide approximately 1.8 times the minimum 1,350 L/day per lot water need suggested by NSE (2011) for single unit residential use.

The more realistic assessment method used to evaluate two differently sized possible recharge areas (which contain 111 and 182 homes, respectively, including those proposed to be constructed on-site) estimated that there should be sufficient groundwater recharge within those areas to provide water from up to 198 and 906 homes, respectively.

The amount of water that an aquifer can store will depend on average porosity and aquifer size/thickness. The porosity of the local bedrock aquifer units may be expected to range between 0.5% to 3%, and that of the much thinner surficial unit above bedrock range 25% to 35%. Considering affected aquifer areas the sizes of the two groundwater recharge areas considered for Method 2, then there may be sufficient groundwater storage within the bedrock HU to supply water to existing homes (including those proposed by Marchand Homes for the site) for an estimated 10.5 to 200 years, and from within the surficial till HU for an estimated 3.9 to 11. 1 years, assuming there is no new groundwater from recharge.

While well interference effects from pumping could not be calculated based on the data available, experience at other sites with similar bedrock geology and development density suggests that pumping induced well interference should not be an issue of large concern on and immediately around the site. However, well interference could be an issue if wells are spaced too close together, or if shallow, higher yielding wells are located too close to lower yielding wells, so maintaining proper (consistent) well spacing and being aware of the possible effects that might exists between deeper and shallower wells is important.

The Halifax Peninsula Leucomonzogranite HU produces generally good quality groundwater, but there may be some issues related to hardness, iron and manganese, and arsenic and uranium may also require treatment. These can be relatively inexpensive and easy to treat. Radon gas in well water and in the air in homes may also be associated with the Leucomonzogranite. This too can be relatively easily mitigated.

9.2 Recommendations

Based on the information available and reviewed, the use of private drilled wells appears to be a reasonable means of providing for the water needs of new homes and lot density for the new homes that are proposed to be constructed on the subject site.

It is understood that the development agreement for this site requires that Level 2 assessment also be done. NSE recommends that a minimum of three wells be drilled and tested for that purpose. In that regard, the following recommendations are offered:

1. That the test wells be located, as best as possible, as far to the south, to the east-central, and northern parts of the site so as to distribute them as broadly across the site to best represent fracture distribution/variability across the site.
2. That any test wells be located, again as best as possible, where they may also serve double duty as water supply wells that may be sold with lots.
3. That reputable drillers only be used for drilling the test wells to ensure that they are properly constructed, developed, and that proper reporting of conditions encountered while drilling can be provided.
4. That drill cutting return samples be collected during the drilling of all test wells to help verify site bedrock geologic conditions.
5. That drillers be asked to carefully note changes in yield and suspected fault zones as test wells are advanced, by doing occasional short-term (5 minute) air lift yield tests to help characterize the HU vertically, as well as horizontally by virtue item 1) above.
6. That pumping tests not be done for only the minimum 6 hours per NSE (2011), but that a mix of longer-term[70] (perhaps one 72 hour test and one 48 and 24 hour test, or two 24 hour test) pumping tests be done (which locations and duration should be defined from driller air-lift test results and other drilling-time findings).
7. That as many wells as possible be used as observation wells during the pumping tests (including neighbouring wells, but only if obtaining complete control of them is possible (i.e. if the home owners are away on vacation)), to help better understand any possible on- and off-site well interference, and to increase the chances that observation wells can actually produce useful data (i.e. respond to the pumping well(s)) to allow obtaining valid values for S for interference calculations.

The following additional recommendations are notwithstanding any of the Level 2 assessment needs – they should be done as any normal part of constructing wells:

- Care should be taken to ensure that drillers correctly report all findings; air lift bail yield results should be based on actual measurements (bucket and stopwatch).

70. . One of the concerns for any hydrogeological testing, but particularly where fracture flow is prevalent, is to be able to identify aquifer boundary conditions. These are situations were the aquifer unit being tested may be in contact either with geologic units with lower hydraulic conductivity, which can result in a decrease in aquifer water supply (referred to as limitation boundaries), or units with higher hydraulic conductivity, or with rivers, which can result in increased aquifer water supply (referred to as recharge boundaries). Identifying these boundaries is important in terms of being able to define supply sustainability, and/or possible sources of water that may affect water supply quantity and quality. These boundary conditions cannot be identified in short-duration pumping tests, but can in general be identified withing the time span of 48 or 72 hour tests (thus the derivation of the “standard” 72 hour test).

- All wells should be developed for a minimum of one hour after drilling.
- Wells should be drilled as far apart as practical, taking into account road, building, septic system, and other setback needs and limitations, to help avoid both water quality issues and pumping induced well interference issues.
- Lots be sold with instructions provided to buyers on what to test for, when to test (to use wells for short periods (a couple of weeks, using bottled water for drinking and cooking in the interim) to allow wells to further develop, and how to properly collect water samples, urging them to have testing done only by certified labs.

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