LiDAR, Surficial Geology Mapping, and Water Wells: Uncovering Potential Surficial Aquifers in Halifax, NS

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ABSTRACT
The fractured bedrock aquifers supplying the greater Halifax area have limited water supply capacity and are experiencing groundwater stress due to extensive residential growth. Recent surficial geology mapping and analysis of water well data were used to locate buried fluvial material in structurally controlled bedrock topographic lows. High potential surficial aquifer areas were highlighted, and test drilling was conducted in three of these areas. Based on the findings of the mapping and field work, a conceptual understanding of the distribution of surficial aquifer materials in key residential growth areas of Halifax is presented.

RÉSUMÉ
Dans la région d'Halifax, la capacité des aquifères rocheux fracturés de fournir de l'eau est limitée et l'exploitation de l'eau souterraine s'accentue dû au développement résidentiel rapide. La cartographie récente et l'analyse des données de puits ont permis de localiser des matériaux fluviatiles enfouis dans des dépressions rocheuses structurales. Des régions à haut potentiel aquifère ont été identifiées dans les matériaux de surface et des forages d'essai on été menés dans trois de ces régions. Une compréhension conceptuelle de la distribution des matériaux aquifères, développée à partir des résultats des travaux de terrain et de cartographie, est présentée pour des secteurs résidentiels clés d'Halifax.

1 INTRODUCTION

Extensive development of subdivisions with on-site services over the past number of years in suburban areas of the Halifax Regional Municipality (HRM) has resulted in large demands on available groundwater resources. Households located in unserviced areas of HRM are typically supplied by drilled water wells completed in fractured bedrock aquifers. These aquifers are located in the metamorphic and plutonic groundwater regions of the province, which are associated with limited groundwater supply capacity (Kennedy and Drage, 2009). Approximately 20% of the groundwater quantity issues reported in the province's water well database (NSE, 2011) (e.g. dry wells or well deepening/stimulation work) occur along the unserviced corridor between Fall River and Hammonds Plains (Figure 1), an area that has experienced significant residential growth in recent years.

Despite this observed trend in residential growth, land developers over the past several decades have not been required to assess the long-term groundwater supply capacity of subdivision developments using on-site services. Environmental and public health risks are created by residential development with insufficient quantity and/or unsatisfactory quality of water, along with public dissatisfaction when water supply expectations are not met. This creates pressure for unplanned extension of central water or sewer services to these areas at a significant cost to rate payers. For example, residents in one HRM subdivision supplied by individual wells recently committed to spending more than $17,000 per household to connect to the Halifax water distribution system due to persistent groundwater quantity problems. Another ten subdivision requests for water servicing are pending along the growth corridor between Fall River and Hammonds Plains. HRM has recently implemented a process to require land developers to assess groundwater supply capacity as part of any new subdivision applications (HRM, 2006).

The presence of surficial aquifer systems has previously been documented in the unserviced growth corridor area (e.g. Cross, 1974); however, the distribution and groundwater supply potential of these aquifers have not been assessed. Mapping of surficial aquifers along this corridor might help alleviate groundwater quantity issues, providing an alternative drill target for residential water supplies. A review of water well logs (NSE, 2011) indicates that at some locations drillers encountering

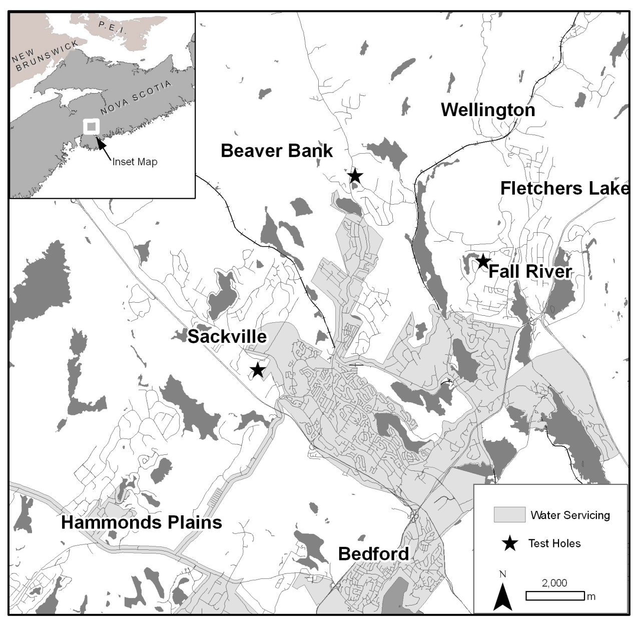

Figure 1. Map of the study area showing locations of test holes.

sand and/or gravel have completed surficial wells by extending the casing into the sand and/or gravel layer and backfilling with pea gravel to reduce siltation and heaving effects. Homeowners and subdivision developers, however, typically prefer bedrock well installations due to the lower cost and perceived lower risk associated with this type of well. Well screens are rarely used during residential well construction in HRM.

2 METHODS

A combination of techniques was used to map the distribution of potential surficial aquifers in HRM using existing maps and databases in conjunction with a limited field program.

2.1 Surficial Geology Mapping

Remapping of surficial materials in the area covered by LiDAR (Light Detection and Ranging) in HRM was completed from 2008-2010 by the Nova Scotia Department of Natural Resources (NSDNR), and a portion of this map is shown in Figure 2 (Utting, 2011).

Aerial LiDAR is a remote sensing method that transmits light pulses from an airborne unit and calculates the distance between the airborne unit and the surface based on the time delay from transmission to reflection. A 'bare earth' topography model was generated from the LiDAR survey, which was then used to improve the precision of mapping surficial materials and bedrock structures.

During this work, a zone of continuous surficial cover (i.e. where no bedrock is present even between drumlins) (Figure 2) was identified. The zone was interpreted to have the highest potential for containing buried fluvial sand and gravel deposits infilling bedrock topographic lows (paleo-valleys).

2.2 Water Well Mapping

The Nova Scotia water well database (NSE, 2011) was used to develop a stratigraphic understanding of surficial deposits within the zone of continuous surficial cover. Water well drillers in Nova Scotia have only used GPS equipment to reference well locations since 2004, and so desktop spatial referencing of historical logs was conducted using property identification information (e.g. civic/lot number).

A surficial thickness map (Figure 3) was then developed using the depth to bedrock data reported on the water well logs, bedrock outcrop features interpreted from the surficial geology mapping (shown as a filled triangle on the map), and the surface elevation data extracted from the LiDAR digital elevation model. There are gaps in the interpolation where well log data are absent; especially in areas of water servicing (see Figure 1). Wells intercepting buried (>12 m depth) sand and/or gravel layers with a minimum thickness of 3 m were identified, and high potential surficial aquifer areas were outlined based on the observed locations of these aquifer materials.

2.3 Field Work

Three sites were selected for more detailed study based on the preliminary results of the aquifer mapping work, and a limited field program involving test drilling was carried out in August 2010 and January 2011. The selection of sites for test drilling was limited to municipally owned park land. Test hole locations are shown in Figure 1. The field program involved test drilling using a combination of standard auger and casing/coring techniques with split spoon sampling at 3 m intervals. Where sand and gravel materials were encountered, a two inch PVC monitoring well with slotted casing over the aquifer interval was completed and a four hour pumping test, including groundwater sampling, was conducted.

2.4 Aquifer Mapping

Using the test drilling results and available water well logs, a series of cross-sections were prepared in the vicinity of the three field sites. The stratigraphic information presented on the well logs was reviewed, generalized for consistency, and then compiled into a geodatabase using Target™ for ArcGIS® to develop an understanding of the subsurface distribution of potential aquifer materials. A 3D model was prepared from the cross-sections and an aquifer thickness map and conceptual model were developed for each site to explain the occurrence of surficial aquifer materials.

3 RESULTS

3.1 Mapping

The surficial thickness map confirmed the general extent of the zone of continuous surficial cover (Figure 3). At numerous locations, the depth to bedrock reported in the well log data exceeded the relief of surficial landforms, indicating the presence of paleo-valleys. In the Beaver Bank area, the paleo-valley forms a general NNW-SSE feature that follows a similar trend of other structurally controlled lows, such as the Bedford Basin. From Sackville to Hammonds Plains the mapping shows a linear trend of the paleo-valley, likely representing a graben or half-graben feature. Within this valley at Halfway Lake, Cretaceous sediment was reportedly encountered above bedrock in a water well (Piper and Pe-Piper, pers. comm.).

Approximately 3000 drilled wells were located to a minimum accuracy of <200 m in the study area. A total of 134 of these wells were interpreted to be completed in surficial aquifer materials. The median yield of the surficial wells (54.4 Lpm) was approximately five times greater than the median yield of the bedrock wells (11.3 Lpm).

3.2 Field Work

Aquifer materials were not encountered during test drilling at the Fall River and Sackville park sites (approximately 15 m of till over bedrock), although it should be noted that

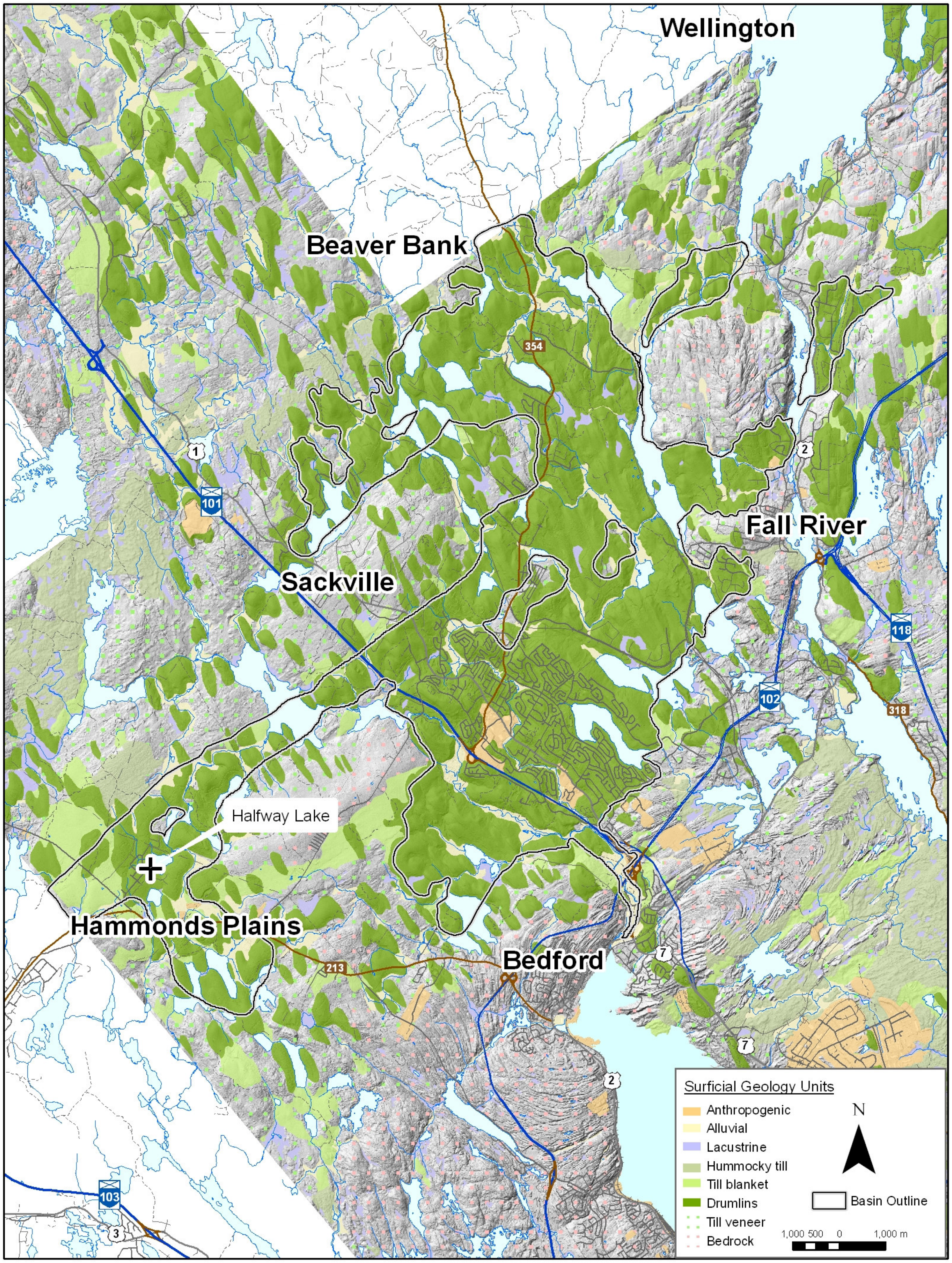

Figure 2. Surficial geology map of the study area.

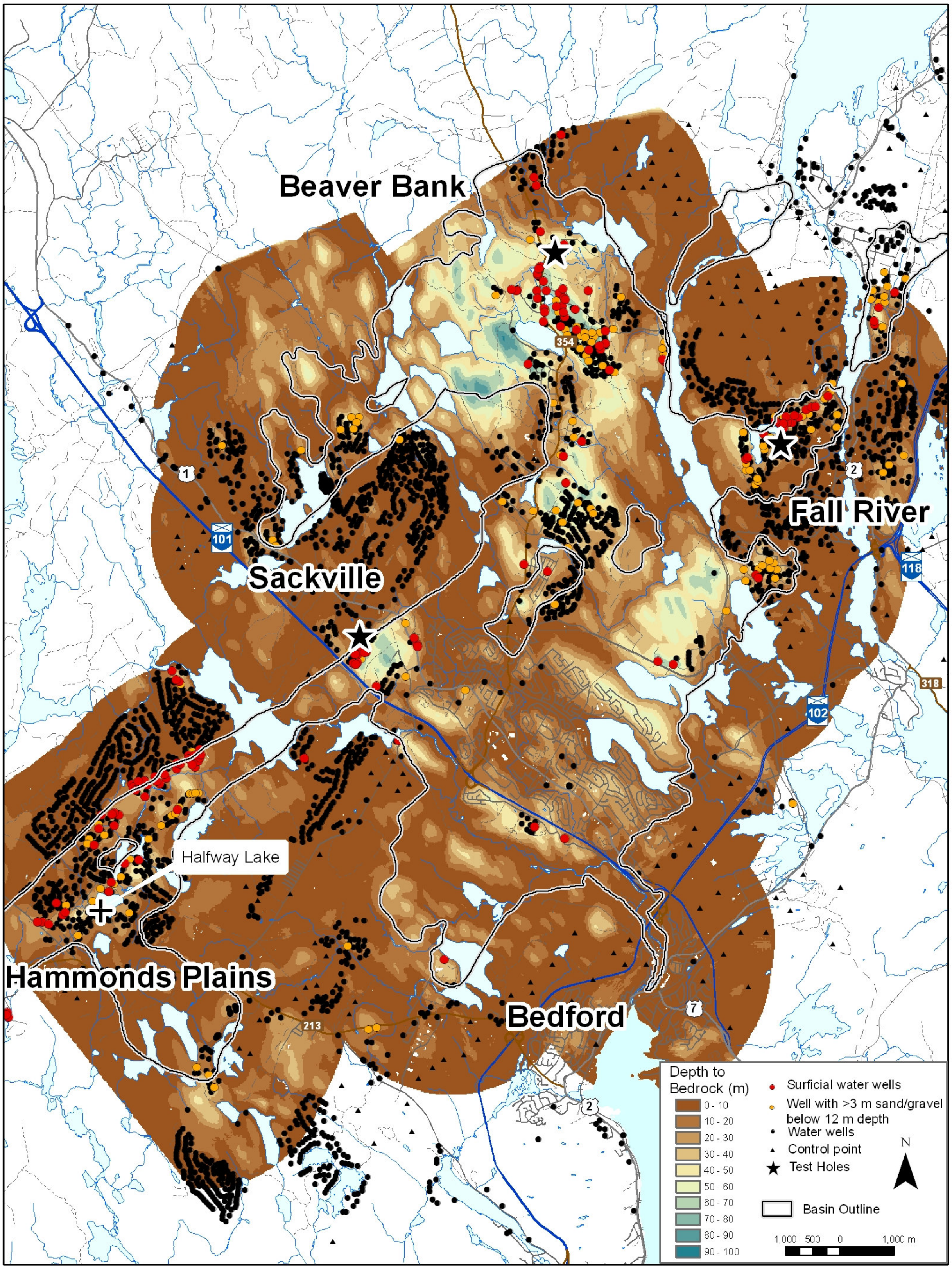

Figure 3. Depth to bedrock map of the study area.

site selection was limited to municipally owned land. A deposit of fine sand, medium sand and gravel lenses (minimum thickness of 5 m) was encountered at the Beaver Bank park site between 25-30 m depth below ground surface (Figure 4). Drilling was suspended at 30 m depth due to the effect of surging sand binding the drill rods. The monitoring well is therefore partially penetrating and the total aquifer thickness at this location is not known.

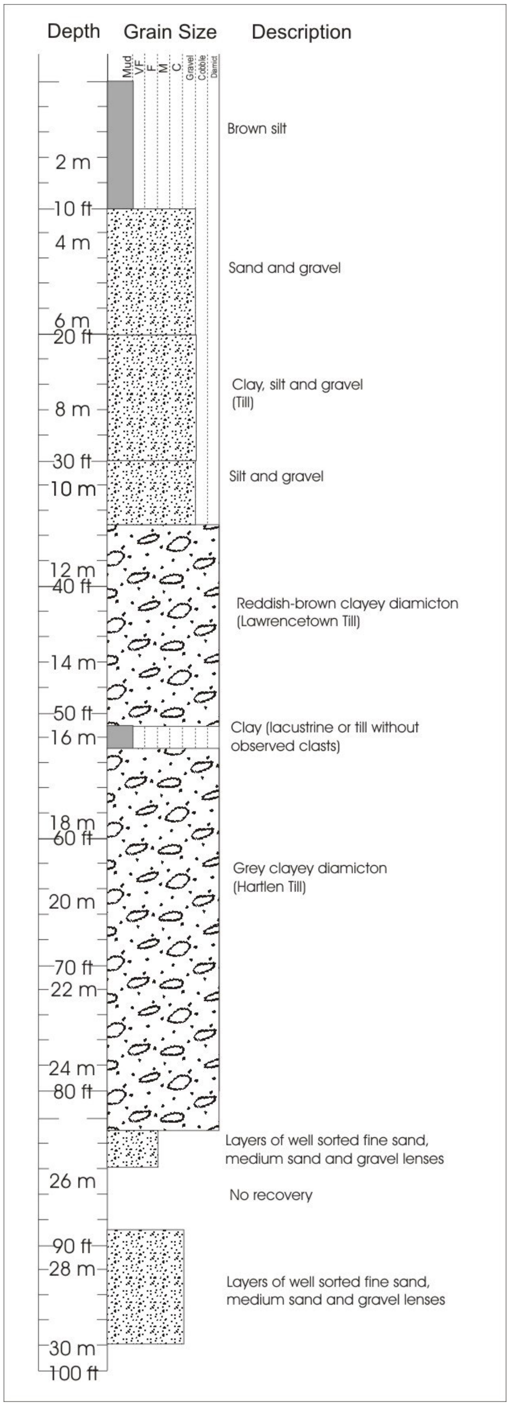

Figure 4. Stratigraphic log of Beaver Bank test well.

A yield of approximately 20 Lpm was interpreted from the monitoring well, although significantly higher yields would likely be possible in a larger diameter, fully penetrating, screened production well at this site. Groundwater quality met all health-based criteria of the Guidelines for Canadian Drinking Water Quality (Health Canada, 2010) although sulphate (220 mg/L), hardness (320 mg/L), and manganese (298 µg/L) were elevated due to the presence of the Carrolls Corner Formation (including gypsum) of the Windsor Group mapped to the north of the site. A screened supply well intercepting this surficial aquifer at a site 800 m south of the Beaver Bank park site shows better groundwater quality (hardness of 150 mg/L and sulphate of 60 mg/L) and a higher long-term yield (45 Lpm; NSDNR, 2011).

3.3 Surficial Aquifer Characterization

A conceptual model was developed to explain the occurrence of aquifer materials at each of the three field sites (Figures 5 to 7). Figure 5 shows fluvial sand/gravel material along an erosional bedrock topographic low associated with geological contacts (e.g. Fall River area). A similar conceptual model is presented for the Sackville and Hammonds Plains areas (Figure 6), except that the bedrock topographic low is interpreted to be structurally controlled. Figure 7 shows fluvial sand/gravel material within erosional features of the underlying metamorphic bedrock, or within sinkhole type erosional features of the Windsor Group carbonate bedrock in the Beaver Bank area.

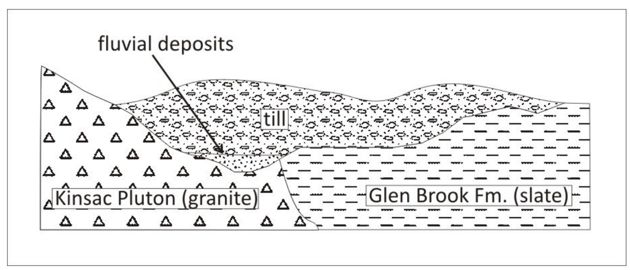

Figure 5. Schematic cross-section of Fall River area, with aquifer material (fluvial deposits) within an erosional low along a bedrock contact.

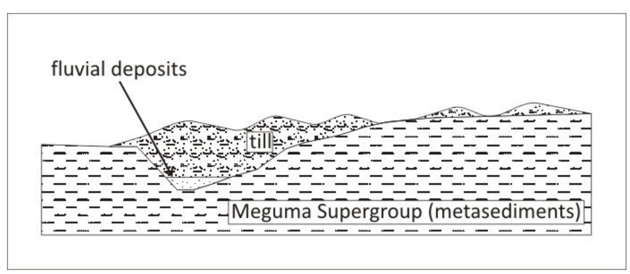

Figure 6. Schematic cross-section of Sackville and Hammonds Plains areas, with aquifer materials (fluvial deposits) in a bedrock topographic low. Note exposed bedrock between drumlins outside of the paleo-valley.

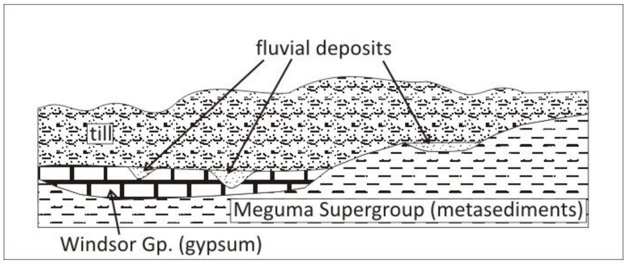

Figure 7. Schematic cross-section in the Beaver Bank area of aquifer materials (fluvial deposits) in bedrock depressions/paleo-valleys and gypsum sinkholes. These features are found within a larger NNW-SSE paleo-valley.

The conceptual models show that where fluvial sand/gravel materials occur, they are typically located at the base of the surficial sequence and are overlain by lower permeability materials (e.g. till) that provide aquifer protection. In some areas, especially in Fall River, the protective till cover is thin and these areas should be highlighted for aquifer protection.

The preliminary surficial aquifer thickness maps (Figures 8 to 10) indicate areas where drilling is most likely to encounter aquifer materials. The mapping shows that the surficial aquifers are discontinuous with a footprint on the scale of hundreds of metres. These aquifers, however, can have local importance due to their significantly higher storativity (several orders of magnitude) relative to underlying fractured bedrock aquifers (NSDNR, 2011). In the Beaver Bank area, the well log data indicate that the occurrence of Windsor Group bedrock (including gypsum) is more extensive than shown on the available bedrock maps (Horne et al., 2009) and may impart high total dissolved solids, sulphate and hardness to groundwater in overlying surficial aquifers.

Limited groundwater chemistry data are available from HRM surficial aquifers and additional test drilling and aquifer characterization are recommended to refine the mapping and develop a more comprehensive understanding of their distribution and groundwater supply potential, including an investigation into the recharge dynamics of these shallow surficial aquifer systems.

4 CONCLUSION

Preliminary high potential areas for surficial aquifer groundwater supply development have been outlined. The identified buried sand and gravel deposits are narrow northeast – southwest features along bedrock contacts in the Sackville, Fall River and Hammonds Plains areas, whereas they have a more regional extent in Beaver Bank and occupy structurally controlled bedrock lows (e.g. paleo-valley or sinkhole). These sand and gravel aquifers supply approximately 5% of households with groundwater in the study area.

The preliminary mapping may help predict the extension of aquifer materials (e.g. contact zone along the Glen Brook and Cunard formations) in undeveloped areas of HRM so that it can be targeted for subdivision water supplies by well drillers and reduce groundwater stress on regional bedrock aquifers. In the Beaver Bank area, it is expected that groundwater quality would be more suitable for residential use in surficial aquifer deposits that are underlain by metamorphic bedrock compared to Windsor Group bedrock (Figure 7). More detailed study (e.g. geophysics, installation of test well and long-term pumping test) is needed to evaluate the potential of these aquifer systems, and the preliminary mapping could be used to help focus this work.

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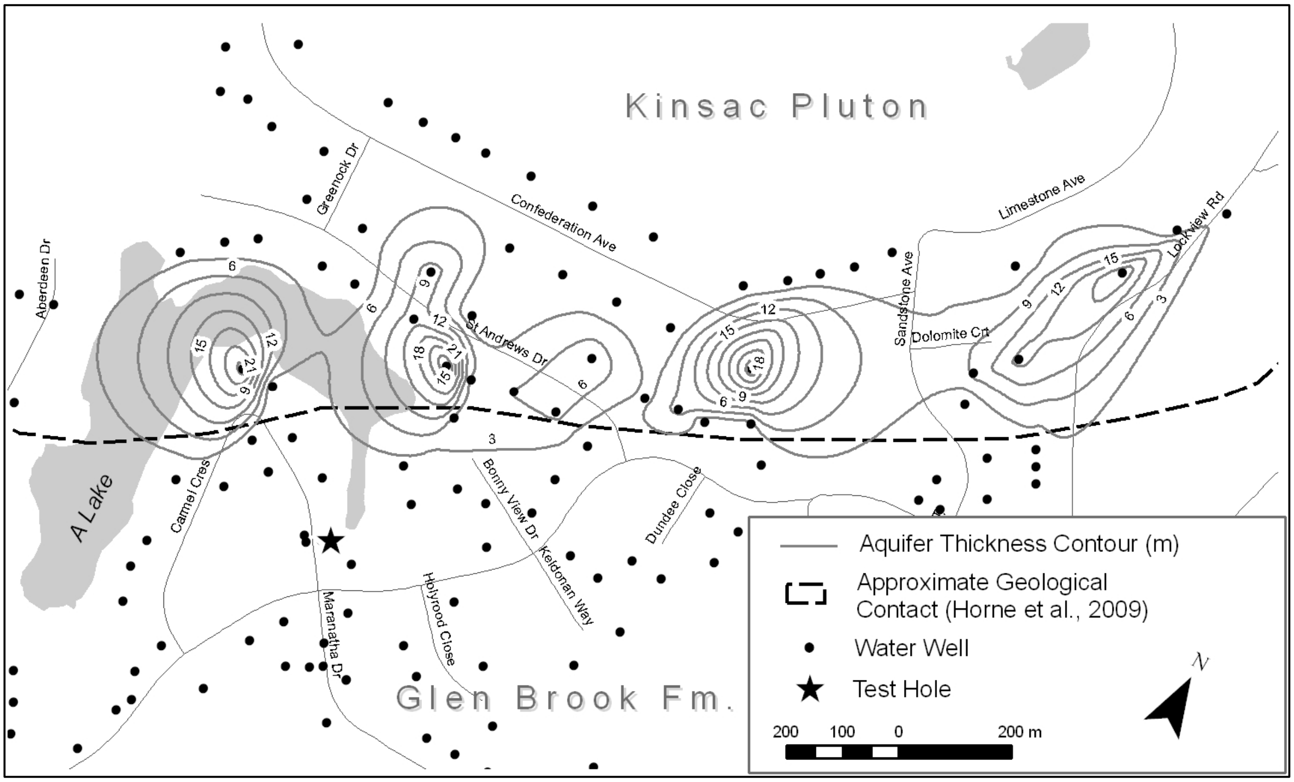

Figure 8. Surficial aquifer thickness in the Fall River area.

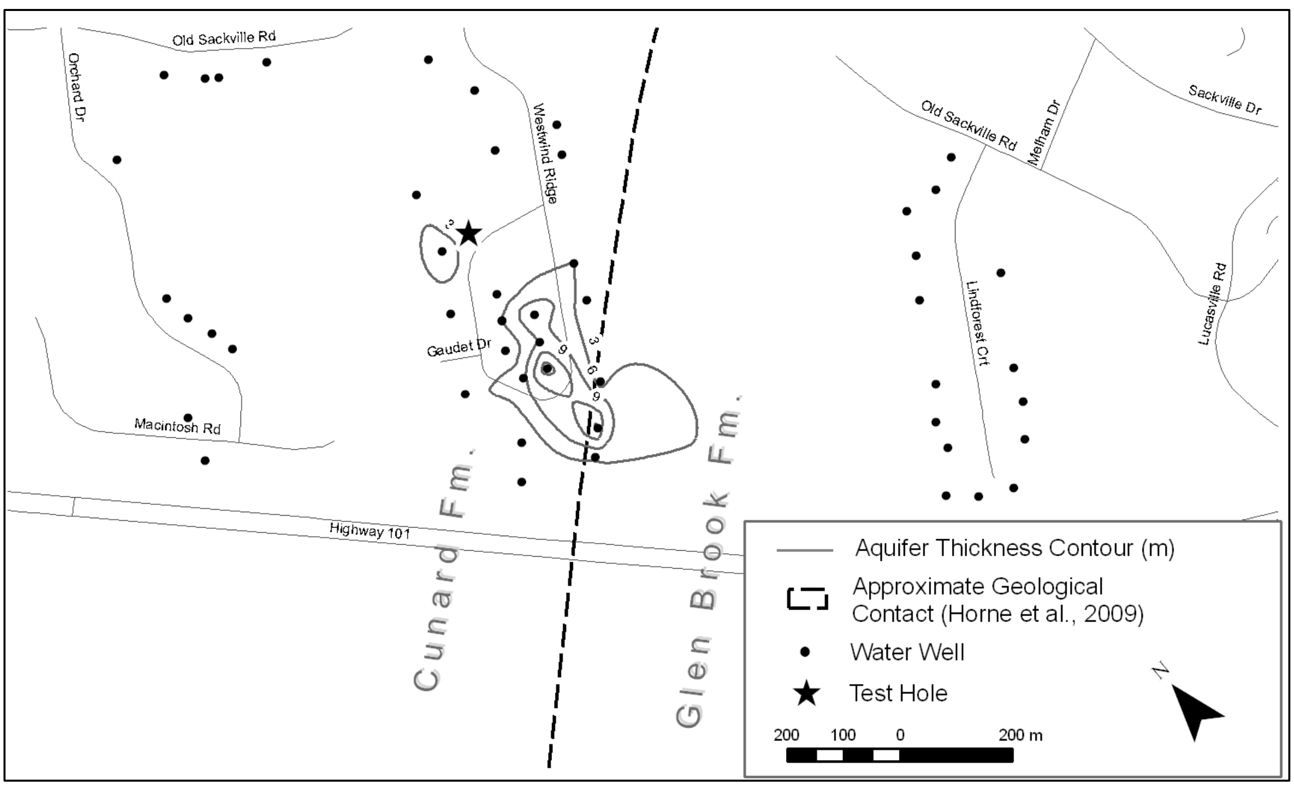

Figure 9. Surficial aquifer thickness in the Sackville area.

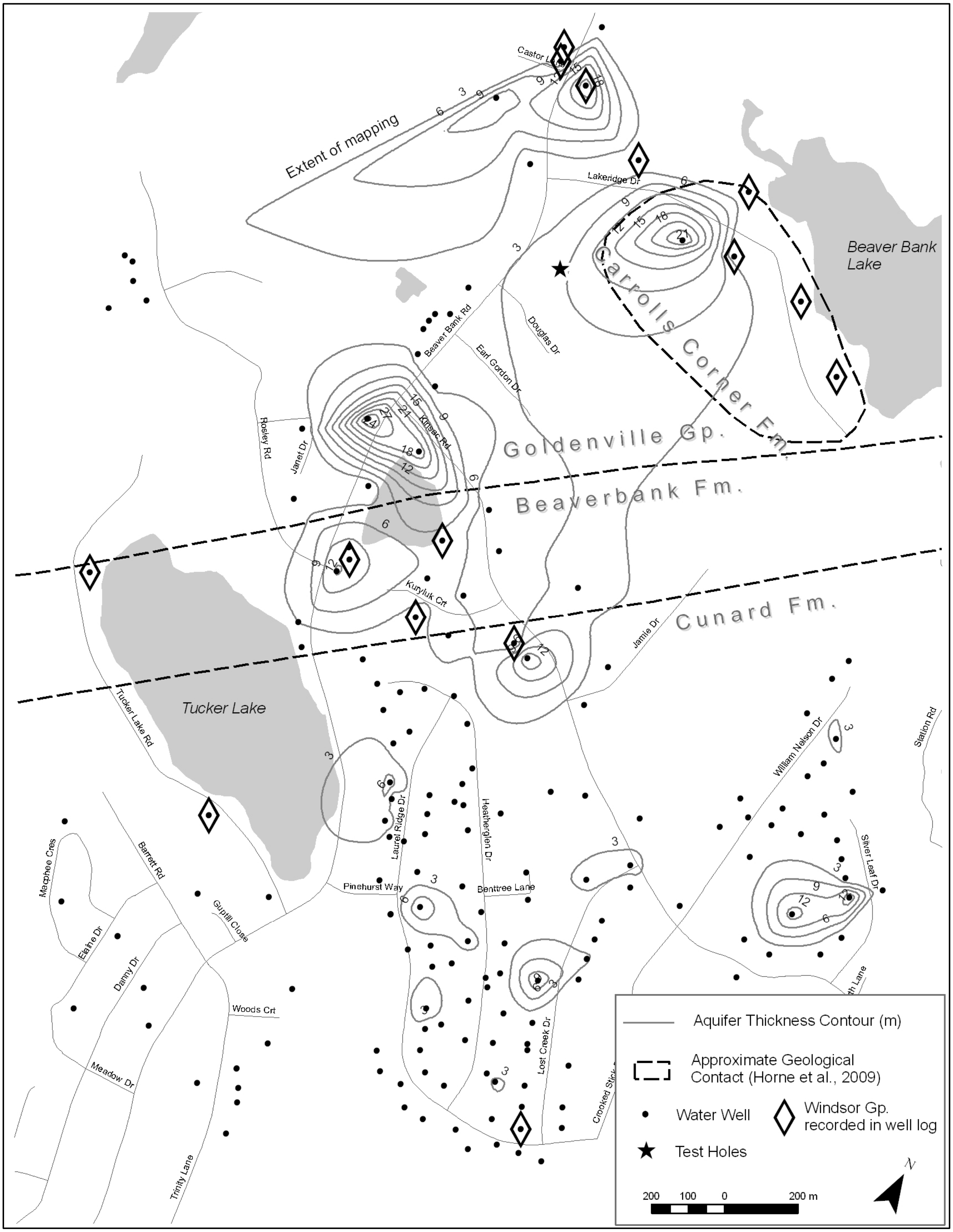

Figure 10. Surficial aquifer thickness in the Beaver Bank area.