Table of Contents

draft for discussion

Page

1. Existing Conditions - Hydrogeology 1

1.1 Data Source and Methodology 1
1.2 Physiography and Topography 2
1.3 Geology 2
1.3.1 Regional Geology 2
1.3.2 Local Geology 3

2. Hydrogeology 5

2.1 Water Supply Aquifers 5
2.2 Groundwater Flow 6
2.3 Groundwater Recharge 7
2.4 Groundwater Discharge 7

3. Water Wells 8

4. Potential Hydrogeological Constraints to Road Constructions and Improvements 9

5. References 11

List of Figures

Figure 1. Surficial Geology, Location of Cross-Sections, MOE Water Wells
Figure 2. Hydrogeological Cross Section (N-S)
Figure 3. Hydrogeological Cross Section (E-W)
Figure 4. MOE Water Wells and Water Supply Aquifers

1. Existing Conditions - Hydrogeology

Groundwater within the Western Vaughan Transportation Improvements study area supports vegetation, animals, and humans. People living in the rural areas obtain their drinking water from wells, and numerous industries rely on groundwater for commercial and industrial use. Aquifers supply farmers with water for irrigation and to develop their products for commercial distribution. Aquatic habitat, in both streams and wetlands, is dependent on specific groundwater conditions. Certain fish species require a specific thermal regime, which may be influenced by groundwater upwelling, and wetland vegetation can be highly sensitive to changes in groundwater quality. Groundwater in turn is replenished by recharge of precipitation through surficial soils.

Paved construction and operation has the potential to locally adjust groundwater recharge and flow patterns and groundwater quality. Such effects are typically in the shallow subsurface. Therefore, an understanding of the groundwater system is important when planning infrastructure such as for the Western Vaughan Transportation Improvements.

A regionally significant groundwater recharge area (Oak Ridges Moraine - ORM) is located just north/northeast of the study area. The study area also includes discharge areas commonly associated with wetlands and rivers and streams. Hydrogeologically sensitive areas are identified on the basis of surficial geology, groundwater recharge and discharge areas, and the locations of water wells.

1.1 Data Source and Methodology

Assessment of study area hydrogeological existing conditions was conducted by way of a desktop study. The desktop study included review of published information including:

- Ontario Geological Survey mapping (Karrow, 1987);
- Ministry of Environment water well records (MOE, 2006);
- Ontario Base Mapping (MNR, 2006); and
- The City of Vaughan Subwatershed Study (GLL, 1993).

Figure 1 shows the regional surficial geology at a scale of 1:30,000. Water well locations within the study area were mapped (Figure 1), and selected water well records were consulted in order to characterize the subsurface distribution of sediments and compare to the regional-scale surficial geology mapping of the Ontario Geological Survey. Aerial photograph was used to verify surficial geology.

Two geological/hydrogeological cross-sections were prepared across the study area based on information from the MOE water well records (Figures 2 and 3). Locations of the cross-sections are shown on Figure 1. These cross-sections were used to illustrate the conceptual understanding of the area in terms of geological and hydrogeological conditions.

1.2 Physiography and Topography

The landforms (physiography) within the area of investigation have been shaped by a cover of glacial deposits, which overlay Devonian and Silurian age limestone and shale bedrock. The ORM, a regional geologic feature, occurs within the north/northeastern portion of the City of Vaughan and is a major landform of particular importance. Its hummocky, knob-and-kettle surface topography reflects the variety of glacial and melt water processes that led to its formation. Most of the rest of the City of Vaughan including the study area is covered by a gently rolling plain of glacial soils such as till with a veneer of glaciolacustrine deposits.

Surficial topographic relief is minimal throughout the study area with the exception of moraine ridges in the northeastern part. The topographic relief is largely the result of glacial depositions (e.g., till) and erosion (river valleys) during the Quaternary period that occurred between 135,000 and 12,000 years ago (Eyles, 2002). Relief within the area ranges from approximately 240 mASL in the north/northeast extents, to approximately 150 mASL in the south and southeastern reaches and along the river valley (Figure 1). The area is drained by a number of permanent streams such as Humber and Don Rivers and many other permanent and intermittent creeks.

1.3 Geology

The distribution of subsurface materials influences the rate and direction of groundwater movement in the Study Area. Although the characteristics of the underlying bedrock are important in understanding regional-scale aquifers and groundwater protections, the shallow overburden sediments are most relevant to this study, given their protective thickness and the relatively shallow impacts associated with highway construction and improvements.

1.3.1 Regional Geology

The study site is located within the South Slope physiographic region (Chapman and Putnam, 1984), which extends from the Oak Ridges Moraine to the north down to the former Lake Iroquois shoreline, well south of the study area. The permeable Oak Ridges Moraine sediments were deposited over the underlying Newmarket Till[1] in a glacial lake that was trapped between the Laurentide Ice Sheet to the north and an ice sheet at the top of the Lake Ontario Basin to the south (Barnett et al., 1998). Re-advance of the southern ice sheet near the end of the last glaciation deposited the Halton Till over both the Newmarket till and Oak Ridges Moraine sediments, forming

1 *Till is a geologic term used to identify a non-homogenous mixture of soils, previously entrained in the glacial ice, that is left when the ice melts.*

the surficial geology of the South Slope. Prior to deposition of the Halton Till there was a brief period when the area was ice free (Interstade). During this time, outwash deposits of sand and gravel were formed across the South Slope as meltwater drained down from the ice-sheet to the north. These can be found in places between the Halton and Newmarket tills.

The surficial expressions of the South Slope is a gently undulating and drumlinized till plain (Halton Till), which has a typical thickness of approximately 10 – 20 m (Sharpe *et al.* 1999). The Halton Till is described as a clayey silt to sandy silt till with interbedded lacustrine sand, silt and clay sediments (Sharpe *et al.* 1999) and is consistent with borehole data obtained during different studies. The interbedded deposits of sand are typically discontinuous lenses within the till.

Thin deposits of glacio-lacustrine[2] sediments are deposited over portions of the Halton and Newmarket Till. These sand and silt sediments formed after retreat of the main ice lobes as water ponded in various locations north of the Iroquois shoreline. These deposits are considered to be thin and discontinuous. Surficial geological mapping shows the presence of these lacustrine sediments (shown in blue) over the Halton Till, which is shown in green (Figure 1). It should be noted that the actual distribution of surficial lacustrine sediments varies locally from the Ontario Geological Survey Mapping. (This regional mapping was typically done remotely using air photo interpretation and is not always accurate on a site-specific scale.)

Regionally, the bedrock is comprised of flat-lying Paleozoic limestones and shales underlying the overburden sediments throughout the study area. Water well information data in the study area was used to interpret the position of the bedrock surface. The extrapolated bedrock surface shown in the N-S and W-E cross-section was estimated from regional bedrock surface mapping. Both the limestone of the Lindsay Formation and the blue-grey shale of the Blue Mountain Formation are Upper Ordovician in age (Liberty, 1969). As can be seen on Figure 1, only minor outcrops of the rock exist in stream valleys in the southern part of the study area. Beneath the study area, the bedrock lies at an elevation of approximately 145 mASL and is overlain by approximately 80-100 m of overburden. Because of its great depth, and the fact that several excellent aquifers exist above it, the bedrock is seldom used as an aquifer in this area.

1.3.2 Local Geology

The detailed site geology is based on the interpretation of MOE water well records. In general, the site geology is consistent with the regional geology described above. The clays silt till and glaciolacustrine deposits dominate the site and underlie everything. It is locally complex with numerous laterally discontinuous lenses of lacustrine and fluvial deposits.

2 Glaciolacustrine is a geologic term used to describe layered sediments created by the settlement of soil particles in a glacial lake environment.

The lateral distribution of surficial soils is shown on Figure 1. The distribution and thickness of overburden is shown in cross-section in Figures 2 and 3. The term “overburden” is used to group the unconsolidated soil deposits lying on the competent bedrock. Within the study area, the thickness of overburden materials is substantial and may be over 80 m thick.

In general, the overburden geology in this area comprises five main lithologic units, listed from the bottom up:

a) Thorncliffe Formation.

b) Newmarket Till.

c) ORM deposits.

d) Halton till interbedded with sand, silty sand and gravely sand.

e) Glaciolacustrine deposits.

The **Thorncliffe Formation,** comprising fine sand and silty material, is a major regional aquifer due to its extent and thickness (Karrow, 1967). The Thorncliffe Formation has been identified in the northern and southern part of N-S cross-section (Figure 2) and along the western and middle part of E-W cross-section (Figure 3) at a depth of about 20-30 m. This formation is missing in the middle and in the east of N-S and E-W section, respectively where the bedrock rises to above this depth (Figures 2 and 3).

The **Newmarket Till,** has a distinct and consistent lithology (Sharp *et al.*, 1999), and is a dense, stony, sandy silt diamicton, ranging in thickness from about 0 to 40 m across the site. It is locally separated by sandy interbeds. The Newmarket silt till contains isolated lenses and thin layers of sand, silty sand and gravelly sand which could potentially serve as a shallow overburden aquifer for local residential water supply. The hydrogeological significance of the till is that it protects the major underlying aquifer (Thorncliffe Formation), and also acts as an underlying aquitard for the thin aquifer above. Based on the OGS mapping shown on Figure 1, the Newmarket till is not exposed at surface across the study area.

The **Oak Ridges Moraine sediments** are composed of fine sands and silts especially near the ground surface, but coarse sands and gravels are common at depth and in fans (Barnett, 1998). Sharpe *et al.* (1996) identified a few soil deposits of many tens of metres, which become coarser with depth, which grade from medium sand to silty clay laminae. Numerous “finger-like” protrusions of highly permeable ORM sediments extend southward toward Lake Ontario, but pinch out beneath the Halton Till (Figures 2 and 3). These are occasionally exposed at surface where valleys have incised the Halton till (Figures 2 and 3).

Coarse-grained sediments associated with the ORM extend and thin westward (Figure 3), acting as important aquifers within the analysis area for residential use. The major contribution to groundwater recharge provided by the ORM highlights the importance of maintaining a contaminant-free natural ground surface in the area where they are exposed.

The Oak Ridges Moraine Aquifer is a major regional aquifer and an important groundwater recharge area. Its sandy and gravelly composition gives it a high permeability and, combined with the hummocky surface topography, facilitates infiltration.

The **Halton Till**, is a low permeable unsorted mixture of clay, silt, sand, gravel and stones in varying proportions. It forms the major component of the overburden in the study area (Figures 2 and 3)n and usually lies in contact with Newmarket till unless separated by ORM sediments. It is laterally extensive within the Vaughn area and extends across the entire analysis area. It thins towards west where it underlies a veneer of glaciolacustrine deposits and overlies the bedrock (where it is near surface) (Figure 3). In places, till contains isolated and thin lenses of sand, silty sand and gravely sand which serve as an isolated shallow overburden aquifer where present for local residential water supply (Figures 2 and 3). The hydrological significance of till is that it inhibits local groundwater recharge thereby reducing the exposure of underlying aquifers to contamination.

Glaciolacustrine sediments are composed of laminated clay and silt and have been surficially deposited over the Halton till. These deposits may be locally thin and discontinuous, but based on the surficial geological map these deposits (shown in blue and light yellow colour on Figure 1) are found extensively over till in the study area. They reach up to 10 m in thickness. These soils are not usually as dense as the glacial till although they have a similar low permeability.

Finally, long narrow stretches of modern alluvial and organic deposits are found along the surficial rivers/streams/creek, as can be seen on Figure 1 along the Humber and Don Rivers and their tributaries. These materials are relatively thin and overlay the till surface. These streams appear to be perched on the till surface in most places although it cuts through the ORM sediments at the east Humber River (Figures 2 and 3).

2. Hydrogeology

The following features are pertinent to the study:

2.1 Water Supply Aquifers

Due to the heterogeneity of overburden deposits, it is difficult to identify a single regional overburden aquifer by location. However, multiple discontinuous aquifers of varying lateral extent exist throughout the study area. Coarse grained sediments associated with the ORM appear to extend eastward and thin westward (Figure 3) acting as an important aquifer for residential use.

These coarse grained sediments are also extensive along N-S section, indicating that ORM aquifer is a major aquifer within the analysis area. Unconfined systems, such as the surficial sand and gravel deposits to the south can provide sufficient yield for private as well as for municipal water supply wells. In contrast, confined or semi-confined systems within fine grained (silty clay) material to the west and south can supply only enough for a single household. Within the study area, over 70% of drilled wells are completed in overburden, indicating that the overburden is an important aquifer for private wells. Wells that tap the bedrock comprise only 30% of wells drilled in the study area, usually in areas of thin drift. Within the shale bedrock, permeable zones are found where the rock is characterized by a well-developed network of fractures and bedding planes. Bedrock aquifers, generally of large lateral extent, will be in deeper dolostone and limestone formations and can provide sufficient yield for a municipal water supply.

Analyses of water wells located along different concession lines (see Figure 4) indicate that there are three aquifers in the area at discrete elevations. The deep aquifer is located at an average elevation of approximately 175 in the north, 130 mASL in the south and is composed of fine sand silt. The geological properties and depth of the aquifer is consistent with the Thorncliffe Formation. This aquifer is not commonly used in the area because the intermediate aquifer is much more economic to tap.

The intermediate aquifer is found at an average elevation of approximately 195 mASL in the north, 145 mASL in the south and is composed of fine sand and silt corresponding to ORM sediments in Figures 2 and 3 and confined within predominantly till material above and below. This aquifer appears to be the most commonly tapped aquifer in the area around the subject property.

The shallow aquifer which corresponds to the isolated area of thick lacustrine sands found to the south of the area. It is an unconfined aquifer and therefore is sensitive to land use. There are also many local wells in the upper 10 to 20 m of the till unit that tap the sand lenses in the till. These discontinuous lenses, while permeable, only provide limited water supplies. They are not one continuous aquifer, but rather are a collection of individual water bearing units in this horizon of the till.

2.2 Groundwater Flow

Groundwater flow is the result of differences in hydraulic head or, simply stated, water table elevation from one location to other. Groundwater flow directions are important with respect to the capture areas for municipal wells and for the supply to local wells, wetlands and streams. Similar to much of Ontario, most of this area is a recharge area, with a strong downward component of groundwater flow to the bedrock aquifers below. Groundwater flow in the bedrock will be predominately lateral towards regional discharge zones such as the Lake Ontario. Regional groundwater flow in the aquifers within the analysis area is south-southeast from the ORM towards Lake Ontario, except where major river valleys exist. Locally, groundwater flow paths bend into river valleys and isolated topographic depressions.

Groundwater flow patterns are more complex in the overburden. In the ORM sediments or equivalent, the groundwater movement is downward and is consistent with the fact that this part of the region is a groundwater recharge area. The surficial till and fine-grained lacustrine sediments covering most of the study area inhibit rapid groundwater movement. Under this condition, in most areas groundwater flow will be downward through the low permeability sediments. Groundwater flow rates are not great in this respect as these soils are usually of low permeability. Where more permeable sand lenses exist, they will conduct groundwater laterally, provided there is an outlet.[3] Locally, groundwater flow paths bend into river valley and isolated topographic depressions.

2.3 Groundwater Recharge

Recharge is the term used to describe downward flowing groundwater, that is, from the ground surface towards the water table. Of all precipitation that reaches the ground surface, some is lost to evapotranspiration and some runs off the surface directly into streams. The remainder infiltrates into the ground. Recharge areas are important because they replenish the groundwater which ultimately discharges as baseflow to river/stream valleys, wetlands etc.

Regionally, significant recharge occurs through the surficial sands and gravels deposits of the Oak Ridges Moraine located just northeast of the study area. The recharge is greatest here due to high permeabilities of the exposed sand and gravel deposits. The Halton till plain consisting of relatively fine-grained clay silty soil covers much of the City of Vaughan. These soils are moderately to slowly permeable although isolated pockets of higher permeable sands and gravels occur locally within the till plain. Infiltration is generally limited on the fine-grained soils of the till plain and as consequence, overland runoff prevails. The patches of outwash deposits and river valley alluvium that occur throughout Vaughan also promote relatively high infiltration and recharge. Recharge also occurs in areas of glaciolacustrine soil deposits overlying the low permeability till in some areas. Generally, the surficial sand accepts significant recharge and acts as a storage reservoir feeding the low downward leakage through the silt and clay below. Where creeks cut into these sediments there is lateral flow and some local discharge occur from these horizontally layered deposits.

2.4 Groundwater Discharge

Discharge is defined as upward flowing of groundwater where the water table intersects the ground surface. Groundwater discharge is important for a variety of reasons. First, it sustains a minimum flow (baseflow) in some streams, commonly even during the dry months of summer. Without groundwater contributions, many fish-bearing streams in the analysis area would dry up periodically throughout the year. Second, it moderates stream temperatures, particularly during hot summer days, and dampens stream temperature fluctuations. Fish species such as Brook Trout

3 For example, a pumping well, or a watercourse.

are highly sensitive to changes in water temperature. Third, groundwater upwelling supports wetland vegetation and animal habitat. However, the groundwater contribution, or baseflow, varies seasonally, from reach to reach of each stream valley. For instance, nearly all water flowing within a particular stream during the dry summer months or cold winter months may be baseflow. During and immediately after storms and during spring freshet, however, baseflow may comprise only a small fraction of the total stream flow.

Within the area of analysis, groundwater discharge areas are predominantly limited to river/stream valleys. For example, the East Don River receives baseflow from ORM. In the case of Cold creek, which drains the entire central part of Vaughan, the baseflow is generated from the large valleys which are deeply cut into the till plain (GLL, 1993). The well-developed Humber River valleys also receive baseflow where particularly buried granular deposits are exposed along the valley walls. However, the portion of streams that are perched in low permeability tills may derive much of their water from surface runoff. Shallow groundwater also discharges where the granular materials (such as sand and gravel) pinches out beneath the Till and create stream headwaters which are source of some creeks (e.g., Rainbow creek in the northwestern reaches) in the analysis area.

In the areas of sand and gravel deposits, groundwater at first infiltrates (recharge) and is then released as baseflow relatively quickly and on a more consistent basis year-round then in the till plain areas of the city. Finally, the bedrock that lies beneath Vaughan is part of a more regional groundwater flow system whose primary discharge area is probably further south toward Lake Ontario although a component of its recharge is undoubtedly originates in Vaughan.

3. Water Wells

Examination of the water well database reveals a total of 1,187 reliably located wells on record[4] within the study area (MOE, 2006). Of these, 833 (approximately 70%) are screened in the overburden, and 354 (approximately 30%) are screened in bedrock. Of these 1,187 overburden wells, 135 (approximately 11%) are screened within the upper 15 m of overburden sediments. Because of shallow depth, these wells are extremely sensitive to land use.

Of the 354 bedrock wells, the majority (349 wells or approximately 98%) are finished in the upper 30 m of the bedrock surface. This is because the upper bedrock layers have usually undergone the most physical weathering and exhibit significant vertical joints and fractures, often enhanced by millennia of dissolution. The remainder are found at greater depths. As can be seen from Figures 2 and 3, all bedrock wells are in confined aquifers, protected by low permeability overburden aquitards. The numbers of bedrock wells are lower in the areas where there is only a thin drift of

4 It is our experience that up to 30% more unreported wells may exist. However, given the large number of wells, we believe we have a representative coverage for the purposes of this study.

available overburden materials. These bedrock aquifers respond as unconfined systems and are not well protected

Based on Permit to Take Water (PTTW) database of 2005, there are only 2 municipal water supply wells within the study area (near Kleinburg area). One of the wells (both wells have the same permit no.: 01-P-3063) operates on a continuous while the other operates on intermittent basis depending on seasonal demand. These two municipal wells pump water from the bedrock.

4. Potential Hydrogeological Constraints to Road Constructions and Improvements

Three hydrogeological indicators are used to identify potential sensitivities:

1. Proximity to groundwater recharge areas;
2. Proximity to groundwater discharge areas; and
3. Proximity to water wells set in shallow, unconfined aquifers.

Recharge areas are the water source for the groundwater system. Therefore, the proximity of infrastructure to such areas may affect water resources that are used by humans and/or support the natural environment. The proximity to a discharge area is also significant because these exhibit groundwater upwelling that supports aquatic habitat. Reductions in upwelling in groundwater-fed wetlands could reduce vegetation diversity by starving those species that require the most moisture. In extreme cases, disruption by human activities could cause wetlands to dry up unseasonably, and affect the hydroperiodicity of certain species. Given the reliance of so many animal species on wetland habitat, animals may be displaced or unable to survive. Similarly such disruption may redirect groundwater discharge, which could lead to flooding of low-lying areas. Reduced discharge into particularly sensitive reaches of streams could also impact fish habitat and spawning grounds.

The proximity of water wells set in shallow, unconfined aquifers is significant for two reasons. First the building of infrastructure may temporarily lower the water levels of nearby shallow wells. Nearby water wells set in the same shallow aquifer could be affected. Another long-term effect could be the permanent lowering of the water table created by permeable bedding of buried services such as storm sewers. Second, these wells are sensitive to inadvertently introduced contaminants such as de-icing compounds (e.g., road salt) entering the groundwater system. Shallow, dug wells relying on tile joints to allow water entry are particularly susceptible to contamination due to the short travel distance necessary to reach the aquifer and the absence of any extensive aquitards to intercept the contaminants.

Based on the indicators/criteria discussed above, areas associated with the ORM sediments or equivalent have the highest sensitivity. Because it is the recharge zone for a considerable amount of the groundwater in the analysis area, any changes to the permeability of the ground surface could impact groundwater supply and any changes to water quality could impact water wells and/or aquatic habitat. Detailed investigation would be required on a site-specific basis to establish hydrogeologic sensitivity for areas in the vicinity of this boundary. The patches of glacial lake and outwash deposits (yellow colour areas on the surficial geology map) and river valley alluvium (brown colour areas on the surficial geology map) that occur through out Vaughan is also designated as hydrogeologically high sensitive areas as they provide relative high infiltration and recharge.

Areas of thick till cover (i.e., greater than 10 m) which are occurring at most of the analysis area is given a low hydrogeologic sensitivity because they are considered to low groundwater recharge potential and low sensitivity to contamination. The glaciolacustrine silt and clay deposits of similar texture as till, bordering the western and southwestern reaches, are given a low sensitivity due to their low vertical permeability. There also exist areas where “finger-like” extension of ORM sediments are within a few metres of, if not exposed at, the ground surface. Such locations are local sites for groundwater recharge, and many shallow wells tap groundwater from these areas. These areas can be designated as moderately sensitive. There are also areas where sand and gravel occur within 5 m of ground surface; these areas can also be designated as moderately sensitive areas. A detailed field investigations or preparation of multiple geologic cross-sections using MOE water well records can help identify such locations in the analysis area.

Construction and operation of new roads placed in "greenfield" conditions will reduce ground water recharge (if unmitigated), by deflection of precipitation to run off. Older roads have already had this impact and their redevelopment imposes only incremental changes. Retrofit of older roads when being redeveloped can actually improve conditions through mitigation, despite greater paved areas. Therefore, when new roads are considered, assessment of changes in recharge is important to protect ground water discharge points (wetlands, springs) that may rely on local recharge.

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