# TECHNICAL MEMORANDUM

| | | | |
|---|---|---|---|
| **DATE** | October 23, 2009 | **PROJECT No.** | 09-1121-0016 |
| **TO** | John Sawarna, P.Eng.<br>City of Kingston | | |
| **FROM** | Bruce Goddard, P.E. | **EMAIL** | bgoddard@golder.com |

**PRELIMINARY GEOTECHNICAL CONSIDERATIONS**
**CITY OF KINGSTON EA STUDY**
**THIRD CROSSING OF THE CATARAQUI RIVER**
**KINGSTON, ONTARIO**

## INTRODUCTION

The Cataraqui River is located in the City of Kingston (City) and forms part of the Rideau Canal Waterway System, which is a major tourist and recreation attraction, as well as a transportation route. The Rideau Canal is a designated UNESCO World Heritage Site, National Historic Site and Canadian Heritage River.

The Cataraqui River is crossed at two locations within the City: Highway 401 in the northern part of the City; and the LaSalle Causeway in the southern portion of the City where the Cataraqui River meets the St. Lawrence River. Near the Highway 401 crossing and immediately to the north, the Cataraqui River is also crossed at Kingston Mills. Highway 401 is for inter-city travel and is simply not intended for local traffic. On the other hand, the LaSalle Causeway crossing allows for intra-urban travel but previous studies have shown that it has historically fallen below the City's accepted policy of Level of Service (LOS) 'D'.

With the continued growth of both population and tourism in the Kingston area, combined with the existing traffic congestion on the LaSalle Causeway and the current role of the Highway 401 crossing, the City is evaluating the need for and feasibility of implementing additional transportation capacity across the Cataraqui River as part of an Environmental Assessment (EA). For the purpose of the EA study, the following options are being considered:

1. Retain the status quo (do nothing);
2. Increase the capacity of the LaSalle Causeway;
3. Increase capacity of the Highway 401 from Montreal Street to Kingston Road 15; or,
4. Construct a new crossing at a location between the LaSalle Causeway and Highway 401 by means of a bridge or tunnel.

**Golder Associates Ltd.**
32 Steacie Drive, Kanata, Ontario, Canada K2K 2A9
Tel: +1 (613) 592 9600 Fax: +1 (613) 592 9601 www.golder.com

The EA study area is located in the physiographic region of Southern Ontario known as the Napanee Plain, as delineated in *The Physiography of Southern Ontario*[1]. The Napanee Plain is flat to undulating, and is characterized by relatively shallow soil deposits overlying bedrock. Geologic mapping[2] indicates that the bedrock within the Napanee Plain consists of grey limestone/dolostone of the Gull River Formation, which contains some shale partings and seams.

The overburden soils within the Napanee Plain generally consist of glacial till, although alluvium is present in river and stream valleys and, in the southern portion of the Plain, low-lying areas are typically covered with deposits of stratified clay. Water well records indicate that the average depth to bedrock within the Napanee Plain is approximately two metres. However, in many areas, bedrock outcrops are observed at ground surface, while deeper soil deposits (in the order of ten metres) are present in the northern portion of the Plain, and within and adjacent to river valleys throughout the Plain.

Based on a geology assessment of the Kingston area by D.L. Townsend titled “Geotechnical Notes of the Kingston Area”, and dated December 1969, the geology in the area generally consists of limestone bedrock overlain by post glacial clays and tills. Pre-Cambrian and Ordovician bedrock is at shallow depth within the Frontenac Axis. The Frontenac Axis connects the Canadian Shield with The Adirondack Mountains in New York and is aligned between Kingston and Brockville, Ontario. The island formation known as the “Thousand Islands” within the St. Lawrence River also forms part of the Axis.

Several fault systems are present within the Frontenac Axis, but outside the EA study area, and are generally aligned in a northeast to southwest direction. The valleys created by the faults have subsequently been filled in with soft post glacial clay and muskeg deposits. The location of these fault lines are readily visible from several limestone escarpments present in this area.

The surficial geologic mapping produced by the Ontario Geologic Survey (OGS) and summarized in Figure 1 shows that bedrock is quite shallow across much of the EA study area. Where overburden is present, it consists mostly of post glacial silts and clays. This mapping also shows that much of the Cataraqui River bank south of Highway 401, and north of Weller Avenue in Kingston are lined with organic deposits. Organic deposits are also present at the Belle Park Fairways golf course. The now closed City of Kingston landfill at Belle Park is also shown on Figure 1, and is located on the northwest side of the organic deposit near Belle Island.

This technical memorandum provides a preliminary assessment of the subsurface conditions and geotechnical considerations within the EA study area. For each of the options, a general overview of soil conditions, preliminary geotechnical considerations and potential construction issues are presented.

## OPTION 1: RETAIN THE STATUS QUO

Since Option 1 deals with retaining the status quo and does not require any major construction, there are no geotechnical considerations for this section.

[1] Chapman, L.J. and D.F. Putnam. *The Physiography of Southern Ontario*. Ontario Geological Survey Special Volume 2, Third Edition, 1984. Accompanied by Map P.2715, Scale 1:600,000.

[2] Map 2544, Ministry of Northern Development and Mines, 1991.

## OPTION 2: INCREASE CAPACITY OF THE LASALLE CAUSEWAY

### Sub-Surface Conditions

The second option of this EA study would involve the widening of the LaSalle Causeway. The approximate length of the Causeway is 450 metres. Located at the mouth of the Cataraqui River where the river flows into the St. Lawrence River, the existing LaSalle Causeway forms an important link within the City of Kingston.

The following reports were collected to obtain information on the subsurface conditions within the EA study area dealing with Option 2. The reports are listed in chronological order, by date of issue:

1. Report by the Ministry of Transportation and Communications – Ontario, titled "Foundation Investigation Report For Proposed Terminals, Kingston – Wolfe Island Ferry Service, City of Kingston and Township of Wolfe Island, County of Frontenac" dated October 10, 1973 (Report W.O. 73-11071).

2. Report by Strata Engineering Corporation for Totten Sims Hubicki Associates Ltd. titled "Preliminary Geotechnical Report, Cataraqui River Crossing, City of Kingston & Township of Pittsburgh" dated April 30, 1991 (Report Number E-90-034).

The surficial geologic mapping produced by the OGS within the Option 2 area indicates that the area east of the Cataraqui River is covered by shallow deposits of silts, clays, and glacial till. The area west of the Cataraqui River has very little to no overburden. The bedrock geology mapping produced by OGS indicates that the bedrock within this area is mapped as limestone of the Gull River formation.

Boreholes from the two previous investigations noted above show that the limestone bedrock is found near surface along the banks of the Cataraqui River, at about elevation 72 metres, but dips to about elevation 54 metres near the river channel creating a bedrock valley within the river. This valley is filled with younger alluvial deposits up to about elevation 70 metres except for the dredged channel which is slightly deeper. Figure 1 provides spot locations of overburden thickness and illustrates this bedrock valley within the Cataraqui River itself.

These alluvial deposits within the Cataraqui River generally consist of a surficial layer of soft organic matter underlain by firm to stiff clay or silty clay over a thin layer of glacial till. Below the glacial till, bedrock was inferred from auger or dynamic cone refusals encountered at all boreholes put down during the 1991 investigation near the Causeway.

The soft greyish brown organic matter, sometimes referred to as "muck", has a thickness of about one to two metres. The underlying firm to stiff clay to silty clay has a thickness up to 13.5 metres, but tapers down to nothing near the banks of the Cataraqui River. Field vane testing carried our within the boreholes indicates undrained shear strengths within the silty clay and clay deposits range from 55 to 80 kilopascals. Below the clayey layer, a thin very dense layer of glacial till was encountered within the deeper boreholes. The glacial till generally has a thickness of less than one metre.

For planning purposes, it can be assumed that groundwater conditions at the LaSalle Causeway should be hydrostatic and near the elevation of the water surface within the Cataraqui River. A more detailed investigation would be required to determine the actual elevations and if artesian conditions exists in this area.

## Geotechnical Considerations

It is understood that in order to increase the capacity of the LaSalle Causeway, the crossing would need to be widened. This could be accomplished by means of expanding the existing Causeway by placing additional fill on either side or both sides of the existing Causeway to allow for new roadway construction. This would also require the construction of an additional bridge adjacent to the current bridge structure found within the Causeway. Based on this type of construction, several geotechnical issues exist.

First, the placement of additional fill will induce additional stresses to the underlying alluvial deposits, which may overstress the underlying alluvial deposits and could induce significant settlements during and after construction of the expanded Causeway. Additional geotechnical investigation is needed to determine the preconsolidation pressures of the underlying deposits in order to provide further guidance related to settlement. This settlement will be greater for the expanded Causeway, and less for the existing Causeway, resulting in possibly considerable differential settlement. This could have a negative impact on existing buried services within the existing Causeway. Furthermore, the settlement of the organic layer could be relatively quicker compared to that for the underlying silty clay deposits. If the underlying deposits are overstressed, some long-term settlement should be expected resulting in possible additional long term maintenance of the roadway.

The settlement of the fill near structures founded on piles within the Causeway will induce additional downdrag forces on the piles. Light weight fills may need to be considered near any existing or new structures within the Causeway should this option be pursued under Phase 3 and Phase 4 of the Ontario Municipal Class EA process. Light weight fill placement may be difficult below the water level; therefore, cofferdam construction should be anticipated if light weight materials are to be placed below the Cataraqui River water level.

Second, a slope stability analysis for both static and seismic loading will be required for the new embankment geometry to ensure adequate long term global stability. This analysis may result in gentler embankment slopes, thus more fill would be required to build the new embankment.

Finally, the silty clay overburden soils have a limited capacity to accept additional stresses and are not likely suitable for foundations of heavy structures such as bridges. Any new structures built into the Causeway may need to be founded on a deep foundation such as driven steel piles, or caissons down to bedrock.

As an alternative to the Causeway (earth embankment), a complete bridge structure could be built adjacent to the existing Causeway, which would address the potential settlement and stability issues.

## OPTION 3: INCREASE CAPACITY OF HIGHWAY 401 FROM MONTREAL STREET TO KINGSTON ROAD 15

## Sub-Surface Conditions

The third option of this EA study would involve the widening of Highway 401, from Montreal Street to Kingston Road 15. The Highway 401 runs from the Ontario-Quebec border on the east to the City of Windsor on the west. It connects several municipalities in southern and eastern Ontario, including Toronto. This roadway is a major transportation corridor and is the primary link between Montréal and Toronto.

The following reports were collected to obtain information on the subsurface conditions within the EA study area dealing in Option 3. The reports are generally listed in chronological order, by date of issue:

1. Report by the Foundation Company of Canada, Engineering Corporation Limited for the Ontario Department of Highways titled “Site Investigation, Cataraqui River Bridge” dated April 28, 1954 (Report Number 1020).

2. Report by the Ontario Department of Highways titled "Hwy. 401 Line 'B' & County Rd. Revision Crossing, Lot 1, Con. II, Twp. Of Pittsburgh – Approximately 5 Miles N.E. of Kingston, Ontario" dated November 5, 1959 (Report W.J. F 59-48 -- W.P. 161-59).

3. Report by the Ontario Department of Highways titled "Foundation Investigation Report for the Proposed CNR Overhead of Highway #15, District No. 8 (Kingston)" dated September 17, 1970 (Report W.O. 70-11067 – W.P. 184-66-00).

It should be noted that only the 1954 investigation was undertaken within the EA study area, while the 1959 and 1970 investigations were undertaken as part of two new overpass structures just east of the EA study area, but are still geologically relevant.

The surficial geologic mapping produced by the OGS within the Option 3 area indicates that the area is covered by a massive-well laminated clay deposit, and/or a deposit of organic matter. The bedrock geology mapping produced by OGS indicates that the bedrock within this area is mapped as limestone of the Gull River formation.

Boreholes from these previous investigations show that the bedrock is quite variable across this area. The bedrock encountered as part of the investigation for the Canadian National Railways (CNR) bridge crossing over Kingston Road 15 near Kingston Mills (1970) was identified as a metamorphic gneiss, while the bedrock cored for the nearby Highway 401 Bridge investigation (1962) over the John F. Scott Road is granite. Furthermore, bedrock encountered as part of the Highway 401 Bridge across the Cataraqui River investigation (1954) varied between granite, horneblend syenite, and syenite gneiss.

Bedrock elevations are also quite variable ranging from about 85 to 89 metres at both the CNR and John F. Scott Road crossings, and from about 75 to 76 metres at the Highway 401 Bridge over the Cataraqui River.

The overburden soils generally consist of a surficial layer of fill, or topsoil underlain by firm to very stiff clay over bedrock. A thin layer of silty sand with gravel, to a gravel and boulder layer was also noted in several boreholes. Below the clay or the thin gravel layer, bedrock was confirmed from several bedrock core samples, or inferred from auger or dynamic cone refusals.

At all borehole locations where fill was encountered, the fill was part of the roadway structure. It ranges in composition from rock fill, to clayey fill material, up to three metres in thickness. Where encountered, the topsoil layer is relatively thin with a thickness generally less than one metre.

The firm to very stiff clay layer was described as being varied, or mottled, with a thickness ranging from 1.2 to 7.6 metres.

The compact to very dense glacial till layer consisting of silty sand to gravel and boulders encountered below the clay layer ranges in thickness from zero to eight metres at the location of the CNR crossing and John F. Scott Road overpass. The glacial till is generally less than one half of a metre at the Highway 401 Bridge crossing over the Cataraqui River.

During these investigations, groundwater was not established in any of the boreholes. However, groundwater levels were inferred from the elevation of the Cataraqui River water level. In all three reports, the native clayey soil above the bedrock is assumed to be relatively impermeable, and would result in insignificant inflow during excavations.

**Geotechnical Considerations**

The widening of this portion of Highway 401 will likely involve the construction of a new bridge adjoining the existing bridge that crosses the Cataraqui River, modifying an existing culvert or constructing a new culvert conveying a tributary of the Cataraqui River, as well as the widening of about 3.7 km of roadway embankment. The Cataraqui River narrows considerably at the existing bridge location, with a width of about 50 metres. A realignment of the on/off ramps at both the Montréal Street (Exit 619) and Kingston Road 15 interchange (Exit 623) would also be likely required as part of this option. Based on this type of construction, several geotechnical issues exist.

It should be noted that very limited soil information is available for the area. Based on a firm to very stiff consistency of the intact clay within the surrounding parts of this portion of the EA study area, no significant settlement is anticipated for the new fill or the existing roadway built onto the clay, provided that the height of the new fill does not induce stresses in the clay that would exceed the preconsolidation pressure of the native clay. However, a significant organic deposit was noted from the OGS mapping between the Cataraqui River Bridge and Exit 619 (Montréal Street) on Highway 401. Any fill consisting of typical roadway fill materials placed on this organic deposit will likely cause significant settlement of the new and existing roadway embankment. Treatment consisting of displacement of the organic matter with "causeway" construction or prior removal should be considered.

Settlement of the approach embankments and the on/off ramps is also an issue. The settlement of the fill near existing bridge structures founded on piles or caissons will also induce additional downdrag forces on the piles. Light weight fills may need to be considered near any existing or new structures should this option be pursued under Phase 3 and Phase 4 of the Ontario Municipal Class EA process.

Depending on the geometry and height of a new approach embankment for a new bridge and/or the new alignment of the on/off ramps required for this option, a slope stability analysis should be undertaken to determine global stability for both static and seismic loadings. This analysis may result in embankment side slopes somewhat flatter than the standard 2 horizontal to 1 vertical.

The soft organic material and the firm to very stiff clay which have limited capacity to accept additional stresses are not suitable for foundations of heavy structures such as open culverts and bridges; closed culverts can likely be supported within the silty clay deposit depending on the height of the fill above it. It is anticipated that the new bridge structure built across the Cataraqui River would need to be founded on a deep foundations such as driven steel piles, or caissons down to bedrock.

Geotechnical investigation is required to determine the subsurface conditions along the roadway and at culvert and bridge structures to further assess the proposed construction.

**OPTION 4: NEW CROSSING BETWEEN THE LASALLE CAUSEWAY AND HIGHWAY 401**

**Sub-Surface Conditions**

The fourth option of this EA study would involve the construction of a causeway, a tunnel or a bridge across the Cataraqui River at a location between the LaSalle Causeway and Highway 401.

The following reports were available to obtain geotechnical information on the subsurface conditions within the study area of Option 4. The reports are generally listed in chronological order, by date of issue:

1. Report by Strata Engineering Corp. for Totten Sims Hubicki Associates Ltd. titled "Preliminary Geotechnical Report, Cataraqui River Crossing, City of Kingston & Township of Pittsburgh" dated April 30, 1991 (Report Number E-90-034).

2. Report by DBA Engineering Ltd for Morrison Hershfield Limited on behalf of the City of Kingston titled "Final Soil and Bedrock Inventory & Preliminary Geotechnical Considerations Report, City of Kingston – Wellington Street EA Study, Kingston, Ontario" dated March 1, 2006 (Project No. 04-5405-001).

It should be noted that the 1991 investigation was undertaken for a recommended John Counter Boulevard (JCB) – Gore Road option, while the 2006 investigation was undertaken as part of the Proposed Wellington Street Extension Routes, which is nearby.

The available surficial geologic mapping produced by OGS for the Option 4 area indicates that the east and west banks of the Cataraqui River are covered very little to no soil cover over bedrock. The bedrock geology mapping produced by OGS indicates that the bedrock within this area is mapped as limestone of the Gull River formation.

From the 1991 investigation four boreholes and three probeholes were put down within the recommended JCB – Gore Road alignment indicating that the limestone bedrock is found at elevations that vary from about 36 to 55 metres within the Cataraqui River. These testholes however did not penetrate the bedrock, therefore the composition and quality of the underlying bedrock are not known. The bedrock geology mapping produced by OGS shows that the bedrock is much higher at the banks of the Cataraqui River, creating a deep bedrock valley within the river. This valley is filled with younger alluvial deposits up to about elevation 73 metres except for the dredged channel which is slightly deeper.

The alluvial deposits generally consist of a surficial layer of soft organic matter underlain by soft to very stiff clay or silty clay over very dense silty sand with some gravel. Below the thin basal silty sand layer, bedrock was inferred from sampler refusal.

The soft greyish brown organic material, sometimes referred to as "muck", has a thickness of about 0.8 to 6.4 metres. The firm to stiff clay to silty clay below the organic layer is up to 31 metres in thickness, but tapers off to nothing near the banks of the Cataraqui River. Field vane testing carried our within the boreholes indicates undrained shear strengths within in the silty clay and clay deposits range from 23 to 103 kilopascals. Below the clayey layer, a very dense but thin layer of silty sand, with some gravel was encountered in several of the testholes. The silty sand generally has a thickness of less than two metres.

The depth of water across the alignment generally ranges from 1.2 to 1.4 metres, except for the location of the dredged channel.

For a preliminary consideration, it can be assumed that groundwater conditions at the recommended 1991 JCB – Gore Road alignment location would be hydrostatic and based on the depth from the water surface within the Cataraqui River. A more detailed investigation would be required to determine the actual groundwater elevation and whether artesian conditions exist in this area.

**Geotechnical Considerations**

At this location, the Cataraqui River has a width of about 1,000 metres. For the construction of a tunnel, several geotechnical considerations require further study. Currently, there is no geotechnical investigation that has penetrated the bedrock; therefore the composition of the underlying bedrock is not known.

A tunnel across the Cataraqui River would intersect two distinct geological formations: limestone bedrock on both sides of the river and near the banks within the river; and soft to very stiff clay within the center of the river. This varying geology and subsurface conditions could require different excavation techniques.

There are two construction methodologies available for the construction of a tunnel across the Cataraqui River: the use of a Tunnel Boring Machine (TBM) to tunnel under the river; and cut and cover technology to excavate through the river sediments with the tunnel created by sinking precast tunnel sections into place.

A tunnel built using a TBM will require sufficient competent soil or bedrock cover, usually two times the diameter of the tunnel, to provide sufficient standup time. Depending on the strength of the soil being tunnelled, TBM tunnelling may require earth pressure balanced equipment for the mining. If the soil being tunnelled has adequate strength the soil standup time would be greater and conventional TBM equipment could be used. Standup time is the amount of time available during tunnelling where the soils can stay in place without collapsing. Standup time provides an opportunity for the tunnel workers to install the tunnel's temporary supporting structure (i.e. the concrete or steel segments).

A TBM built tunnel would also require the excavation of two large access shafts on either side of the Cataraqui River. One shaft is required for launching the TBM, while the other is required for receiving the TBM. Finally, a tunnel excavated using the TBM may encounter significant problems in the mixed face zone where the soil transitions from rock to soil at the banks of the Cataraqui River.

The second tunnelling method involves excavation in the wet or dry and then placing precast concrete tunnel elements in the excavation base. Excavation in the dry could require installing temporary cofferdams typically consisting of interlocked steel sheet piling to allow the excavation of a trench below the bottom of the Cataraqui River for the tunnel construction. Once the tunnel is in place and sealed, it is simply covered over with some of the previously excavated material. Excavation in the wet would require extensive use of divers to direct the excavation, tunnel placement, and sealing before dewatering. Due to the shallow depth of water across the alignment, this tunnel construction method may be found to be more practical. This method is often found to be more economical, for it does not require specialized boring equipment, nor does it require significant earth cover.

For both tunnelling methods, significant rock excavation will be required at both banks of the Cataraqui River. Nearby vibration sensitive structures, such as buildings or underground services, may be impacted by the rock removal operations.

For the construction of a bridge, the following geotechnical issues exist.

<u>Approach Embankment Design</u>

The approach embankments will require the removal of the soft organic soil as part of the construction process, either by displacement using "causeway" construction methods or by prior excavation. The strength and compressibility of the underlying native clay soil may limit the choice of materials considered for approach embankment design since the unit weight of the materials affects the stability and post construction settlement performance of the embankments (side slopes, the need for pre-loading, surcharging or wick drains in the design). In addition, any settlement of the approach embankments will induce negative skin friction forces on the bridge deep foundations. Long term settlements of the approaches could also result in increased roadway maintenance costs.

Bridge Foundations

The soft overburden soils are not suitable for bridge foundations. Any new bridge structure built across the Cataraqui River would need to be founded on bedrock in the river bank areas and elsewhere on deep foundations such as driven steel piles, or caissons which drive their support from the bedrock.

**ADDITIONAL CONSIDERATIONS**

The guidelines provided in this technical memorandum are preliminary in nature, and are based on a limited amount of factual information and are intended solely for the planning and selection of a preferred option. The chosen option should it deal with a crossing of the Cataraqui River, will require more detailed geotechnical investigations and design guidance.

We trust that this technical memorandum provides sufficient information for your present requirements. If you have any questions concerning this technical memorandum, or if we can be of further service to you on this issue, please do not hesitate to contact us.

Yours truly,

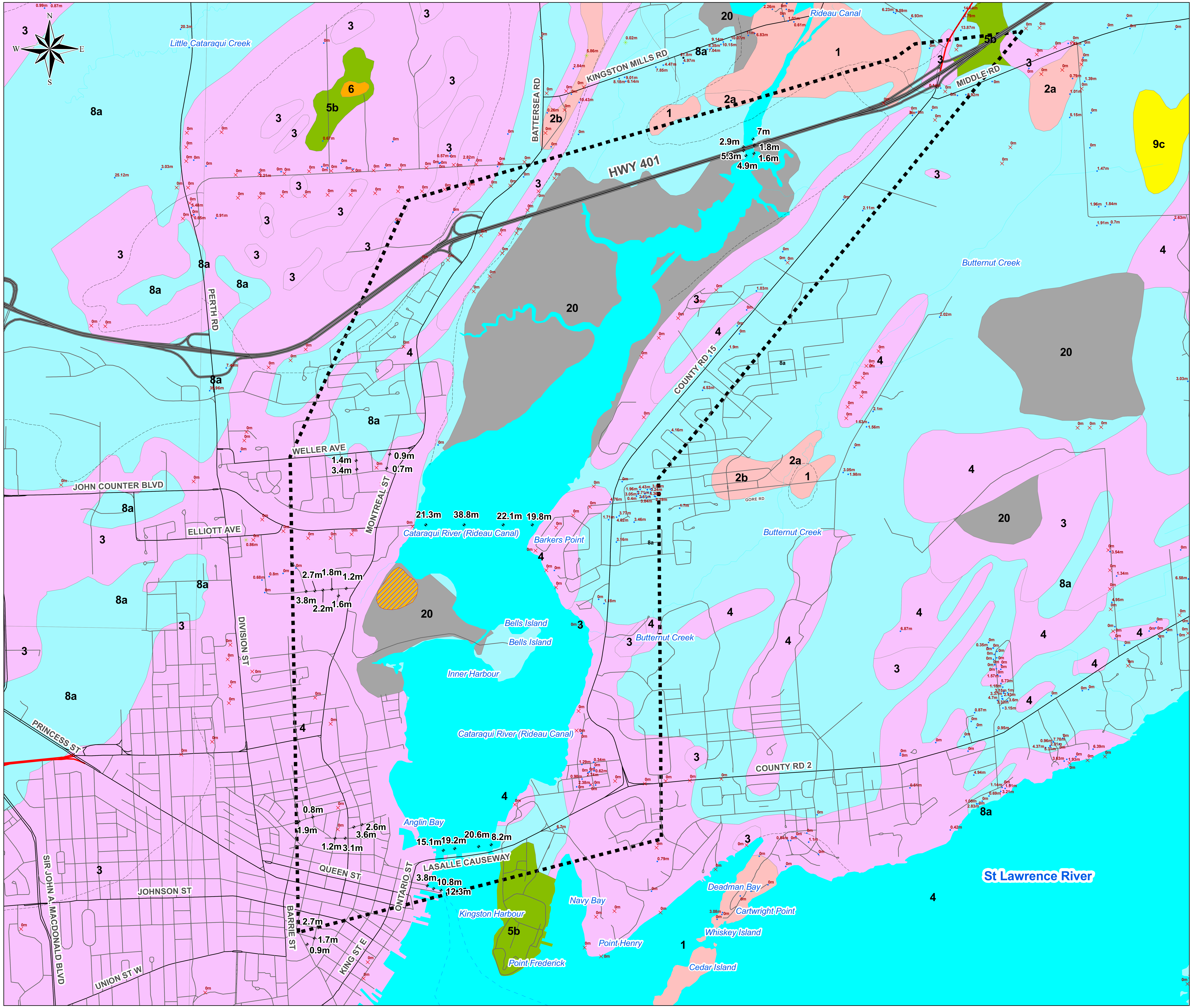
**GOLDER ASSOCIATES LTD.**

B.D. Goddard, P.E.

G.S. Webb, P.Eng.
Principal

NRL/BDG/GSW/cg/kdc
n:\active\2009\1121 - geotechnical\09-1121-0016 jlr cataraqui river ea\geotech\09-1121-0016 tech memo final august 6 2009.docx

Attachment: Figure 1 - Surficial Geology and Overburden Thickness




## LEGEND

Data Point - Overburden Thickness (m)

- Outcrops
- Water Wells
- Water Wells Not Reaching Bedrock
- Other
- Borehole
- Major Road
- Minor Road
- Contact - Approximate
- Contact - Observed
- Former Landfill
- Study Area Boundary

| | |
|---|---|
| 20 | **Organic deposits**: peat, muck, marl |
| 9 | **Coarse-textured glaciolacustrine deposits**:sand, gravel, minor silt and clay<br>9a: Deltaic deposits<br>9b: Littoral deposits<br>9c: Foreshore and basinal deposits |
| 8 | **Fine-textured glaciolacustrine deposits**: silt and clay, minor sand and gravel<br>8a: Massive to well laminated<br>8b: Interbedded silt and clay and gritty, pebbly flow till and rainout deposits |
| 5a | **Till**: Silty sand to sand-textured till on Precambrian terrain<br>5a: Shield-derived silty to sandy till |
| 5b | Stone-poor, sandy silt to silty sand-textured till on Paleozoic terrain |
| 5c | Stony, sandy silt to silty sand-textured till on Paleozoic terrain |
| 5d | Clay to silt-textured till (derived from glaciolacustrine deposits or shale) |
| 5e | Undifferentiated older till may include stratified deposits |
| 4 | **Bedrock-drift complex in Paleozoic terrain**<br>4a: Primary till cover<br>4b: Primary stratified drift cover |
| 3 | **Paleozoic limestone bedrock (Gull River Formation)** |
| 2 | **Bedrock-drift complex in Precambrian terrain**<br>2a: Primary till cover<br>2b: Primary stratified drift cover |
| 1 | **Precambrian bedrock** |

## NOTE

This figure is to be read in conjunction with the accompanying Golder Associates Ltd. report No. 09-1121-0016

## REFERENCE

Produced by Golder Associates Ltd. under License with the Ministry of Northern Development and Mines © Queen's Printer for Ontario, 2009.
Armstrong, D.K. and Dodge, J.E.P. 2007. Paleozoic geology of southern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 219
Gao, C., Shirota, J., Kelly, R.I., Brunton, F.R. and van Haaften, S. 2006. Bedrock topography and overburden thickness mapping, southern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 207
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 18

750 375 0 750
1:15,000 METRES

PROJECT

CATARAQUI RIVER EA

TITLE

**SURFICIAL GEOLOGY AND OVERBURDEN THICKNESS**

Golder Associates
Ottawa, Ontario

| PROJECT No.09-1121-0016 | | | SCALE AS SHOWN | REV. 0 |
|---|---|---|---|---|
| DESIGN | NL | 18 JUNE 2009 | **FIGURE: 1** | |
| GIS | BT | 18 JUNE 2009 | | |
| CHECK | | | | |
| REVIEW | | | | |