CITY OF OTTAWA

Low Impact Development Technical Guidance Report

Implementa on in Areas with Potena l Hydrogeological Constraints

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City of Ottawa
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Attention: Ved Proag, P.Eng.
Project Manager

Low Impact Development Technical Guidance Report for Implementation in Areas with Hydrogeological Constraints

Dear Ms. Proag,

Dillon Consulting Limited (Dillon), in partnership with Aquafor Beech Limited (Aquafor), is pleased to present this Technical Guidance Report for the implementation of low impact development (LID) measures for stormwater management in areas with hydrogeological constraints.

Yours sincerely,

DILLON CONSULTING LIMITED

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cc: Amanda Lynch, P.Eng., City of Ottawa

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Glossary of Terms

Aquifer: A porous water-bearing geologic formation that yields water for consumption.

Best Management Practice (BMP): In the context of this document, a BMP is intended to mean a structural (or non-structural) device designed to infiltrate, temporarily store, or treat stormwater runoff in order to reduce pollution and/or flooding. Also called a stormwater control measure or SCM.

Depression storage: a technique for incorporating shallow depressed areas into urban landscaped areas for storing and infiltrating runoff. Typically, depression storage areas are small and have limited capacity and limited duration of retention in order to address property owner concerns relating to insects, damage to structures and inconvenience of ponded water on their property.

Detention: the temporary storage of stormwater to control discharge rates, and allow for sedimentation.

Drawdown time: the period between the maximum water level and the minimum level (dry-weather or antecedent level).

Evapotranspiration: the combination of evaporation and transpiration. For the purpose of this document, the evapotranspiration volume shall correspond to free-standing water lost to the atmosphere as well as soil and plant moisture lost to the atmosphere. Harvested rainwater which is used for irrigation and lost to the atmosphere will not be considered evapotranspiration, but rather volume retention through capture during the respective rainfall event. Irrigated volumes will instead be treated as a demand on the rainwater harvesting system which is intended to ensure sufficient capture volume is available for subsequent rainfall events to achieve the required target (see Re-use).

Exfiltration: loss of water from a drainage system as a result of percolation or absorption into the surrounding medium (e.g., the infiltration of water into the native soil through a perforated pipe wall as it is conveyed).

Filtration: the interception and removal of fine particulate material and pollutants from runoff as it passes through an engineered filter media, synthetic filter cells and/or cartridges. Filters shall consist of an appropriate filter media per the LID Stormwater Planning and Design Guide (2010, v1.0, Wiki Document or as amended from time to time) or a third party verified manufactured or proprietary product. Filtered runoff may be collected and returned to the conveyance system or allowed to partially infiltrate. Filtration may also occur as water passes through native overburden materials.

Green infrastructure (GI): natural and human-made (engineered) elements that provide ecological and hydrological functions and processes. Green infrastructure can include components such as natural heritage features and systems, parklands, naturalized end-of-pipe stormwater management systems, street trees, urban forests, natural channels and floodplains, and LID BMPs. At its core, GI elements are a fundamental approach to rainwater management that protects, restores, or mimics the natural water cycle while delivering environmental, social, and economic benefits.

Impervious: a hard surface area (e.g., road, parking area or rooftop) that prevents or retards the infiltration of water into the soil.

Infiltration: the downward entry of water into the site soils, as contrasted with percolation which is movement of water through soil layers. For the purpose of this document, infiltration volume shall correspond to the volume which recharges shallow and deep aquifers. Irrigation water which enters the surface of the soil shall not be considered infiltration (see Re-use).

Infiltration rate: The rate at which stormwater moves from the surface into the soil, typically measured in inches per hour, millimeters, centimeters or meters per second. It is critical to note that infiltration rate and hydraulic conductivity are two different concepts and that conversion from one parameter to another cannot be done through unit conversion (see hydraulic conductivity and saturated hydraulic conductivity). Typically saturated hydraulic conductivity is used to calculate the infiltration rate to be used as a design input based on approximate relationships and often include an infiltration reduction factor (or safety factor).

Hydraulic Conductivity: otherwise known as the coefficient of permeability, is a measure of the soil's ability to transmit water when submitted to a hydraulic gradient. The hydraulic conductivity depends on the soil grain size, the structure of the soil matrix, and the relative amount of saturation present in the soil matrix. **It is critical to note that hydraulic conductivity and infiltration rate are two different concepts and that conversion from one parameter to another cannot be done through unit conversion (see infiltration rate)**.

Saturated Hydraulic Conductivity: a measure of the soil's ability to transmit water when submitted to a hydraulic gradient when saturated. Saturated Hydraulic Conductivity of water in soil (which is closely related to the intrinsic permeability of the soil) can be measured by both field and laboratory experiments, however for the design of Low Impact Development practices, in-field testing is required.

Karst geology: Regions of the earth underlain by carbonate rock typically with sinkholes and/or limestone caverns/voids. Infiltration practices in these areas are strongly discouraged when they are not overlain by a sufficient thickness of overburden deposits to provide filtration and attenuation of the infiltrating stormwater.

Low Impact Development (LID): a stormwater management strategy that seeks to mitigate the impacts of increased runoff and stormwater pollution by managing runoff as close to its source as possible. LID comprises a set of site design strategies that minimize runoff through distributed, small scale structural practices that mimic natural or predevelopment hydrology through the processes of infiltration, evapotranspiration, harvesting, filtration and detention of stormwater. These practices can effectively remove nutrients, pathogens and metals from runoff, and they reduce the volume and intensity of stormwater flows.

Partial Infiltration Design: Partial-infiltration designs are used where subgrade soils have an infiltration rate **below 15mm/hr** and when all of the water cannot drain into the subgrade within a reasonable period of time, especially during extreme storm events. A perforated outlet pipe (also called an underdrain) should be included through which excess water discharges.

Permeability: The rate a fluid (in this case water) passes through a porous medium, usually expressed in calculations per specific ASTM or AASHTO tests (typically expressed in inches per hour or meters per second etc.).

Piezometer: a shallow device which measures the pressure (more precisely, the piezometric head) of groundwater at a specific point. A piezometer is designed to measure static pressures and is used for measuring pore pressures in ground.

Porosity: Volume of voids (pore space) in a material divided by the total volume of the material.

Recharge: the infiltration and movement of surface water into the soil, past the vegetation root zone, to the zone of saturation or water table.

Re-use: includes storing stormwater runoff and then using it as a source of water for internal and/or external uses. Re-use is also referred to as rainwater harvesting. For the purpose of this document, the runoff collected will be treated as the retained volume. The volume utilized for internal and/or external uses will be treated as a demand on the rainwater harvesting system which is intended to ensure sufficient capture volume is available for subsequent rainfall events to achieve the required target.

Runoff: water from rain, snow melt and/or irrigation that flows over the land surface.

Stormwater: refers to rainwater and melted snow that flows over roads, parking lots, lawn and other sites in rural and urban areas.

Stormwater Management: refers to practices which aim to reduce runoff volumes, minimize the impact of polluted runoff flowing into watercourses, control the rate at which runoff is discharged, and/or prevent flooding from occurring, and reduces the strain that stormwater places on stormwater infrastructure.

Transpiration: the portion of precipitation, surface water or groundwater runoff absorbed by plants and animals and released in vapor form back to the atmosphere.

Water Balance: the accounting of inflow and outflow of water in a system according to the components of the hydrologic cycle. The Water Balance of an area over a period of time represents the way in which precipitation falling within that time period is partitioned between the processes of evaporation, transpiration, infiltration, and runoff, taking account of changes in water storage.

Water budget: the mathematical expression of the water balance.

Water table: subsurface water level which is defined by the level below which all the spaces in the soil are filled with water; the entire region below the water table is called the saturated zone.

Seasonal High Water Table: the highest water table level that would be observed in a year with normal precipitation levels.

Watershed: An area of land that drains into a river or a lake. The boundary of a watershed is based on the elevation (natural contours) of a landscape.

1.0

Introduction

The implementation of Low Impact Development (LID) for stormwater management has become an increasing priority for the City of Ottawa (the City), regulatory bodies, and the land development community. LID is defined as *a stormwater management strategy that seeks to mitigate the impacts of increased runoff and stormwater pollution by managing runoff as close to its source as possible. LID comprises a set of site design strategies that minimize runoff through distributed, small scale structural practices that mimic natural or predevelopment hydrology through the processes of infiltration, evapotranspiration, harvesting, filtration and detention of stormwater. These practices can effectively remove nutrients, pathogens and metals from runoff, and they reduce the volume and intensity of stormwater flows.* (adapted from the United States Environmental Protection Agency (U.S. EPA, 2007) and consistent with the *Low Impact Development Stormwater Planning and Design Guide,* prepared on behalf of the Toronto and Region Conservation Authority (TRCA) and Credit Valley Conservation Authority (CVC) (TRCA/CVC, 2010 or Wiki document; amended from time to time).

With the added industry and agency focus on LID as well as the City requirements to implement LID for erosion control/mitigation in priority watersheds, the City has been facing challenges in reviewing development applications for sites constrained by clay soils, shallow bedrock and high groundwater elevations. These are common conditions throughout the City of Ottawa, and occur frequently in areas supporting greenfield development currently. This document is thus intended to focus on LID implementation issues in areas with constraints of this nature. The reader is referred to other guidance for more general information concerning LID implementation and where other constraints may occur, including, but not limited to, documents prepared for projects in Ontario such as the Ministry of the Environment and Climate Change (MOECC)[1] document Low Impact Development Stormwater Management Guidance Manual (Draft No. 2; 2017), the proposed Ministry of the Environment, Conservation and Parks (MECP) Consolidated Linear Infrastructure ECA Draft Design Criteria/ECA templates and TRCA/CVC, 2010, or Wiki document; amended from time to time as noted above.

The following technical guidance document will present a description of; the issues/constraints, the rationale for LID measures in difficult settings, a review of technical issues and requirements, a process/approach for selection of LID measures in areas with constraints, and examples of LID implementation. It contains a series of recommendations to address hydrogeological constraints to the implementation of LID techniques. These recommendations should be interpreted as actions that a practitioner can undertake, assess and/or apply in pre-design and design. To successfully implement LID, it is necessary to fully understand the site-specific conditions and context, therefore, it is necessary to complete the following, sequential steps:

1. Identify and complete the proper site investigations in order to characterize the site-specific hydrogeological conditions. This may include, but is not limited to;
    a. Geotechnical investigations to determine soil composition/ types, stratification, properties, bearing capacity, depth to bedrock, soil management options in view of their

[1] Currently the Ministry of the Environment, Conservation and Parks

quality, i.e. to determine if contamination is present under Part XV.1 of the Environmental Protection Act (EPA)

   b. Hydrogeological investigations
      i. In-situ infiltration testing to confirm hydraulic conductivity and design infiltration rates
      ii. Groundwater conditions, including seasonally high groundwater elevation, seasonal fluctuations, and potential for groundwater contamination

2. To ensure site investigations and testing is performed per industry standards and at the appropriate time of year
3. That site assessment and testing as well as approvals are considered within the context of the standard City of Ottawa development process
4. The detailed design of the LIDs should be completed only when the aforementioned steps have been completed. In this manner the design of the LID is a by-product of Steps 1-3.

It is also noted that the guidance presented here is intended for use in all development conditions, including new development and infill developments when potential impacts have been adequately studied and mitigated. This guideline should be consulted following a water budget assessment that determined that lot level controls are needed to maintain recharge, reduce runoff and/or maintain the function of a specific natural feature etc.

2.0 Hydrogeological Constraints

As discussed above, the potential LID options available for implementation at a site are often constrained by the subsurface conditions present. Several of these typical constraints are specifically common in the Ottawa area as outlined below. It should be noted that the specific type of LID may be constrained, but the City takes the position that constraints do not alleviate applicants from providing LID as there are typically alternative options available.

2.1 Ottawa Geology /Hydrogeology

2.1.1 Surficial Geology

The surficial geology present within the Urban Area of the City is shown on **Figure 1**. As identified on the figure, low permeability soils are commonly found throughout the City and are typically comprised of glacial deposits such as glaciofluvial and glaciomarine tills with abundant clay (OGS, 2003). Colluvial and fluvial deposits often contain clay, silt, and typically fine-grained material that results in generally low permeability conditions. Most of this sediment is a result of the former Champlain Sea, which deposited large amounts of clay and fine-grained material across the region following the last glacial period (GSC, 2008).

While finer grained silts and clays are common, some coarse-grained sandy deposits occur in some areas, such as around the Ottawa International Airport and the area to the west of it. Some of this glaciomarine sand is reported to also extend further to the east and west of the airport, but to a lesser extent (OGS, 2003). A smaller area of coarse-grained sand is also reported north of Navan Road, from Blackburn to Notre Dame-des-Champs. Coarser grained glaciofluvial deposits also occur in some areas more centrally in the City, as well as to the south (e.g., western extension of the Kars esker).

As noted on **Figure 1**, shallow bedrock is also relatively common in Ottawa, but is discussed below.

2.1.2 Bedrock Geology

Bedrock within the City of Ottawa consists predominantly of Paleozoic limestone (with some dolomite, shale, and sandstone layers). The Oxford, Rockcliffe, Ottawa, Billings, and Carlsbad Formations dominate the Urban Area, with the sandstone of the Nepean and March formations being more predominant in the west near Kanata (OGS, 2006). Precambrian igneous and metamorphic rocks underlie the Nepean Formation, but are present at the bedrock-overburden interface (or ground surface) in parts of Kanata (i.e., South March Highlands and extending into Kanata Lakes/Beaverbrook).

Many of these bedrock deposits are also present at or near surface as noted on **Figure 2**. To estimate the extent of shallow bedrock (exposed bedrock and/or thin soils) in the Urban Area, the City compared the ground surface topography (City of Ottawa, 2012-15) to that of the upper bedrock surface (OGS, 2001 and 2006), and areas with less than 1m drift thickness were identified. As discussed below, these shallow bedrock areas create additional challenges to overcome when developing and implementing LID measures.

2.2 General LID Constraints

Any proposed development site may contain a number of general constraints which may restrict the use of LID approaches or result in the use of alternatives to obtain design targets. While a variety of these constraints may occur in a location, site investigations completed early within the project schedule allow for identification of any such constraints as well as time to incorporate design alterations to address any identified constraints. While not necessarily all geotechnical or hydrogeological in nature, the general constraints to LID include:

1. Low hydraulic conductivity soils;
2. Sensitive clays or unstable sub-soils;
3. High groundwater or areas where increased infiltration will result in elevated groundwater levels which can be shown to impact critical utilities or private property;
4. Shallow bedrock and areas of blasted bedrock;
5. Karst or micro-karst;
6. Areas proximal to existing development on private services, particularly where shallow potable water wells may be present;
7. Contaminated soils (i.e. Brownfields);
8. High Risk Site Activities including spill prone areas. Infiltration-based LID practices should not accept runoff from catchment areas that are associated with high risk site activities;
9. Prohibitions and or restrictions per the approved Source Protection Plans;
10. Flood risk prone areas where wastewater systems have been shown through technical studies to be sensitive to groundwater conditions that contribute to extraneous flow rates that cause property flooding / sewer back-ups and where LID BMPs have been found to be ineffective;
11. Surface water dominated or dependent features including but not limited to marshes and/or riparian forest wetlands which derive the all or a majority of their water from surface water, including streams, runoff, and overbank flooding. Surface water dominated or dependent features which are identified through approved site specific hydrologic or hydrogeologic studies, and/or Environmental Impact Statements (EIS) may be considered for a reduced volume control target. Consultation with the MECP and local agencies is required;
12. Existing urban areas where risk to life, property or infrastructure has been identified through an appropriate area specific study;
13. Limitations on Available Area to implement the LID on-site;
14. Existing utilities;
15. Mature Trees; and,
16. Typical Ratio of Impervious drainage area to treatment area facility.

As noted previously, this document is intended to focus on LID implementation issues in areas with hydrogeological constraints such as the presence of clay soils, shallow bedrock and/or high groundwater elevations. The reader is referred to other guidance for more general information concerning LID implementation and where other constraints may occur, including the MOECC document Low Impact Development Stormwater Management Guidance Manual (Draft No. 2; 2017), the proposed Ministry of the Environment, Conservation and Parks (MECP) Consolidated Linear Infrastructure ECA Draft Design Criteria/ECA templates and TRCA/CVC, 2010, or Wiki document; as amended from time to time.

2.3 Specific Constraints

2.3.1 Low Hydraulic Conductivity Soils

As discussed in **Section 2.1** above, a significant portion of the surficial geology in the Ottawa Urban Area consists of low permeability soils comprised of fine-grained materials and correspondingly low saturated hydraulic conductivities (**Figure 2**). Given that LID measures can be designed to infiltrate into the subsurface as a primary runoff control mechanism, this can sometimes limit their efficacy at certain sites if infiltration is desired. Notably, low permeability soils are common in many areas where active greenfield development is occurring within the City, including portions of Kanata North, Kanata West/Stittsville, Barrhaven South, South Gloucester, and Orleans.

To determine whether a site is considered to have low permeability soils, a grain size analysis is typically required or in-field infiltration testing can be used. Furthermore, a clay sequence may not be laterally continuous over the entire site, and may not extend to a significant depth. In some cases, characterization of the clay sequence may identify sandy seams or other discontinuities that may act as secondary permeability features. Sites where such discontinuities have been identified may require an increased level of investigation (e.g., increased borehole and/or hydraulic testing frequency).

Generally speaking, low permeability soils can be identified and characterized during the pre-development hydrogeological investigation, as outlined in **Section 3.4**.

2.3.2 Sensitive Clays

The low permeability soils discussed above are typically part of the Ottawa Valley Clay Plain which is a deposit resulting from the Champlain Sea. Champlain Sea clay (also sometimes referred to as Leda clay, sensitive clay, or quick clay) varies in thickness, but is often characterized by a brown-grey upper portion, and a lower grey, saturated portion below it. These deposits are typically characterized as sensitive due to their potential response to increases in vertical effective stress, or disturbance, and changes in water content (i.e., potentially making the clays unstable), as well as the significant amount of settlement that can occur with consolidation. Considerations related to these deposits are summarized here, but the reader can refer to **Appendix A** for further details (Thurber, 2019 - Geotechnical Input – Low-Impact Development in Areas of Sensitive Marine (Leda) Clay, Ottawa, Ontario).

If sensitive marine clays are overstressed (by increasing the vertical effective stress beyond the clay's preconsolidation pressure), consolidation settlement can often range from 10 to 50 cm (or more). Primary consolidation, where excess porewater dissipates, can take 3 to 7 years, after which secondary consolidation will continue to cause settlement of the clay. Even if the preconsolidation pressure is not exceeded, settlement can still occur; especially if the water table is lowered, thereby drying the clay. When the water content in sensitive marine clays is decreased, the volume can significantly shrink. Infiltration-based LIDs could potentially help maintain the water table elevation at pre-development levels, and decrease the amount of shrinkage and settlement.

Slope stability can also be a concern when sensitive marine clays are disturbed. As sensitive marine clay becomes more saturated, the potential for landslides increases in areas that have been over-steepened by erosion or human activity. To account for this, the City's "Slope Stability Guidelines for Development Applications in the City of Ottawa" recommends that the slopes should be assumed to be fully saturated thereby assuming worse-case conditions. For this reason, additional input from infiltration-based LID measures would already be accounted for.

Sensitive marine clays may also impact the performance of paved structures such as roads and parking areas. Adequate drainage away from this type of infrastructure is necessary to prevent damage from settlement. Additional considerations may be necessary when designing LID options near roadways and other pavements in areas with Champlain Sea clay, or sensitive marine clay.

Generally speaking, the presence of sensitive clays likely has several implications when implementing LID measures. These should be accounted for when completing the pre-development hydrogeological investigation, and will likely require the assistance of a geotechnical engineer.

2.3.3 High Groundwater Conditions

Similar to the low permeability soils discussed above, high groundwater conditions are also relatively common in the Ottawa Urban Area, and can limit the effectiveness of certain LID measures. These often occur in areas with low permeability soils, or proximal to wetlands (**Figure 2**).Typically, infiltration-based LID options require an offset between the bottom of the facility invert, and the seasonally high-water table. Future grade changes should also be accounted for while completing this assessment.

Site specific investigations are required to assess whether high groundwater conditions are present. It is noted that sites that also have low permeability soils, typically have high groundwater conditions; however, high groundwater conditions may also occur at sites with coarser deposits and/or shallow bedrock conditions.

Although long term static water table levels may be lower post-development, the pre-development seasonal high-water table should be considered as representative of transient conditions that may occur

post-development at sites of this nature with poorly drained soils (e.g., clay sites), such as may occur during the spring freshet or higher intensity or sustained storm events.
For sites with foundation drainage via sump pumps, LID measures that promote infiltration should not be located near buildings.

Lastly, while the function of some infiltration-based LID options may be limited during seasonal high groundwater conditions (i.e., during spring freshet conditions), they may still be feasible during the remainder of the year; however, while high water table conditions persist, alternative stormwater management measures will need to be available/implemented.

2.3.4 Shallow Bedrock

As discussed in **Section 2.1**, shallow bedrock is relatively common in the Ottawa area (**Figure 3**), notably in the west end. Thin soils and the bedrock geology at a site can limit the potential for implementing stormwater management strategies that rely on infiltration as the primary solution. Similar to the high groundwater condition constraint discussed above, infiltration-based LID measures typically require an offset between the bottom of the facility invert, and the bedrock surface.

For the purposes of this guidance document, shallow bedrock has been defined as exposed bedrock and/or areas with less than 1 metre of overburden. While the type of bedrock can affect the amount of infiltration into it, the flow is often significantly lower than overburden and does not provide the same level of filtration. Bedrock with higher rates of infiltration (e.g., karst, as discussed below), do not allow for filtration of the stormwater, and typically have preferential pathways such as fractures or voids.

While shallow bedrock can limit the selection of available LID options, it may only be limited to a specific area of a site. Furthermore, there are other LID measures that can be implemented in place of infiltration-based options.

2.3.5 Karst

Karst formations form in calcium carbonate-based rocks (e.g., limestone) when mildly acidic surface water infiltrates through fractures in the stone. Over significant periods of time (thousands to millions of years), fractures are dissolved into larger and larger voids and eventually caverns. These voids and caverns often remain undiscovered and can results in hydrogeological anomalies, or more dramatically, the formation of sinkholes.

In the context of LID implementation, infiltration-based LID measures may result in increased dissolution of karstic limestone, or infiltration into a preferential pathway; however, these concerns are likely only an issue when the infiltrating stormwater is able to reach the karst. If, for example, the karstic bedrock is overlain by a significant amount of overburden and below the water table, it would not necessarily be a constraint to LID implementation.

In areas with potential karst (**Figure 4**), site-specific investigations should be completed to identify its potential presence, and the potential risks/constraints associated with it (i.e., not a concern if the karst is overlain by saturated overburden deposits). It should be noted that the extent of potential karst formations identified on **Figure 4** (OGS, 2008) is an estimate only and subject to change. It is our understanding that Karst mapping in the Ottawa area is currently under review and will likely be updated in the future.

2.3.6 Areas with Private Services

While most of the Ottawa Urban Area is serviced with municipally supplied drinking water infrastructure, some portions rely on private water supply wells. Typically, water supply wells are installed with a hydraulic seal and at a depth that prevents influence from shallow groundwater or infiltrated stormwater from a potential LID measure; however, some wells may be vulnerable to this type of impact. As discussed above, certain bedrock formations may also present preferential pathways for infiltration.

When implementing LID measures in areas where some existing development is present with servicing by water supply wells, consideration must be given to the potential impact to those wells. This may limit the type or location of the LID options.

2.3.7 Brownfield Sites

At sites with contaminated soils or groundwater that has not been fully remediated, or sites with a high risk of contamination from onsite activities, increased groundwater flow is typically discouraged as it can increase the potential for migration of contaminants and/or further impact to groundwater. At properties such as these, infiltration-based LID measures may not be feasible in the vulnerable areas; however, portions of the site may still be viable, and other LID options should be implemented. Additional investigations (i.e., beyond the requirements outlined in **Section 3**) are typically required at these type of sites.

3.0 LID Implementation in Areas with Hydrogeological Constraints

3.1 LID Overview and Philosophy

Current stormwater management practices typically include conventional practices such as ponds, wetlands, hydro-dynamic separator as well as source and conveyance control systems known as LID-BMPs.

LIDs are human-made or engineered systems and are a subset of Green Infrastructure used for the management of rainwater and stormwater runoff, with the goal of improved water quality, enhancing runoff volume control and erosion control. LID is the term most commonly used in Ontario, Canada and the U.S., but it can be alternately referred to as sustainable urban drainage systems, water sensitive urban design, or stormwater source controls. For the purpose of this document, the following definition, adapted from the United States Environmental Protection Agency (U.S. EPA, 2007) and consistent with the Stormwater Planning and Design Guide (wiki.sustainabletechnologies.ca) and other resources listed in shall apply:

Low Impact Development (LID) is a stormwater management strategy that seeks to mitigate the impacts of increased runoff and stormwater pollution by managing runoff as close to its source as possible. LID comprises a set of site design strategies that minimize runoff through distributed, small scale structural practices that mimic natural or predevelopment hydrology through the processes of infiltration, evapotranspiration, harvesting, filtration and detention of stormwater. These practices can effectively remove nutrients, pathogens and metals from runoff, and they reduce the volume and intensity of stormwater flows.

The underlying concept is that each LID and traditional practice within the treatment train provides successive storage, attenuation and water quality benefits. Furthermore, LID source and conveyance practices may be beneficial in order to meet objectives beyond the field of stormwater management such as community sustainability objectives, energy/water conservation, reduction and reuse of materials, ozone protection, reduction of the effects of 'Urban Heat Island', habitat creation, aesthetic improvements and green-space creation and revitalization as well as climate change adaptation and co-benefit creation.

The five (5) key principles for the use of LID are as follows:

1. **Use existing natural systems as the integrating framework for planning;**
    - Consider regional and watershed scale contexts, objectives and targets;
    - Look for stormwater management opportunities and constraints at watershed/subwatershed and neighbourhood scales;
    - Identify and protect environmentally sensitive resources; and

- Restore, enhance, and expand natural areas.

2. **Focus on runoff prevention**
   - Minimize impervious cover through innovative site design strategies and application of permeable surfaces;
   - Incorporate green roofs and rainwater harvesting systems in building designs;
   - Drain roofs to pervious areas with amended topsoil or stormwater infiltration practices; and
   - Preserve existing trees and design landscaping to create urban tree canopies.

3. **Treat stormwater as close to the source area as possible**
   - Utilize decentralized source and conveyance stormwater management practices as part of the treatment train approach to infiltrate, filter, absorb, evapotranspirate and retain for future re-use.
   - Flatten slopes, lengthen overland flow paths, and maximize sheet flow; and
   - Maintain natural flow paths by utilizing open drainage (e.g., swales).

4. **Create multifunctional landscapes**
   - Integrate stormwater management facilities into other elements of the development to conserve developable land;
   - Utilize facilities that provide filtration, peak flow attenuation, infiltration and water conservation benefits;
   - Design landscaping to reduce runoff, urban heat island effect and enhance site aesthetics.

5. **Educate and maintain**
   - Provide adequate training, funding, or legal agreements to monitor and maintain lot level and conveyance stormwater management practices on public property;
   - Teach property owners, managers and their consultants how to monitor and maintain source and conveyance control stormwater management BMPs on private property; and
   - Establish legal agreements to ensure long-term operation and maintenance.

3.2 City Drivers for LID Implementation

With the added focus on LID as described in the Interpretation Bulletin, Expectations Re: Stormwater Management (February 2015), as well as the City requirements:

- for improved runoff volume control
- for erosion control/ mitigation in priority watersheds,
- to provide water quality improvements,
- to reduce stormwater runoff and increase conveyance capacity,
- to maintain the pre-development water balance, and
- to mitigate the projected impacts of future climate resulting from climate change.

The City of Ottawa is endeavoring to implement LID as part of new development, infill-developments, linear reconstructions and retrofits.

The need for LID in the City has also been identified as next-steps for areas of the City built before stormwater management was a standard requirement through local studies (Pinecrest Creek/Westboro Area, the Eastern Subwatersheds SWM Retrofit Study and others) and is a key approach in the treatment and control of stormwater runoff to the Ottawa River and its many tributaries through the 2010 Ottawa River Action Plan (ORAP).

3.3 Geotechnical Investigations

Investigation requirements to support LID implementation overlap in part with the required geotechnical investigations to support development. The City Geotechnical Investigation and Reporting Guidelines for Development Applications outlines the geotechnical requirements for site plan approval, plan of condominium, building permits, and draft plans of subdivision. The investigations required for LID measures should be completed coincident with the required geotechnical investigations. For some project types, some additional requirements beyond the typical geotechnical scope may be required.

Table B-1 (**Appendix B**) outlines the geotechnical requirements as described under these guidelines as well as the LID requirements. The extent of the geotechnical investigation may be increased based on soil conditions present at the site.

Groundwater Level Measurement is required, more-so if:

- Excavations may extend below the groundwater level, particularly in permeable soils.
- Basement levels will be constructed and therefore the need for a foundation drainage system must be evaluated.
- Soils that are potentially vulnerable to seismic liquefaction, cyclic mobility, or any cyclic softening modality, exist on the site.
- The site is potentially underlain by compressible Champlain Sea clay, and therefore groundwater affects the capacity of the soil to accept load. Geotechnical and Hydrogeological Requirements for LID.

In addition to the above **general requirements**, the table below provides a summary of the geotechnical/hydrogeology investigation activities which are necessary for the detailed design of various LID measures. In-situ infiltration testing and groundwater level monitoring will be required for the design of LID practices. Per Appendix B (Table B-1), the borehole depth required by the City varies, from 4 to 10 m in depth (or greater), but must be no less than 1m below the maximum depth of excavation for basements or buried site services.

For LIDs, the minimum borehole depth must be no less than 1.5 m below the maximum depth of excavation of the LID practice itself, per the Stormwater Planning and Design Guide 2010, v1.0 or Wiki Document (wiki.sustainabletechnologies.ca), as amended from time to time.

Geotechnical Investigation Activities for LID SWM Options

LID Practice	Geotechnical Investigation Activities			
	Boreholes	Piezometers/ Monitoring wells	Laboratory Soil Testing	In-situ Infiltration Testing
Bioretention	●	●	●	●
Bioswale	●	●	●	●
Enhanced Grass Swales	●	n/a	●	●
Perforated Pipe	●	●	●	●
Permeable Pavements sidewalks & MUTs	●	●	● (Resilient Modulus or Soaked CBR)	●
Prefabricated Modules	n/a		●	●
Infiltration Facilities	●	●	●	●
Stormsewer Daylighting	●	●	●	●

Boreholes - Boreholes are typically specified to extend a minimum of 3 m or to bit refusal (boreholes are recommended to be advanced a minimum of 1.5m below the proposed invert of proposed LID practice). The resolution of the investigation (i.e. quantity and spacing between boreholes) will vary from site to site. Resolution of the borehole investigations shall be such that sufficient information is collected for detailed design purposes.

Groundwater Elevation Monitoring – For larger sites, groundwater elevation monitoring shall be undertaken per ASTM D5092/ D5092M-16 Standard Practice for Design and Installation of Groundwater Monitoring Wells.

For smaller sites or individual LID facilities, piezometers can be used. Piezometers or monitoring wells typically consist of 25 or 50 mm diameter casings installed to depths of 3.5 to 4.5 m and encased within an above ground and/or flush mount, lockable, steel housing. Piezometers or monitoring wells shall be installed to determine the seasonal high-water table including seasonal fluctuations and, where required, the groundwater flow direction (gradient). Usually one year of monitoring, preferably continuous data logging, is required to determine the seasonal high-water table.

Geotechnical Laboratory Soil Testing - Soils samples collected as part of geotechnical investigations characterize the soil properties including natural moisture content, plasticity characteristics, particle size distribution, and analytical results for contaminates. It is beneficial if geotechnical investigations include recommendations regarding soil disposal alternatives. The information can be used in the interpretation of in-situ infiltration testing results and the selection of geotextile properties as part of subsequent detailed design.

Resilient Modulus Soaked California Bearing Ratio (CBR) - If permeable pavements are proposed, specifically permeable interlocking concrete pavers (PICP), porous concrete or permeable asphalt etc., determination of the resilient modulus or soaked CBR of the native soils must be included to determine the base and sub-base requirements to ensure adequate structural strength for users.

In-situ Infiltration Testing - is required to characterize the hydraulic properties of the existing native material on-site. The designer of the LID shall ensure a qualified professional conducts in-situ saturated hydraulic conductivity testing within the area of the proposed LID. The measurements should be taken in soils that are indicative of the proposed invert of the LID system. Approved field tests for estimating the infiltration rate of the native soil that include:

- Guelph permeameter test;
- Double-ring infiltrometer test;
- Phillip-Dunn Infiltrometer; and
- Borehole permeameter test;

Other methods may be utilized upon approval by the City based on professional judgement and experience of a qualified person– all to the satisfaction of City staff. Testing should be completed in compliance with the TRCA Wiki[2] for infiltration testing recommendations and ASTM D3385, as well as TRCA/CV (2010).

The resolution of the investigation (i.e. spacing between and quantity of test holes) should be such that sufficient information is collected for detailed design purposes. The table below describes recommended testing resolution.

Recommended Soil Boring and Test Ping

Surface (footprint) area of the LID system (m^2)	Boreholes and/or Pits	Recommended In-Situ Infiltration Sites
< 100	1	1-2
100 to 500	2	3-5
500 to 1000	3	6-10
>1000	4	+11

Additional tests should be conducted if local conditions indicate significant variability in soil type, geology, water table levels, bedrock or topography. Similarly, uniform site conditions may indicate that fewer tests are required. All testing should be completed when native soils are not frozen nor during frost conditions, with a minimum of 48 hours of no precipitation prior to testing.

[2] https://wiki.sustainabletechnologies.ca/wiki/Design_infiltration_rate

3.4 Additional Pre-Development Hydrogeological Investigation Requirements

Prior to the potential development of a property, a hydrogeological investigation is required to further characterize the site conditions. To support the implementation of LID measures within the City, some additional requirements should be considered while completing this investigation. A hydrogeological investigation should be completed under the direction of a qualified groundwater professional licensed by the Association of Professional Geoscientists of Ontario, or Professional Engineers Ontario (i.e., P.Geo. or P.Eng. with appropriate training and experience in hydrogeology). Further, investigations should be initiated sufficiently early to allow the required data collection (as outlined below) in advance of design work.

Field investigations should be completed by appropriately qualified individuals with experience in the logging of soil conditions, and familiar with the data collection methods being employed.

3.4.1 Schedule and Duration

The pre-development hydrogeological investigation should be initiated at a point that allows for seasonal measurements of groundwater levels throughout the year and well in advance of design activities. Such measurements should be compared to historical precipitation levels to assess whether the data is consistent with long-term averages for the site. The qualified groundwater professional directing the investigation should also ensure that static groundwater level measurements are collected at all monitoring wells regularly throughout the expected spring freshet period so as to ensure that a reasonable estimate of the maximum seasonal high-water table is obtained. It is suggested that the proponent consider the use of pressure transducers/data loggers for this purpose, and expected that these would be employed at a reasonable sub-set of the monitoring well locations at least. The adequacy of the dataset should be described and rationalized in the hydrogeology report.

3.4.2 Monitoring Well/Piezometer Requirements

Monitoring wells/piezometers shall be constructed in accordance with the requirements of O.Reg. 903 as amended and in a manner to facilitate hydraulic testing (e.g., slug testing) potentially required to support groundwater mounding calculations or to determine the seasonal high-water table. Well screens shall be 1.5 m in length and positioned to capture the expected seasonal high-water table condition. It is noted that at some points of the year, this may require screen placement within, or partially within unsaturated soils (e.g., if significant water table lowering has occurred during drier conditions). Anticipated future grade raises (to the extent known) should also be considered.

3.4.3 Hydrogeological Analysis

Where hydraulic testing (e.g., slug testing or other method as determined by the qualified groundwater professional) is required to support the investigations and/or is undertaken to provide an early estimate of the in-situ hydraulic conductivity for the purposes of LID feasibility studies or LID selection, this should be completed at each monitoring well to allow estimation of the saturated hydraulic conductivity of the materials present. This testing should be completed at a time when saturated conditions are present throughout the screened intervals of the monitoring wells. This may require that the testing be completed during spring conditions. If testing cannot be completed at a time when saturated conditions occur, the qualified groundwater professional may propose an alternative approach in consultation with the City. The proponent should complete the hydraulic testing following industry standard methods such as those outlined in ASTM D4044 / D4044-15 (2015).

3.5 Current Approaches and Guidance

The following sections describe the current approaches and guidelines relating to the implementation of LID and the various obstacles/barriers and constraints which have been raised by development proponents and practitioners as part of various applications and through approvals processes. The following is intended to outline the City's expectations and represent the recommended direction and guidance which the City intends to provide to the broader development community and consulting industry on the implementation of LID.

3.5.1 Minimum Infiltration Rates

Per the *Interpretation Bulletin: Ontario Ministry of Environment and Climate Change Expectations Re: Stormwater Management* (February 4, 2015), several areas of Ministry Guidance are identified as requiring improvement and the following clarification regarding the minimum infiltration rates currently specified in the 2003 manual is provided:

The 2003 Stormwater Manual contains guidance for a number of lot level and conveyance controls but specifies that the application of a number of management practices may not be suitable if the native soil has a percolation rate less than 15 mm/hr (see for example Pg. 4-6: Table 4.1: Physical Constraints for SWMP Types - infiltration trenches, reduced lot grading, soakaway pits, rear yard ponding, and pervious pipes).

This has contributed to the limited application of these measures as many of the soils within Ontario do not meet this criterion. The infiltration rate has an obvious effect on the speed with which a facility will be emptied between rainfall events. Thus, LID facilities should be sized for optimum control of water quantity. Area-wide quantity criteria may be achieved through the use of multiple smaller LID facilities distributed over a large area.

For example, stormwater management practices such as bioretention and biofiltration use multiple treatment mechanisms including retention, filtration, evaporation and transpiration as well as infiltration. If the lot level and conveyance facilities can be sized such that they empty between events, or will be installed in areas where quantity control is not a primary concern (areas draining directly to a large surface water body like Lake Ontario, for example), LID facilities can be used where the infiltration rate is less than 15 mm/hr to achieve water balance and water quality (including thermal impacts) through retention, filtration, evaporation and transpiration. Thus, the soil infiltration capacity guidance in the manual should not be interpreted as a prohibition. Rather, it should be interpreted as a caution that controls relying primarily on infiltration may not be as effective on soils with low infiltration rates as they would be on soils with higher rates of infiltration."

For additional information on the *Interpretation Bulletin: Ontario Ministry of Environment and Climate Change Expectations Re: Stormwater Management* (February 4, 2015), see the Resource Directory (Appendix D).

It is recommended that the practitioner acknowledge that there shall be no minimum native soil infiltration rate for the implementation of LID, provided the native soil infiltration rate is > 0mm/hr. If the in-situ native soil infiltration rates are less than 15mm/hr, the Low Impact Development Stormwater Management Planning and Design Guide (wiki.sustainabletechnologies.ca) recommends that an underdrain is required and the LID shall be a 'partial-infiltration' design.

3.5.2 Low Hydraulic Conductivity Soils

Soils with low hydraulic conductivity (i.e., finer grained soils with higher silt and clay content) have reduced capacity to infiltrate runoff volumes, which may limit the feasibility of infiltration-based LIDs (i.e. LIDs that rely primarily on infiltration).

Recommendation: To encourage infiltration in these soils, infiltration is enhanced by maintaining a hydraulic head above the point at which infiltration slows to negligible levels. Therefore, it is recommended that the practitioner allow water to remain within the storage reservoir below the underdrain or outlet continuously, or at least for longer time periods than the typical 48 to 92 hour drawdown time requirements for other BMPs; this creates a portion of the total storage regarded as effectively permanent. The storage should also be designed to be more vertically oriented to increase available hydraulic head. To obtain vertically oriented storage, BMPs should have higher side wall to bottom ratios.

While the presence of low hydraulic conductivity soils may limit the feasibility of infiltration-based LIDs, it does not preclude the use of and does not necessarily limit the use of LIDs which utilize other mechanisms such as filtration, evapotranspiration (ET) and re-use as the primary processes.

	Infiltration	ET	Re-use	LID Filtration	Filtration	Hydro-dynamic	Sedimentation
Low Hydraulic Conductivity Soils	●	○	◘	◘	◘	◘	◘
○- Constraint does not limit or impact; ● -Constraint limits or impacts; ◘ - Constraint may limit or impact							

3.5.3 High Groundwater

In Ontario the required vertical separation between a practice and the water table or bedrock is frequently cited as 1 meter. This comes from the 2003 Stormwater Management Planning and Design Manual. Per the TRCA Wiki "whilst this is a great rule of thumb, like all aspects of LID, this 1 m figure might require amendment on a site-by-site basis. In areas where a 1.0 m separation cannot be provided, or where conditions dictate that an even greater separation may be warranted, additional discussion and/or analysis specific to the physical characteristics of the site and the proposed design should be completed.

Recommendations

The design practitioner is advised to pre-consult with the City to understand their requirements and/or expectations prior to undertaking work, and to complete an appropriate level of analysis to support their conclusion.

Recommendation 1: For sites where < 1.0 m separation from the seasonally high groundwater elevation is anticipated, it is recommended that the practitioner undertake additional investigations and/or prepare documentation supporting a proposed design. This may include but is not limited to:

- Extended monitoring programs
- Groundwater mounding analysis (see Section 3.5.4).
- Hydrogeological assessment

Recommendation 2: For sites where ≥ 1.0 m separation from the seasonally high groundwater elevation is anticipated, the requirement for additional investigation and/or documentation supporting a proposed design may be reduced. Factors to consider include:

- risks due to short periods of groundwater mounding and potentially unobserved seasonal fluctuations.
- the potential for functional impacts associated with reduced percolation rates.
- retaining an unsaturated zone beneath the practice maintains the physical and biochemical water quality treatment benefits provided within the vadose zone.

- It should also be considered that where low permeability soils occur, seasonally saturated conditions may continue to occur post-development (i.e., irrespective of development-related longer term dewatering effects).

Recommendation 3: It is recommended that the practitioner shall complete a minimum of 1-year of required continuous groundwater elevation monitoring for all developments except for small scale development situations (e.g., severance, single lots). For single lots, continuous groundwater monitoring between March 1st and May 31st is sufficient to capture the groundwater elevation at the site.

Recommendation 4: Seasonally high groundwater conditions may not completely exclude the use of infiltration-based LIDs. Through the minimum of 1-year of continuous groundwater elevation monitoring, seasonal groundwater conditions can be assessed and may indicate that poor infiltration conditions may be limited to a single season (i.e. spring) and/or represent only a portion of the total year.

To the extent final post-development grades are anticipated to be higher, this should also be factored into the assessment.

The design of the infiltration-based LIDs which accounts for these seasonal impacts on the function of the LID due the higher water table conditions i.e. during the spring melt, is acceptable, provided:

- The loss of seasonal infiltration does not impact another design objective
- Does not impact a sensitive species or habitat
- Does not create unsafe conditions or risks to human health, infrastructure or public and/or private property

Note: The American Society of Civil Engineering (ASCE) North American Permeable Interlocking Concrete Pavement (68-18) standard provides structural design guidance for facilities that experience 0 to 120 days in a year when the Subbase has standing water (Wet Days).

While the presence of a seasonally high-groundwater may limit the feasibility of infiltration-based LIDs, it does not preclude the use of and does not necessarily limit the use of LIDs which utilize other mechanisms such as filtration, evapotranspiration (ET) and re-use as the primary processes.

	Infiltration	**ET**	**Re-use**	**LID Filtration**	**Filtration**	**Hydro-dynamic Separation**	**Sedimentation**
High groundwater	●	○	◘	◘	◘	◘	◘
○- Constraint does not limit or impact; ● -Constraint limits or impacts; ◘ - Constraint may limit or impact							

3.5.4 Groundwater Mounding

When the bottom of the LID facility cannot be vertically separated by a minimum of 1 m from the seasonally high-water table (and/or from the bottom of the LID facility to the top of bedrock elevation) or the following conditions cannot be met, a groundwater mounding analysis is required.

This is of particular importance in the context of water table and fine textured soils as it relates to the attraction of soil surfaces to water, which are strong in fine textured clays and silty clays and weaker in coarse-textured sands or sandy loams. This attraction, referred to as the matric potential, allows water to move up from the water table into the soils. Groundwater mounding describes the localized raising of the water table beneath infiltration practices. The separation between the base of the infiltrating practice and the water table should be modelled and the effect of groundwater mounding taken into consideration.

Recommendation: It is recommended that the practitioner perform a groundwater mounding analysis using the Simulation of Groundwater Mounding Beneath Hypothetical Stormwater Infiltration Basins by the USGS or equivalent (See **Resource Directory**). The practitioner should consider that saturated hydraulic conductivity estimates required as input to such modeling is best obtained through in-situ hydraulic testing (i.e. Guelph permeameter test, Double-ring infiltrometer test, Phillip-Dunn Infiltrometer, and others) or in-situ hydraulic testing of monitoring wells (e.g., Borehole permeameter slug tests) – all to the satisfaction of the City staff. It is recommended a groundwater mounding analysis is **not** required for the following conditions per Source: Environment Quality Act Modernization, Design standards for stormwater management (Draft 2017, Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques):

Criterion	Condition 1	Condition 2
Area of the infiltration practice bottom	≤ 10 m^2	≤ 25 m^2
Distance separating the infiltration practice bottom from the seasonal high-water table	≥ 2,0 m	≥ 2,0 m
Minimum saturated hydraulic conductivity of the subsoil within 1 m below infiltration practice bottom	≥ 15 mm/h (1)	≥ 40 mm/h (1)
(1) Before the safety factor being considered.		

Mounding of groundwater can be mitigated by including underdrain systems and correctly sizing and spacing of the pipes. In most large infiltrating LID systems lateral drains should be spaced between 5 – 6 m apart, but when groundwater mounding must be minimized, this distance will be reduced and should be recalculated.

3.5.5 Anticipated Groundwater Elevations After Implementation/Development

In limited circumstances the infiltration of rainfall and/or runoff could result in an elevated groundwater level after implementation which could impact critical utilities or private properties. While this condition has not been widely documented, it is reasonable for practitioners to consider such short or long-term effects.

Recommendation 1: It is recommended that the practitioner undertake a comprehensive hydrogeological study to definitively assess this condition. The identification of this condition through a comprehensive hydrogeological study, may limit the feasibility of infiltration-based LIDs, but it does not preclude the use of and does not necessarily limit the use of other mechanisms such as filtration, ET and re-use as the primary processes.

	Infiltration	ET	Re-use	LID Filtration	Filtration	Hydro-dynamic Separation	Sedimentation
Areas where increased infiltration will result in elevated groundwater levels which can be shown through an appropriate area specific study to impact critical utilities or property (i.e. susceptible to flooding)	●	○	◘	◘	◘	◘	◘
○- Constraint does not limit or impact; ● -Constraint limits or impacts; ◘ - Constraint may limit or impact							

3.5.6 Bedrock Offsets (Shallow Bedrock/Thin Soils) and Areas with Blasted Bedrock

The physiography of a proposed development site is a key determinant in the process of formulating strategies. In simplistic terms, physiographic characteristics such as topography and the characteristics of the soils and geology underlying the site dictate the potential to implement strategies that employ infiltration as the primary solution. Similarly, other hydrogeologic characteristics such as depth to water table (see **Section 3.5.3**) or depth to bedrock and the presence of areas of blasted bedrock (as discussed below) profoundly influence the feasibility of using various types of stormwater management facilities.

Shallow Bedrock

The Low Impact Development Stormwater Management Planning and Design Guide (wiki.sustainabletechnologies.ca) recommends that the bottom of the facility (i.e. invert) should be vertically separated by 1 m from the top of bedrock elevation. Shallow bedrock (thin soils) mapping (**Figure 2**) identifies that there are many areas of the City where a high degree of caution should be undertaken in the siting and planning of infiltration based LIDs.

Recommendation 1: It is recommended that the practitioner undertake site specific investigations where the site has areas with < 2.0 m of overburden. This accounts for the fact that most LIDs extend approx. 1.5 m BGS. The mapping included in the guidance document is cautionary and should only be used to flag areas where additional investigation may be necessary.

Recommendation 2: For sites where < 1.0 m separation from bottom of the LID facility (i.e. invert) to the top of bedrock elevation is anticipated, it is recommended that the practitioner undertake additional investigations and/or prepare documentation supporting a proposed design. This may include but is not limited to:

- Groundwater mounding analysis (see **Section 3.5.4**).
- Hydrogeological assessment

Regardless, other forms of LID which do not rely on infiltration (filtration, evapotranspiration and re-use) will typically be an option. To the extent that final post-development grades are anticipated to be higher, this should also be factored into the assessment.

Areas with Blasted Bedrock

Where shallow bedrock is encountered, development of the area in question may also involve blasting to allow placement of services and/or foundations, and the extent of blasting required may vary. The blasting of bedrock can create preferential pathways for infiltrated runoff and could lead to unintended consequences and impacts to private property and human health, specifically, basement flooding and possibly elevated contaminant levels beneath and within basement areas. Where blasting is more localized, this constraint may not be an issue elsewhere on the property.

While infiltration-based practices may be limited in blasted rock areas, other forms of LID, such as filtration, evapotranspiration, etc., are still viable options that should be pursued.

Recommendation 1: It is recommended that the practitioner prevent the infiltration of stormwater from the LID directly adjacent to areas of blasted rock where the horizontal offset from the excavation limit of the LID (i.e. trench wall) is less than 1.5m from the area of blasted rock to mitigate potential accumulation of infiltrated stormwater in trenches. Where the horizontal offset from the excavation limit of the LID is less than 1.5m, an impermeable liner shall be placed at the side walls and bottom of the excavation in accordance with the detail provided in **Figure 5**.

Recommendation 2: Site specific geotechnical and hydrogeological investigations will determine the required spatial extent in which the practitioner will prevent the infiltration of stormwater from the LID in development areas where:

- the need for blasting extends beyond trenching for installation of sewers and other utilities or services; or
- there are adjacent existing or planned residential buildings with basement floors located in blasted rock.

In these cases, an impermeable liner shall be placed at the side walls and bottom of the excavation.

	Infiltration	ET	Re-use	LID Filtration	Filtration	Hydro-dynamic Separation	Sedimentation
Shallow bedrock†	●	○	◘	◘	◘	◘	◘
Areas with blasted bedrock	●	○	◘	◘	◘	◘	◘
○- Constraint does not limit or impact; ● -Constraint limits or impacts; ◘ - Constraint may limit or impact							

† May limit infiltration capabilities if bedrock is within 1m of the proposed facility invert.

3.5.7 Karst (Macro and Micro Karst)

In general, Karst will represent a constraint where shallow bedrock is also present on a site. The Low Impact Development Stormwater Management Planning and Design Guide (wiki.sustainabletechnologies.ca) describes the potential dangers of karst formations, in which there are undetected sinkholes, trenches and caverns. Karst is a hydrogeologically sensitive unit. Infiltration via karst features may:

- Impact existing well users due to fast infiltration with little or no quality control, resulting in stormwater becoming a potential source of contamination.
- Impact existing structures, infrastructure and or public or private property, as the subsurface flow path often cannot be mapped or is not fully understood.

In areas where karst or micro-karst are known or suspected to exist, as shown in **Figure 4,** a full assessment of the potential impacts of infiltrating rainwater and/or runoff should be undertaken.

Recommendation 1: If there is sufficient filtration or unsaturated overburden present, karst is not considered a constraint to LID implementation; however, it is recommended that the practitioner undertake a site-specific investigation to confirm the site conditions if karst is suspected. Similarly, if there are significant sequences of saturated overburden overlying the karst and this condition will still be true post-development, the presence of the karst feature may not be limiting.

Recommendation 2: if thin soils over karst are present at a site, it is recommended that the practitioner undertake additional investigations to confirm the site conditions. If unsaturated karst is identified, infiltration should not be promoted.

While the presence of a karst/ micro-karst may limit the feasibility of infiltration-based LIDs, it does not preclude the use of and does not necessarily limit the use of other mechanisms such as filtration, evapotranspiration (ET) and re-use as the primary processes.

	Infiltration	ET	Re-use	LID Filtration	Filtration	Hydro-dynamic Separation	Sedimentation
Karst / Micro-karst	●	○	◘	◘	◘	◘	◘
○- Constraint does not limit or impact; ● -Constraint limits or impacts; ◘ - Constraint may limit or impact							

3.5.8 Areas with private services (shallow wells)

Areas where new development is planned where there are existing homes on private services need to consider the potential for unwanted impacts to groundwater that may serve as the drinking water source for some of all of the existing groundwater users. This is of particular concern where relatively shallow private water wells may occur, or more rapid groundwater transport may occur due to preferential pathways (e.g., fractured bedrock).

Recommendation: Where proper filtration of stormwater can be demonstrated and the risk to drinking water wells can be shown to be minimized, particularly for transient pollutants such as winter de-icing compounds (i.e. salts), infiltration-based LID should not be precluded. Consideration for the specific location of the LIDs within the site and in the context of the proposed development type should be considered. For example, sodium and chloride ions in de-icing salts applied to asphalt areas travel easily with the runoff water. City of Ottawa protocols do not include road salting on internal residential roads unless there is an ice storm, therefore the contamination risk of private drinking water well from de-icing compounds in a residential roads setting will be minimal.

3.5.9 Brownfield Developments

Brownfields are defined as undeveloped or previously developed properties that may be contaminated. They are usually, but not exclusively, former industrial or commercial properties that may be underutilized, derelict or vacant. An Environmental Site Assessment (ESA) is required to develop Brownfield sites. These sites are different from Greyfield sites, which are previously developed sites that are known or have been shown not to be contaminated.

Recommendations - Due to contamination risk to groundwater and/or mobilization of the contaminants off-site, infiltration practices are not recommended for sites with anthropogenically contaminated soils that may pose a leaching concern to groundwater and these have not been fully remediated, or sites with high risk of contamination from onsite activities because of the associated.

Recommendation 1: It is recommended that the use of infiltration-based LID within non-remediated sites with contaminants that may leach to groundwater shall be prohibited due to the possibility and risk of mobilizing the contaminants.

Recommendation 2: LID <u>filtration</u> practices may be permitted where facilities are designed with an impermeable liner which prevents runoff from transporting soil contaminants.

Recommendation 3: if remediation is to occur as part of the site development activities which will remove the contamination and/or reduce the risk to groundwater and/or mobilization of the contaminants off-site, then infiltration-based LID may be permitted.

Catchment areas with contaminated soils and high-risk site activities do not preclude the use of those LID BMPs that utilize filtration, evapotranspiration or re-use as the primary processes. Additionally, catchment areas that are isolated from the respective contaminants and/or high-risk site activities such are generally considered safe and should not be excluded from infiltration.

	Infiltration	**ET**	**Re-use**	**LID Filtration**	**Filtration**	**Hydro-dynamic Separation**	**Sedimentation**
Contaminated soils (i.e. Brownfields)	●	○	○	○	○	○	◘
○ Constraint does not limit or impact; ● Constraint limits or impacts; ◘ Constraint may limit or impact							

3.5.10 Other Considerations

3.5.10.1 Lining LIDs (Infiltration vs . Filtration)

LID measures that are infiltration based provide groundwater recharge, improve water quality, reduce erosion, and attenuate runoff, among other benefits. In situations where infiltration is not possible due to in-situ conditions, such as brownfield development (**Section 3.5.9**) or areas of blasted rock (**Section 3.5.6**), the LID measure can still be implemented with the incorporation of a liner. This liner prevents native material from entering the LID, as well as preventing the filtered water from infiltrating into the native soil or blasted rock. The addition of the impermeable liner allows for a partial water balance benefit and partial erosion control due to some volume reduction through evapotranspiration. The water quality improvement is the same, with or without the liner as the runoff is filtered as it passes through the media.

3.5.10.2 Developments with Sump-Pump Discharge to Sewer

For sites where foundation drainage via sump pump is present, or proposed as part of the development, best practices require that stormwater be kept away from the foundation area to minimize the volume of water intercepted by foundation drains, and consequently reduce the risk of basement flooding.

Recommendation: where sump pump systems are or will be present, infiltration-based LID measures should be placed away from building footprints to limit the ingress of stormwater to the foundation and sump. In situations such as these, low permeability material is typically placed on the ground surface around the building foundation. Infiltration-based LID measures may still be implemented away from building footprints, as well as other LID options. It is recommended that a minimum offset of 4 m per the Ontario Building Code (OBC) (Note: min. 3 m is permissible if an impermeable liner is used) from building foundation with livable basements areas and/or mechanical rooms and/or underground utilities, be maintained per the Low Impact Development Stormwater Management Planning and Design Guide (wiki.sustainabletechnologies.ca).

3.5.10.3 Other Constraints

In addition to the constraints discussed above, a number of other constraints may occur, as outlined in the Table below. Potential constraints such as these will typically require additional attention and analysis when completing the pre-development hydrogeological investigation. Individuals competent to assess these potential risks should participate in and direct the investigations to the extent necessary.

The table below summarizes the impact of these constraints on different aspects of LID and stormwater management, including infiltration, evapotranspiration, re-use, LID filtration, and filtration.

Impact of Other Constraints on LID Methods

Constraint	Constraint Limits or Impacts Implementation				
	Infiltration	**ET**	**Re-use**	**LID Filtration**	**Filtration**
a) Shrinking clays or unstable sub-soils	◘	○	○	○	○
b) High Risk Site Activities including spill prone areas	●	○	○	○	○
c) Prohibitions and or restrictions per the approved Source Protection Plans and where impacts to private drinking water wells cannot be appropriately mitigated	●	○	○	○	○
d) Flood risk prone areas or structures and/ or areas of high inflow and infiltration (I/I) where wastewater systems (storm and sanitary) have been shown through technical studies to be sensitive to groundwater conditions that contribute to extraneous flow rates that cause property flooding / sewer back-ups and where LID BMPs have been found to be ineffective	◘	○	○	○	○
e) For existing Linear Developments where reconstruction is proposed and where available surface and subsurface areas is not available based on a site-specific assessment completed by a qualified person	◘	◘	n/a	◘	◘

f) For developments within partially separated wastewater systems where reconstruction is proposed and where based on a site-specific assessment completed by a qualified person can be shown to: a. Increase private property flood risk liabilities that cannot be mitigated through design, b. Impact pumping and treatment cost that cannot be mitigated through design.	●	○	○	○	○
g) Surface water dominated or dependant features including but not limited to marshes and/or riparian forest wetlands which derive all or a majority of their water from surface water, including streams, runoff, and overbank flooding. Surface water dominated or dependant features which are identified through approved site specific hydrologic or hydrogeologic studies, and/or Environmental Impact Statements (EIS) may be considered for a reduced volume control target. Pre-consultation with the MOECC and local agencies is required	◘	◘	◘	◘	○
h) Existing urban areas where risk to water distribution systems has been identified and substantiated by a qualified person through an appropriate area specific study and where the risk cannot be reasonably mitigated per the relevant design guidelines	◘	○	○	○	○
i) Existing urban areas where risk to life, human health, property or infrastructure has been identified and substantiated by a qualified person through an appropriate area specific study and where the risk cannot be reasonably mitigated per the relevant design guidelines	◘	◘	◘	◘	◘
j) Water reuse feasibility study has been completed to determine non-potable reuse of stormwater for onsite or shared use. Potable reuse may be considered on case specific basis	○	○	●	○	○
○- Constraint does not limit or impact; ● -Constraint limits or Impacts; ◘ - Constraint may limit or impact					

3.6 Approvals Considerations

Section 53 of the OWRA requires that an approval must be obtained in order to establish, use and operate, alter, extend or replace any sewage works (sewage works are defined as works used for the collection, transmission treatment or disposal of sewage or any part of such work, but not including plumbing to which the *Building Code Act,* 1992 applies). Under the OWRA, sewage includes drainage, stormwater, commercial wastes and industrial wastes and such other matter or substance as is specified by the regulations. An approval is needed to use, operate, establish, alter, extend or replace a new or existing sewage works unless specifically exempted, under either s. 53 or O. Reg. 525/98. (OWRA, s. 53). Approvals are issued under EPA 20.2.

Operations that require an approval include:

- Stormwater management facilities (including LID); and
- Storm sewers

Everything that discharges stormwater or drainage (i.e. sewage) requires approval unless specifically **exempted**. In general, the need for, and nature of, an approval depends on the site and the activity. However, specific exemptions for certain types of sewage works equipment, system and application have been granted through legislation. The OWRA and Approval Exemption Regulation (O.Reg. 525/98) exempt minor sewage works from the approval requirements of the Act.

Under the O.Reg. 525/98 **Approval Exemptions**, the use, operation, establishment, alteration, extension or replacement of or a change to stormwater management facility can be exempted from requiring an ECA if **all** of the following applicable conditions are met. A stormwater management facility is defined as a facility for the treatment, retention, infiltration or control of stormwater. More specifically, an ECA is not required if the stormwater management facility (i.e. the works) are:

1. designed to service one lot or parcel of land (land cannot be part of an original larger stormwater management system); AND
2. discharging into a storm sewer that is not a combined sewer; AND
3. not servicing industrial land or a structure located on industrial land; AND
4. not located on industrial land.

Industrial lands are defined as lands used for the production, process, repair, maintenance or storage or goods or materials, or the processing, storage, transfer or disposal of waste, but does not include lands used primarily for the purpose of buying or selling,

5. goods or materials other than fuel, or
6. services other than vehicle repair services

Other approval exemptions under Section 53 include:

7. drainage works under the Drainage Act or a sewage works where the main purpose of the work is to drain land for the purposes of agricultural activity;
8. drainage works under the *Cemeteries Act*, the *Public Transportation and Highways Improvement Act* or the *Railway Act.*
9. Routine maintenance per Section 53 (6) (0.a).

A final approval exemption includes:

10. Vegetated filter strip system that manages runoff as part of an agricultural operation per Reg. 525/98 s. 3.2.

If the site is located within an MVCA, RVCA, or SNC regulated area the LID will be subject to permitting under the Conservation Authorities Act.

To obtain an ECA through the City of Ottawa Transfer of Review (ToR) agreement with MECP, the proposed LID must comply with the following conditions:

1. Achieve 80% TSS (stand-alone or as part of treatment train); and,
2. There are no wells within the drainage area.

If the LID achieves less than 70% TSS removal, the application must be a Direct Submission to the MECP.

3.7 Examples

Seven (7) LID projects from across Ontario have been summarized in **Appendix C** that demonstrate LID implementation feasibility in locations with hydrogeological constraints.

These examples include:

- High groundwater – Aurora Community Center, Aurora; Hemmingwood Way, Ottawa
- Low Hydraulic Conductivity – Various
- Groundwater Mounding – Hazeldean Road, Ottawa
- Flat Topography – Brampton Flight Centre/Hamilton Airport, Cheltenham & Hamilton
- Brownfields – John Rebecca Park, Hamilton
- Lining LIDs – Brownfield Park Redevelopment
- Bedrock – IMAX

4.0 Summary

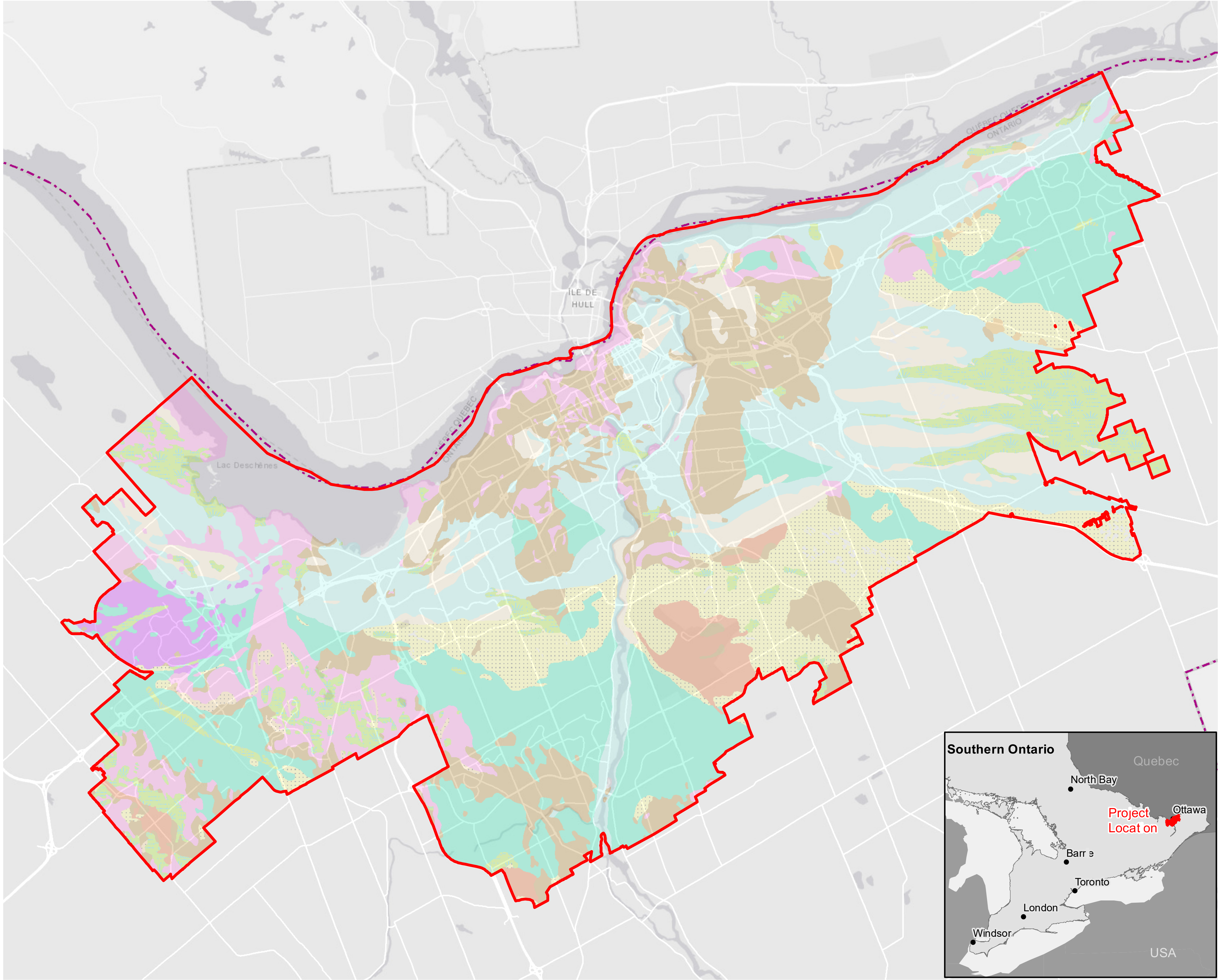
Pre-consultation is critical component of LID implementation. The design practitioner is advised to pre-consult with the City of Ottawa to understand their requirements and/or expectations prior to undertaking work, and to complete an appropriate level of analysis to support their conclusion. The City of Ottawa has many areas where hydrogeologic constraints will be encountered; however, site investigations completed early in the design process ensure that constraints can be identified and the selected LID measure can function as intended to meet the City and Ministry requirements.

5.0 Closure

This report was prepared exclusively for the purposes, project and site locations outlined in the report. The report is based on information provided to, or obtained by Dillon Consulting Limited (Dillon) or our sub-consultant, Aquafor Beech Limited, as indicated in the report. The report represents a reasonable review of available information within an agreed work scope, schedule and budget. Further review and updating of the report may be required as local and site conditions, and the regulatory and planning frameworks, change over time.

This report was prepared by Dillon our sub-consultant, Aquafor Beech Limited, for the sole benefit of our Client, the City of Ottawa. The material in it reflects our best judgment in light of the information available at the time of preparation. Any use which a third party makes of this report, or any reliance on or decisions made based on it, are the responsibilities of such third parties. Dillon and Aquafor Beech accept no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report.

Figures



CITY OF OTTAWA

LID IMPLEMENTATION WORKSHOP

PROJECT LOCATION AND SURFICIAL GEOLOGY

FIGURE 1

- Urban Area Boundary
- City of Ottawa Boundary
- Road
- glacial, diamicton
- colluvial, diamicton
- glaciofluvial, sand, gravel
- wetland, organic deposits
- fluvial, clay, silt, sand
- fluvial, sand, silt

Primary Genesis & Material

- glaciomarine, clay, silt
- glaciomarine, clay, silt, sand
- glaciomarine, sand
- glaciomarine, sand, gravel
- Unknown , Paleozoic Bedrock
- Unknown , Precambrian Bedrock

Note:
Data and symbolization provided by the City of Ottawa.

0 0.5 1 2 km

SCALE 1:140,000

N W E S

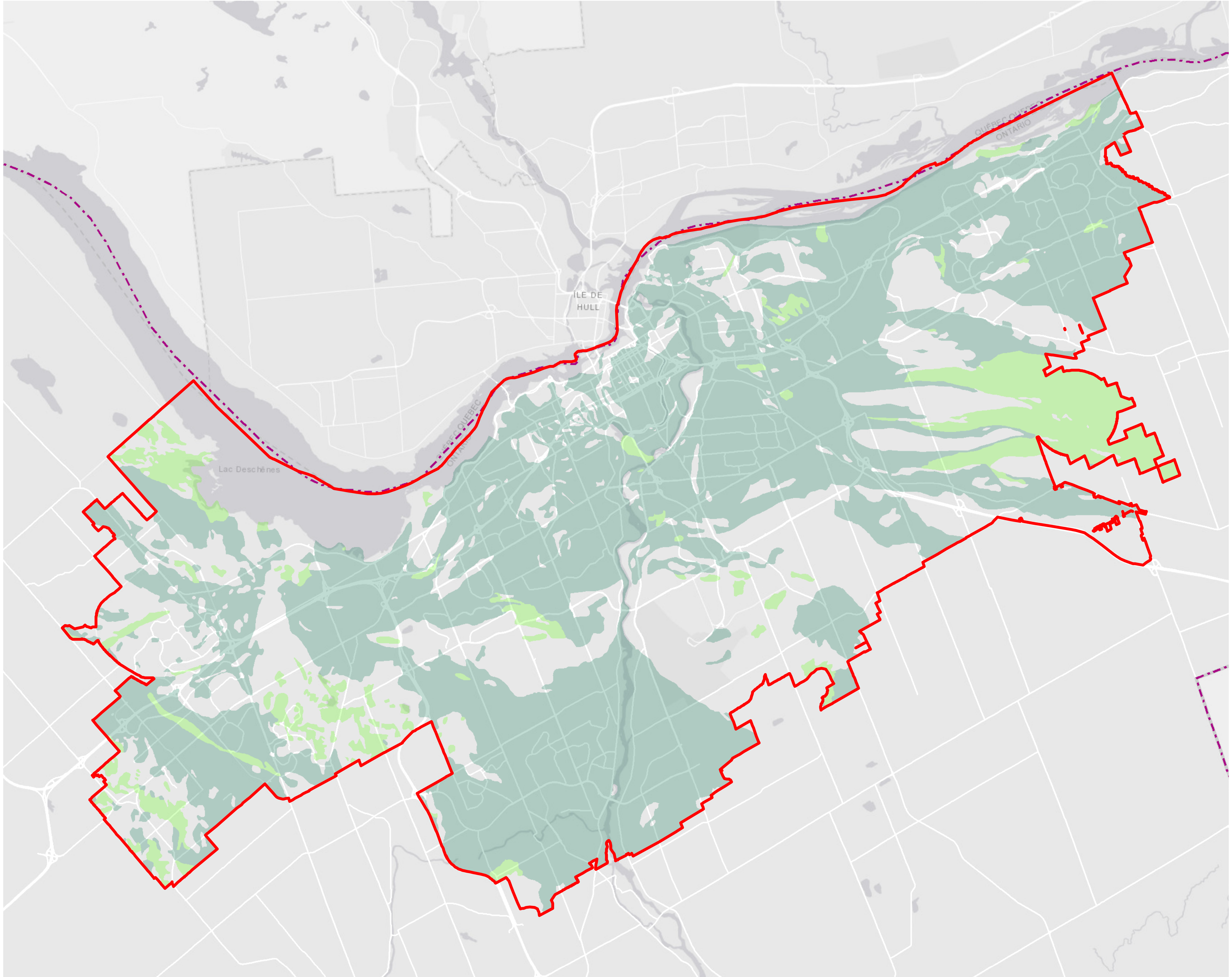
MAP DRAWING INFORMATION:
DATA PROVIDED BY MNRF, CITY OF OTTAWA,
SURFICIAL GEOLOGY, ONTARIO GEOLOGICAL SURVEY (OGS), 2003.

MAP CREATED BY: LK
MAP CHECKED BY: KR
MAP PROJECTION: NAD 1983 UTM Zone 18N

DILLON CONSULTING

PROJECT: 19-9237
STATUS: DRAFT
DATE: 2019-09-18

FILE LOCATION: I:\GIS\199327 - LID Implementation Ottawa\MXD\Fig1_OttawaSoils_CitySymbolization.mxd



CITY OF OTTAWA

LID IMPLEMENTATION WORKSHOP

LOW PERMEABILITY AND WETLAND AREAS

FIGURE 2

- Urban Area Boundary
- City of Ottawa Boundary
- Road
- Low Permeability
- Wetland, Organic Deposits

Note:
Low permeability soils are defined by material classified as diamicton or glaciomarine sediments.

0 0.5 1 2 km

SCALE 1:140,000

N E S W

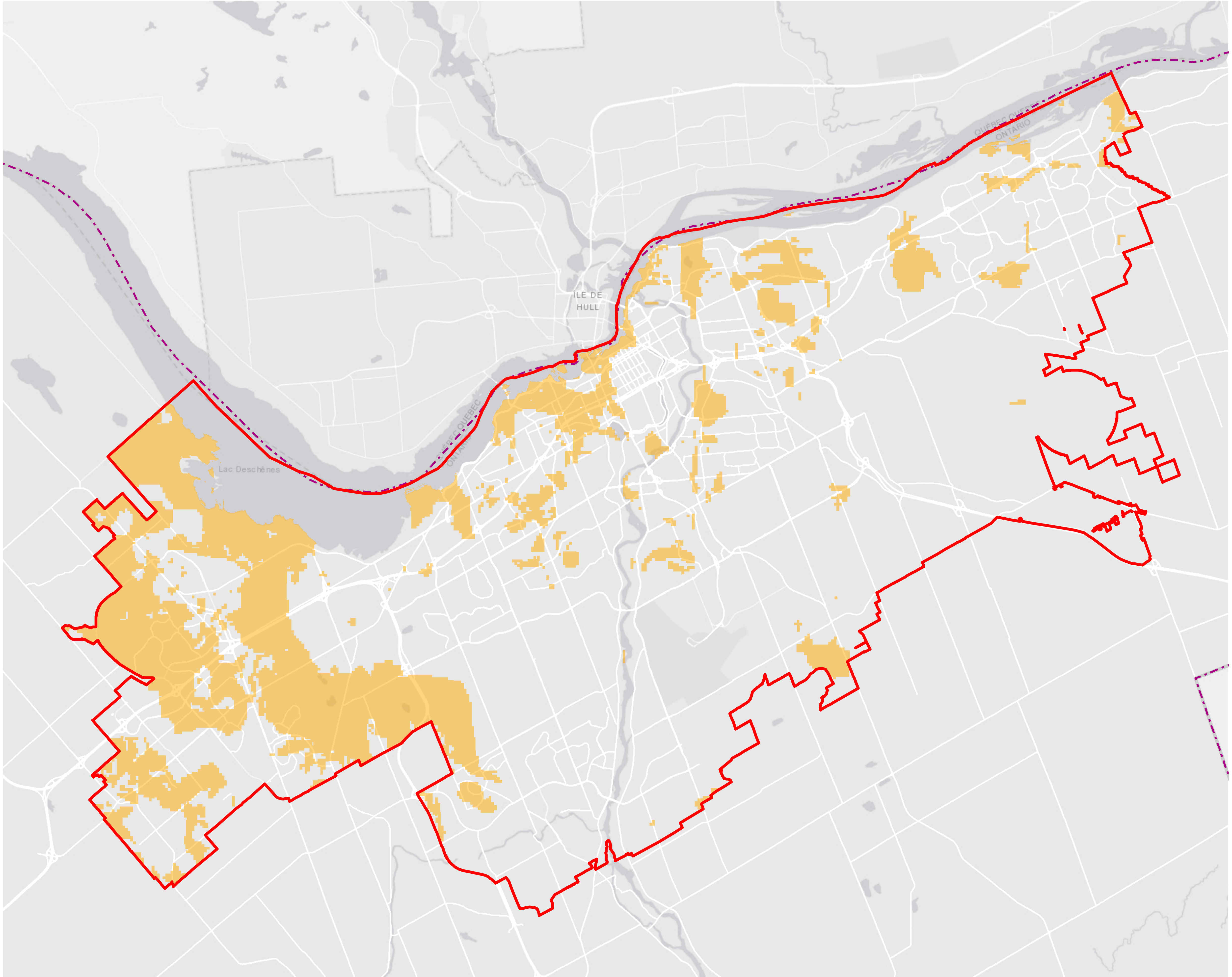
MAP DRAWING INFORMATION:
DATA PROVIDED BY MNRF, CITY OF OTTAWA,
SURFICIAL GEOLOGY, ONTARIO GEOLOGICAL SURVEY (OGS), 2003.

MAP CREATED BY: LK
MAP CHECKED BY: KR
MAP PROJECTION: NAD 1983 UTM Zone 18N

DILLON CONSULTING

PROJECT: 19-9237
STATUS: DRAFT
DATE: 2019-09-18

FILE LOCATION: I:\GIS\199327 - LID Implementation Ottawa\MXD\Fig3_LowPermWetland.mxd



CITY OF OTTAWA

LID IMPLEMENTATION WORKSHOP

SHALLOW BEDROCK

FIGURE 3

- Urban Area Boundary
- City of Ottawa Boundary
- Road
- Shallow Bedrock (0 - 1 m)

Notes:
Shallow bedrock data (0-1m drift thickness) was derived by the City of Ottawa using the following data sets:
- Bedrock Topography and Overburden Thickness Mapping, Ontario Geological Survey, 2006.
- Urban Geology of the National Capital Region, Geological Survey of Canada, 2001.
- LIDAR topography, City of Ottawa, 2012-2015.

0 0.5 1 2 km

SCALE 1:140,000

N
W E
S

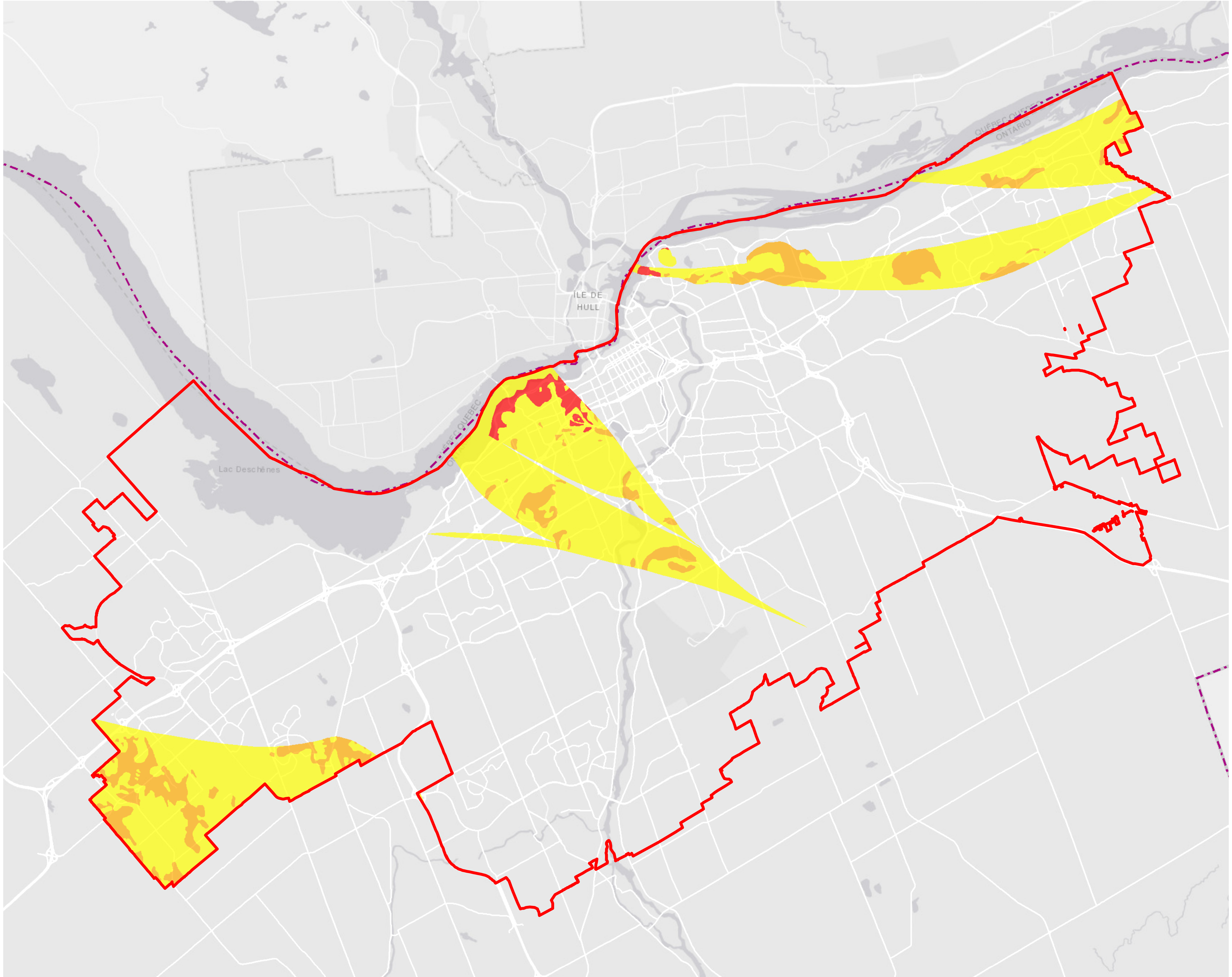
MAP DRAWING INFORMATION:
DATA PROVIDED BY MNRF, CITY OF OTTAWA,
SURFICIAL GEOLOGY, ONTARIO GEOLOGICAL SURVEY (OGS), 2003.

MAP CREATED BY: LK
MAP CHECKED BY: KR
MAP PROJECTION: NAD 1983 UTM Zone 18N

DILLON CONSULTING

PROJECT: 19-9237
STATUS: DRAFT
DATE: 2019-09-18

FILE LOCATION: I:\GIS\199327 - LID Implementation Ottawa\MXD\Fig2_ShallowBedrock.mxd



CITY OF OTTAWA

LID IMPLEMENTATION WORKSHOP

AREAS WITH KARST GEOLOGY

FIGURE 4

- Urban Area Boundary
- City of Ottawa Boundary
- Road
- Known Karst
- Inferred Karst
- Potential Karst

Note:
Data and symbolization provided by the City of Ottawa.

0 0.5 1 2 km

SCALE 1:140,000

N S E W

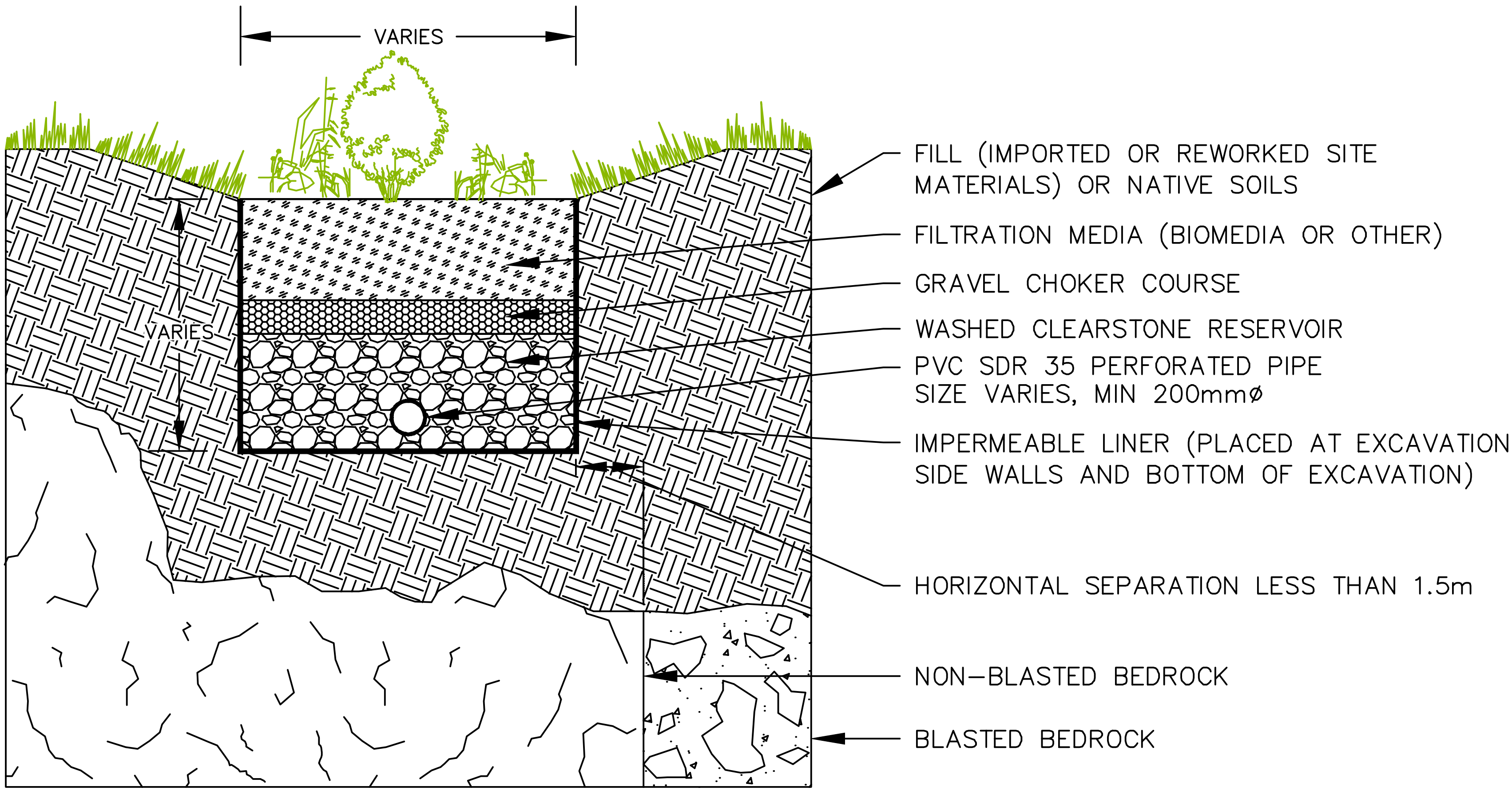
MAP DRAWING INFORMATION:
DATA PROVIDED BY MNRF, CITY OF OTTAWA,
KARST GEOLOGY, ONTARIO GEOLOGICAL SURVEY (OGS), 2003.

MAP CREATED BY: LK
MAP CHECKED BY: KR
MAP PROJECTION: NAD 1983 UTM Zone 18N

DILLON CONSULTING

PROJECT: 19-9237
STATUS: DRAFT
DATE: 2019-09-18

FILE LOCATION: I:\GIS\199327 - LID Implementation Ottawa\MXD\Fig4_AreasWithKarstGeology.mxd



NOTES:

1. IMPERMEABLE LINER TYPES INCLUDE EPDM (ETHYLENE PROPYLENE DIENE MONOMER), GCL (GEOSYNTHETIC CLAY LINER), RPE (REINFORCED POLYETHYLENE), PVC (POLY VINYL CHLORIDE), OR OTHERS AS APPROVED. IMPERMEABLE LINER SEAMS SHALL BE SEALED PER MANUFACTURER SPECIFICATIONS.
2. IMPERMEABLE LINER MUST BE USED WHEN THERE IS A VERTICAL OR HORIZONTAL SEPARATION OF LESS THAN 1.5m FROM BLASTED ROCK

Aquafor Beech Limited
#6-202-2600 SKYMARK Ave, MISSISSAUGA, ONTARIO, L4W 5B2
PHONE: (905) 629-0099, FAX: (905) 629-0089

BIORETENTION DETAIL FOR HORIZONTAL SEPARATION FROM BLASTED BEDROCK LESS THAN 1.5m

STANDARD DETAIL	
APPROVED:	DWG No.: 5
REVISION No.: 1	
DATE: 2020-02-20	

Appendix A

LID in Areas of Sensitive Marine (Leda) Clay (Thurber, 2019)

September 17, 2019 File: 26131

Matthew McCurdy
Dillon Consulting Limited
177 Colonnade Road South, Suite 101
Ottawa, Ontario
K2E 7J4

GEOTECHNICAL INPUT
LOW-IMPACT DEVELOPMENT (LID) IN AREAS OF SENSITIVE MARINE (LEDA) CLAY
OTTAWA, ONTARIO

Dear Mr. McCurdy:

The following letter presents geotechnical input for a Low-Impact Development (LID) study currently being undertaken by Dillon Consulting Limited (Dillon) for the City of Ottawa (the City). Specifically, this letter addresses potential geotechnical implications of LID in areas underlain by sensitive marine (Leda) clay.

It is a condition of this report that Thurber's performance of its professional services is subject to the attached Statement of Limitations and Conditions.

1. PHYSIOGRAPHIC SETTING

The City of Ottawa is located within a physiographic region known as the Ottawa Valley Clay Plain (Chapman and Putnam, 1984), which is characterised by a deposit of sensitive marine clay. This deposit, also known as Champlain Sea clay or Leda clay, varies in thickness from a metre or less to depths in excess of 60 m (Belanger and Harrison, 1980). Where present, the clay deposit is typically underlain by thin deposits of silt and sand and glacial till. For current surficial geology mapping of the Ottawa area, the reader is referred to the "Urban Geology of the National Capital Area" published by the Geological Survey of Canada (Belanger, 2008). It is noted that areas of the mapping indicated to consist of sand may be underlain by Leda clay. In areas of existing development, the clay is typically overlain by fill material.

In general, the upper portion of the marine clay deposit has been weathered/desiccated to a stiff to very stiff grey-brown crust (i.e., the weathered crust). Beneath the weathered crust, the clay is saturated, grey in colour, and generally soft to firm in consistency. The transition between the weathered crust and the grey clay typically coincides with the 'permanent' pre-development groundwater level (i.e., the grey clay has always been saturated). In some areas, particularly on the eastern side of the City, the clay deposit is overlain by a thin layer of sand (i.e., a sand cap). In these areas, the weathered crust can be absent, with the sand cap directly overlying soft to firm grey clay. In general, the softest portion of the grey clay is directly beneath the weathered crust (or sand cap) and the clay gradually becomes more stiff with depth.

Leda Clay has a very low hydraulic conductivity and poor drainage characteristics; water does readily infiltrate into clay.

2. ASSUMPTIONS

For the purpose of this memo, it is assumed that LID would be incorporated into the City right-of-way and could include such features as bioretention areas or infiltration trenches/chambers, and possibly permeable pavements.

It is noted that incorporating LID into the City right-of-way alone would likely only have local effects with respect to the issues discussed below. On a development scale, LID would also need to be incorporated on the private lots to attain widespread impacts.

3. GEOTECHNICAL INPUT

The implementation of LID tends to result in a higher groundwater level compared to traditional development practices, usually with the intention of maintaining the pre-development groundwater level (as much as practical).

Leda clay presents several geotechnical issues that are impacted by changes in the groundwater level. Raising the groundwater level can have both positive and negative impacts depending on the issue that is being considered. The following sections present a discussion on the geotechnical issues associated with Leda clay and considerations for the implementation of LID.

3.1 Issues that are Positively Impacted by LID

3.1.1 Consolidation Settlement

If Leda clay is overstressed (loaded such that the vertical effective stress within the soil exceeds the clay's preconsolidation pressure), the resulting consolidation settlement can be significant, often in the range of 10 to 50 cm, or higher, depending on the thickness of clay that is subjected to consolidation. Since the process of primary consolidation requires dissipation of excess porewater, and the long drainage paths associated with a thick clay deposit, the primary consolidation process can take years to complete, often in the range of 3 to 7 years. Following primary consolidation, secondary consolidation (creep) will continue indefinitely with a decaying rate of settlement.

Due to the significant issues associated with this potential level of settlement, it is common practice to limit the loading on a site such that the preconsolidation pressure is not exceeded. Even when load increases are kept below the preconsolidation pressure, settlement can occur. The factors that need to be considered in a geotechnical assessment of the allowable loading on a deposit of Leda clay include: foundation loading from structures, grade raise fill (i.e., a permissible grade raise), and the potential for post-development groundwater level lowering. Permanently lowering the groundwater level reduces the natural buoyant force within the soil fabric and thereby increases the vertical effective stress, which can overstress the clay and result in consolidation settlement.

Since LID tends to maintain a higher groundwater level, the implementation of LID would decrease the risk of consolidation settlement, which is favourable. Notwithstanding this assessment, some post-development groundwater level lowering should still be assumed by the geotechnical engineer in the assessment of the permissible grade raise to account for potentially dry seasons and the potential for deeper sewer pipes to create a drainage path that could permanently lower the groundwater level below pre-development levels, as well as the fact that the effects of LID on the groundwater level may be localized around the LID features.

3.1.2 Foundation Settlement due to Soil Shrinkage

Leda clay retains a high water content in its natural state and exhibits large volume shrinkage upon drying (Bozozuk, 1962). This is a common issue where high water demand trees are planted in close proximity to a structure, with the resulting soil shrinkage causing foundation damage during periods of dry weather. Bozozuk (1962) also states that the construction of 'paved streets and sewers which intercept and drain away surface water cause the soils to dry out gradually and to shrink', which manifest as differential settlement of the streetscape including sidewalks and pavements.

Currently, tree planting on development sites is required to conform to the City's "Tree Planting in Sensitive Marine Clay Soils – 2017 Guidelines", which is aimed at reducing the risk of foundation settlement due to soil shrinkage by specifying setbacks and tree planting restrictions.

Since LID tends to maintain a higher groundwater level, the implementation of LID would decrease the risk of foundation settlement due to soil shrinkage, which is favourable. At this time, changes to the City's tree planting policy are not recommended, since the groundwater level could still lower during prolonged periods of dry weather and since widespread use of LID on private lots may be required to be able to rely upon a higher groundwater level. Further studies in this regard may allow for some future moderation of the City's tree planting policy.

3.2 Issues that are Negatively Impacted by LID

3.2.1 Slope Stability

One of the defining characteristics of Leda clay is that it is sensitive to disturbance (also known as a 'quick' clay), meaning that the undisturbed shear strength of the soil is much higher than the remoulded (or disturbed) shear strength. This issue can result in catastrophic retrogressive slope failures (landslides), which often originate at a slope that has been over-steepened by erosion or human activity and is often triggered, in part, by an elevated groundwater level in the slope.

Currently, development applications in the City of Ottawa are required to submit a geotechnical report that assesses slope stability in accordance with the document "Slope Stability Guidelines for Development Applications in the City of Ottawa", which recommends that the geotechnical engineer assume that the slope is fully saturated to account for the worst-case condition that can be encountered during the spring snowmelt and/or during periods of sustained heavy rainfall. The guidelines also prohibit development within the 'Limit of Hazard Lands', which is the setback distance between the development and the crest of the unstable slope.

With respect to LID, the geotechnical slope stability analyses that are typically carried out for a site should already assume the worst-case groundwater condition (full saturation); therefore, LID is not expected to impact the assessment of slope stability; however, it is noted that LID could unnecessarily increase the risk of slope failure by contributing to a fully saturated condition. To limit this risk, no LID features should be permitted within the Limit of Hazard Lands.

3.2.2 Frost Susceptibility – Road performance

Leda clay is considered frost susceptible and adequate drainage of the granular pavement structure beneath the asphalt paving is critical to pavement performance. Therefore, LID features should be designed such that water is allowed to drain away from the pavement structure, which typically extends to at least 0.65 m below grade for residential streets (the minimum City pavement structure thickness) to as much as 1.0 m for arterial roadways. Otherwise, if water is allowed to accumulate in the pavement structure, significant frost related damage to the pavement should be expected.

It is also noted that the clay subgrade may soften if it is saturated due to being in close proximity to LID features. A geotechnical engineer should be involved in the LID design to provide guidance on potential impacts to road performance. It may be necessary to account for a saturated subgrade in the pavement design, or to offset the LID feature from the roadway.

4. SUMMARY

The implementation of LID has both positive and negative effects with respect to the geotechnical issues associated with Leda clay. Generally, these factors are unlikely to significantly affect the feasibility of including LID features in a development, and overall will likely have a net benefit, provided that the design allows for adequate drainage of the pavement structure and the LID features are located outside the Limit of Hazard Lands.

5. CLOSURE

We trust this letter provides the information you require at this time. If you have any questions regarding this letter, please contact either of the undersigned at your earliest convenience.

Yours truly,
Thurber Engineering Ltd

Stephen Dunlop, P. Eng.
Senior Geotechnical Engineer

Paul Carnaffan, P.Eng.
Principal, Branch Manager

Attachments: Statement of Limitations and Conditions
References

THURBER

References:

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THURBER

STATEMENT OF LIMITATIONS AND CONDITIONS

1. STANDARD OF CARE

This Report has been prepared in accordance with generally accepted engineering or environmental consulting practices in the applicable jurisdiction. No other warranty, expressed or implied, is intended or made.

2. COMPLETE REPORT

All documents, records, data and files, whether electronic or otherwise, generated as part of this assignment are a part of the Report, which is of a summary nature and is not intended to stand alone without reference to the instructions given to Thurber by the Client, communications between Thurber and the Client, and any other reports, proposals or documents prepared by Thurber for the Client relative to the specific site described herein, all of which together constitute the Report.

IN ORDER TO PROPERLY UNDERSTAND THE SUGGESTIONS, RECOMMENDATIONS AND OPINIONS EXPRESSED HEREIN, REFERENCE MUST BE MADE TO THE WHOLE OF THE REPORT. THURBER IS NOT RESPONSIBLE FOR USE BY ANY PARTY OF PORTIONS OF THE REPORT WITHOUT REFERENCE TO THE WHOLE REPORT.

3. BASIS OF REPORT

The Report has been prepared for the specific site, development, design objectives and purposes that were described to Thurber by the Client. The applicability and reliability of any of the findings, recommendations, suggestions, or opinions expressed in the Report, subject to the limitations provided herein, are only valid to the extent that the Report expressly addresses proposed development, design objectives and purposes, and then only to the extent that there has been no material alteration to or variation from any of the said descriptions provided to Thurber, unless Thurber is specifically requested by the Client to review and revise the Report in light of such alteration or variation.

4. USE OF THE REPORT

The information and opinions expressed in the Report, or any document forming part of the Report, are for the sole benefit of the Client. NO OTHER PARTY MAY USE OR RELY UPON THE REPORT OR ANY PORTION THEREOF WITHOUT THURBER'S WRITTEN CONSENT AND SUCH USE SHALL BE ON SUCH TERMS AND CONDITIONS AS THURBER MAY EXPRESSLY APPROVE. Ownership in and copyright for the contents of the Report belong to Thurber. Any use which a third party makes of the Report, is the sole responsibility of such third party. Thurber accepts no responsibility whatsoever for damages suffered by any third party resulting from use of the Report without Thurber's express written permission.

5. INTERPRETATION OF THE REPORT

a) Nature and Exactness of Soil and Contaminant Description: Classification and identification of soils, rocks, geological units, contaminant materials and quantities have been based on investigations performed in accordance with the standards set out in Paragraph 1. Classification and identification of these factors are judgmental in nature. Comprehensive sampling and testing programs implemented with the appropriate equipment by experienced personnel may fail to locate some conditions. All investigations utilizing the standards of Paragraph 1 will involve an inherent risk that some conditions will not be detected and all documents or records summarizing such investigations will be based on assumptions of what exists between the actual points sampled. Actual conditions may vary significantly between the points investigated and the Client and all other persons making use of such documents or records with our express written consent should be aware of this risk and the Report is delivered subject to the express condition that such risk is accepted by the Client and such other persons. Some conditions are subject to change over time and those making use of the Report should be aware of this possibility and understand that the Report only presents the conditions at the sampled points at the time of sampling. If special concerns exist, or the Client has special considerations or requirements, the Client should disclose them so that additional or special investigations may be undertaken which would not otherwise be within the scope of investigations made for the purposes of the Report.

b) Reliance on Provided Information: The evaluation and conclusions contained in the Report have been prepared on the basis of conditions in evidence at the time of site inspections and on the basis of information provided to Thurber. Thurber has relied in good faith upon representations, information and instructions provided by the Client and others concerning the site. Accordingly, Thurber does not accept responsibility for any deficiency, misstatement or inaccuracy contained in the Report as a result of misstatements, omissions, misrepresentations, or fraudulent acts of the Client or other persons providing information relied on by Thurber. Thurber is entitled to rely on such representations, information and instructions and is not required to carry out investigations to determine the truth or accuracy of such representations, information and instructions.

c) Design Services: The Report may form part of design and construction documents for information purposes even though it may have been issued prior to final design being completed. Thurber should be retained to review final design, project plans and related documents prior to construction to confirm that they are consistent with the intent of the Report. Any differences that may exist between the Report's recommendations and the final design detailed in the contract documents should be reported to Thurber immediately so that Thurber can address potential conflicts.

d) Construction Services: During construction Thurber should be retained to provide field reviews. Field reviews consist of performing sufficient and timely observations of encountered conditions in order to confirm and document that the site conditions do not materially differ from those interpreted conditions considered in the preparation of the report. Adequate field reviews are necessary for Thurber to provide letters of assurance, in accordance with the requirements of many regulatory authorities.

6. RELEASE OF POLLUTANTS OR HAZARDOUS SUBSTANCES

Geotechnical engineering and environmental consulting projects often have the potential to encounter pollutants or hazardous substances and the potential to cause the escape, release or dispersal of those substances. Thurber shall have no liability to the Client under any circumstances, for the escape, release or dispersal of pollutants or hazardous substances, unless such pollutants or hazardous substances have been specifically and accurately identified to Thurber by the Client prior to the commencement of Thurber's professional services.

7. INDEPENDENT JUDGEMENTS OF CLIENT

The information, interpretations and conclusions in the Report are based on Thurber's interpretation of conditions revealed through limited investigation conducted within a defined scope of services. Thurber does not accept responsibility for independent conclusions, interpretations, interpolations and/or decisions of the Client, or others who may come into possession of the Report, or any part thereof, which may be based on information contained in the Report. This restriction of liability includes but is not limited to decisions made to develop, purchase or sell land.

Appendix B

Summary of Geotechnical Invesgation Requirements

Table B-1 City of Ottawa Geotechnical Requirements

Project Type	General Maximum Spacing between Boreholes*	Minimum Depths of Investigation*	Soil stratigraphy	Groundwater Level (Piezometers/ Monitoring wells)	In-situ Infiltration Testing	Depth to high water or bedrock	Laboratory Soil Testing
Residential Subdivision	300m	4 to 6m, or to bedrock, but no less than 1m below the maximum depth of excavation for basements or buried site services	Included in standard borehole	Project Dependent	Not required	Bedrock may be identified during borehole drilling	Included in Geotechnical Investigation Requirements
	150m		Included in standard borehole	Project Dependent	Not required	Bedrock may be identified during borehole drilling	Included in Geotechnical Investigation Requirements
Infill Housing	30 to 50m	4 to 6m, or to bedrock, but no less than 1m below the maximum depth of excavation for basements or buried site services	Included in standard borehole	Project Dependent	Not required	Bedrock may be identified during borehole drilling	Included in Geotechnical Investigation Requirements
Single House, Additions, and Decks on sites that are not part of a previously approved planning application	N/A	Ontario Building Code Requirements	Included in standard borehole	Project Dependent	Not required	Bedrock may be identified during borehole drilling	Included in Geotechnical Investigation Requirements
Individual Buildings	30-50m, within the building area	Low rise (≤2 storeys): 6-7m depth Mid rise (3-5 storeys: 8-10m depth High rise (≥ 6 storeys): 10-15m depth	Included in standard borehole	Project Dependent	Not required	Bedrock may be identified during borehole drilling	Included in Geotechnical Investigation Requirements
Low-rise Building Campus	100m		Included in standard borehole	Project Dependent	Not required	Bedrock may be identified during borehole drilling	Included in Geotechnical Investigation Requirements
Widening of Existing Roadway	50m	1.5m, but no less than the planned excavation depth.	Included in standard borehole	Project Dependent	Not required	Bedrock may be identified during borehole drilling	Included in Geotechnical Investigation Requirements

*The spacing and number of boreholes provided is dependent on project type, but a minimum of three (3) boreholes per site is required. Refer to Geotechnical Investigation and Reporting Guidelines for Development Applications in the City of Ottawa for further information.

Appendix C

LID Project Examples

Aurora Community Centre (ACC) LID Retrofit

Location: Aurora, ON

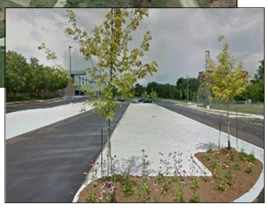
The LID Retrofit Design for the Aurora Community Centre (ACC) demonstrates innovation, forward thinking approaches combined with proven integration of LID with a functional parking lot design.

Hydrogeological Issue: High Groundwater

Solution: Focus on filtration-based LID

LID Type(s): **three (3) permeable pavement parking areas, a permeable pavement trail, three (3) bioswales, a large rain garden.**

The Aurora Community Centre (ACC) is located at 1 Community Centre Drive. The 9,890 m^2 parking facility has remained largely unchanged since its constructed in 1969, with the exception of a building expansion in the 1990s. At the project onset the parking surface had degraded and was in need of replacement along with the associated concrete walkways and curbing.



As part of the Comprehensive Stormwater Master Plan (CSWM-MP), proposed source control measures within public lands were identified. Public lands such as schools, parks and community centers were recognized as being important tools in the process of defining broader LID implementation variables. The ACC was identified as a potential public land retrofit site as it has a high community appeal and serves as community 'hub' (high volumes of visitors) and can serve as a signature project for the Town to demonstrate innovation and environmental stewardship.

The design which was implemented in 2017 included **three (3) permeable pavement parking areas, a permeable pavement trail, three (3) bioswales, a large rain gardens and an enhanced hydrodynamic separator.**

Field investigations identified a series of site constraints including:

- 600mm concrete York Region water main and one 900 mm concrete class IV York Region Sanitary Sewer passing though the parking lot.
- One aerial utility line also passes through the parking lot.
- The ACC site is within the floodplain of Tannery Creek
- The ACC site is within the Well Head Protection Area (WHPA) (100m of an existing York Region Municipal drinking Water Well.
- **Hydrogeological Constraint of a seasonally high groundwater elevation**. Based on the results of the groundwater monitoring from September 2014 to May 2015, the seasonally high groundwater table was recorded at:
  - 251.85m at location GW1, corresponding to 1.0m BGS, with fluctuations of up to 1.22m
  - 252.9m at location GW2, corresponding to 0.52m BGS, with fluctuations up to 2.05m

The seasonally high ground water elevations was considered as part of proposed designs. From the groundwater monitoring it can be concluded that the following Actions be taken in design:

1. The invert of each LID facility shall be such that to maximize the offset from the seasonally high groundwater elevation. A minimum 300mm of separation shall be provided wherever possible.
2. Due to seasonally high ground water elevations, the focus of each LID facility design shall be on 'filtration' as opposed to 'infiltration' of stormwater runoff. Infiltration shall be considered an added benefit to the overall function of the SWM system, but not a primary objective or a primary functional element of the LID design. An infiltration rate of 1mm/hr shall be used in all subsequent analysis, based on in-field testing, soil types and borehole logs.
3. To enhance the filtration of runoff, the provision of adequate media depth not less than 300mm shall be provided. Media additives should be considered to increase the removal efficiency, with a focus on phosphorous removal per the objectives of the LSPP and the Town's CSWMP.

Hazeldean Road LID Design

Location: Ottawa, ON

Hydrogeological Issue: Groundwater Mounding

Solution: undertake groundwater mounding analysis

LID Type(s): **Subsurface infiltration facility**

The stormwater management strategy for Hazeldean Road involved releasing flows directly into an adjacent creek. In order to do so, the proponent proposed to meet water quality and quantity (including infiltration) targets, as well as to implement erosion control measures. As such, the proponent proposed a LID solution with an accompanying monitoring plan which included a large subsurface infiltration facility.

The main infiltration facility was designed with a bottom of tank elevation (invert) of 100.1m and a corresponding groundwater elevation proximal to that location at BH1 and BH7 are 101.77m and 99.39m respectively. While subsequent groundwater elevations were recorded at BH1 and BH7 on September 1, 2016 and reported as 99.0m and 100.02m respectively, the seasonally high groundwater elevation (as recorded on January 28, 2016) posed a potential limitation to subsurface infiltration.

As such, the facility as designed is not in conformance with the LID Stormwater Planning and Design Guide (2010, v1) which recommends that “the bottom of the facility should be vertically separated by one (1) metre from the seasonally high-water table or top of bedrock elevation” in regards to Soakaways, Infiltration Trenches and Chambers.

To address the above noted constraint, a groundwater mounding analysis using the ***Simulation of Groundwater Mounding Beneath Hypothetical Stormwater Infiltration Basins (USGS)***. From the analysis, it was concluded that **based on the groundwater mounding calculations, it would suggest that the groundwater mound could extend into the infiltration gallery however, the full-year infiltration benefits from the infiltration gallery were not required to achieve the annual infiltration targets. As such, the LID design was suitable for implementation.**

Brampton Flight Centre Hanger Development & Drainage Plan

Location: Brampton Flight Centre, Cheltenham, ON

As part of site grading, drainage plan drainage plan development for several new hanger developments proposed throughout the Flight Centre, LID stormwater solutions were proposed.

As an airport, the site has limited topographic relief as well as extensive existing flooding problems throughout. The preferred solution to address these issues was the use of LID approaches to manage stormwater where traditional systems could not. Detailed designs for each phase of the project included the evaluation of LID several design alternatives such as bioswales, permeable pavement parking lots, rainwater harvesting systems, subsurface storage systems, subsurface channel drains, etc.

Site examinations included:

- geotechnical investigation,
- 1-year of continuous groundwater monitoring,
- in-situ infiltration testing to determine the native soil infiltration rate

Ultimately, after careful site examination, bioswales were selected as the preferred LID alternative for future phases.

As of 2018, more than a dozen bioswales have been successfully designed and constructed on site.

Hydrogeological Issue: Flat Topography

Solution: Careful evaluation of suitable LID techniques for low slope sites

LID Type(s): **Bioswales**

Brownfield Park Redevelopment

Location: Hamilton, ON

Hydrogeological Issue: Brownfield

Solution: Additional excavation to remove contaminated soils within 1m of LID

LID Type(s): **Bioretention gardens**

A public park was proposed within the City of Hamilton with the goal of passive recreation and special public activities and events. The site had an area of 0.82 hectares, and included the design of an ice rink/spray pad, three tree groves, and four bioretention areas (rain gardens).

The bioretention gardens were dispersed throughout the proposed 0.82 ha park, and were designed to improve water quality and quantity control for the contributing drainage areas within the proposed park property. The rain garden areas were each approximately 177 m^2 in size, with a 300mm ponding depth, overflow risers and underdrains.

The existing property of the proposed park was utilized as a parking lot, but was also found to be formally utilized as a heating field storage and distribution business. Through an Environmental Site Assessment (Phase 1 and 2), the site was found to have areas of contamination.

Within the location of the proposed rain gardens, it was recommended that during excavation in that area of the rain gardens, the footprint be excavated an additional 1m beyond the proposed 1.5m facility depth (total 2.5m) including an additional 1m beyond the limits of the rain garden footprint along the horizontal and that this material be disposed of off-site at a licenced landfill. In addition, impermeable liners were used to separate on-site soils. In this way, stormwater would be prevented from infiltrating through the impacted material.

Beach Boulevard Park

Location: Hamilton, ON

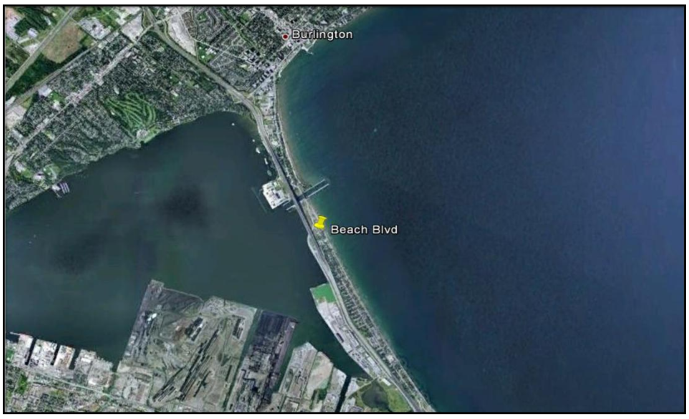
Hydrogeological Issue: High groundwater

Solution: Locate LID invert above seasonally high groundwater elevation and expand facility footprint laterally to meet volume storage requirements.

LID Type(s): **Vegetated Filter Strip and Soakaway pits**

Field investigations were commenced in 2011 for the Beach Boulevard Park Redevelopment project in order to facilitate the design and construction of an on-site Low Impact Development (LID) SWM technique (soakaway pit).

The vacant redevelopment site is located on Beach Boulevard directly east of the Skyway Bridge in Hamilton, ON. Although the site was known to be underlain with high permeability sands, a major concern of the design was its locations and the seasonally high ground water below the surface which were strongly influenced by the water levels of Lake Ontario and Hamilton Harbour. The site area was serviced by combined sewers and as such the redevelopment was not permitted to add any additional flow to the existing system. As such, the ability to implement a zero-discharge LID solution was a critical to the ability to convert the vacant land into a new City park.



To address the concerns regarding the feasibility of implementing a soakaway pit to infiltrate the 100-year event, a series of site assessments was conducted, including:

- Three (3) shallow piezometers were installed to measure seasonally high groundwater elevation
- In-situ infiltration testing was completed using the Guelph Permeameter at 3 locations
- Soil profile and material type was collected using a hand auger and soil coring device (8 locations)

The field testing identified a seasonally high (March-April) groundwater elevation of 1.28m below the ground surface at an elevation of approximately 75.0m and an average infiltration rate of greater than 150mm/hr (or 62mm/hr with a 2.5 safety factor applied)

The designs for the soakaway pit included a 3.5m vegetated filter strip for pre-treatment, the placement of 200mm filtration media for water quality improvements and required that the soakaway invert not extend below 75.3m, allowing a 300mm offset from the seasonally high-water table and at 550mm offset from the normal water table elevation. The design including all grading and design elevations, dimensions, storage volumes, draw-down times, flow paths, material specifications, construction sequencing and erosion and sediment control.

Expansion and Redevelopment of IMAX Parking Lot Facility

Location: Mississauga, ON

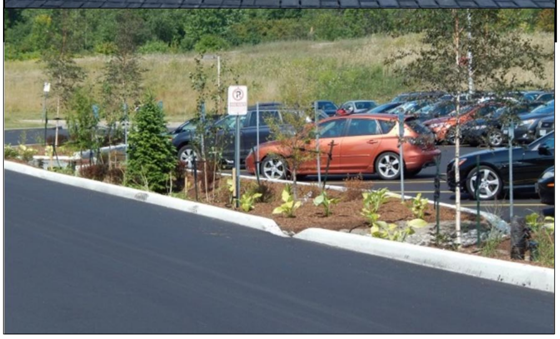
Hydrogeological Issue: Low Permeability Soils and Bedrock

Solution: Relocated LID

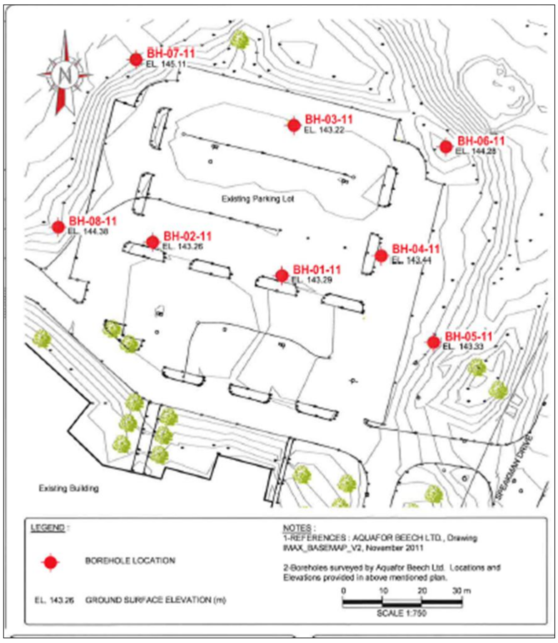
LID Type(s): **Bioswales and Permeable Interlocking Concrete Pavement**

From 2012 and 2013, the detailed design and construction for the reconstruction of the failing employee parking lot at the IMAX Corporation headquarters located within the Sheridan Business in Mississauga, Ontario was completed. The existing parking lot consisted of a traditional asphalt surface with standard curb and gutter drainage. The parking surface was severely degraded consisting of extensive cracking and rutting as well as spalling in several locations.

The detailed design aimed to refurbish the existing asphalt surface and expanded the existing facility to provide additional parking spaces as a result of IMAX Corporation anticipated employee growth within the upcoming years.



In addition to providing a larger facility, the secondary objective of the this showcase pilot project was to incorporated innovative combinations of proven Low Impact Development (LID) SWM techniques such as permeable pavement, bioswale features as well as other products such as Imbrium Jellyfish and SorbtiveMEDIA (phosphorous removal technologies) systems as part of the redevelopment for the purpose of reducing runoff volumes, improving water quality, encouraging infiltration and groundwater recharge, increasing baseflow to streams, reducing erosion, and protecting potable groundwater supplies.



Site reconnaissance and background information suggested the presence of a high groundwater table on-site, which was observed as water flowing over the pavement surface from adjacent hillsides without the occurrence of rainfall. The field investigation program included: 8 boreholes, 4 monitoring wells per O.Reg 389/09 and 4 days of in-situ infiltration testing.

Field testing found silty clay with a lower infiltration rate of 1.9 to 4.8 mm/hr, that the seasonally high groundwater elevation was not a concern (depths of 2.7 to 3.5m BGS), however an unexpected bedrock separation issues was identified. Along the southern ½ of the parking lot area, bedrock was found only 0.3m BGS. In design, the permeable pavement areas were relocated to the north ½ of the site where bedrock separation issues were not present (>6m), and bioswales which were designed as filtration techniques within the bedrock were designed to control runoff from asphalt surface of the southern ½ of the site. Constructed in fall 2012, the LID systems have been in continuous operation.

Hemmingwood Way ATM & Bioretention Measures

Location: Ottawa, ON

Hydrogeological Issue: High Groundwater

Solution: Focus on filtration-based LID

LID Type(s): Bioretention facilities

Design firm: Robinson Consultants

The primary objective of the project was to provide area traffic management and reduce existing surface runoff through the implementation of bioretention measures along Hemmingwood Way in the west end of Ottawa.

Six bioretention cell s were proposed on Hemmingwood Way between Covington Place E and Centrepointe Drive E. All of the bioretention cells were located within curb extensions, ranging in length of 19-33m and with an average width of 3m. Field investigations of existing conditions included assessment of the existing drainage, land use, roadway, utilities, natural environment, and transit services, as well as subsurface investigations, geotechnical and field permeability, groundwater levels, and a Phase I and Limited Phase II environmental site assessments.

Assessments of physical suitability for each bioretention facility was based on the Low Impact Development Stormwater Management Planning and Design Guide. This included assessing each proposed bioretention facility location achieved the recommended criteria. The minimum recommended criteria included:

- Site Topography (Drainage area slopes of 1-5%)
- Available head (1-1.5m elevation difference between inflow of underdrain and storm sewer invert)
- Water table (Minimum of 1m separation from seasonally high water table)
- Drainage Area (Impervious drainage area to bioretention cell area 5:1 to 15:1)
- Setbacks from Buildings (Minimum 4m setback)

Based on the long-term water level measurements collected at monitoring wells installed along Hemmingwood Way, the maximum water level exceeds the MECP recommended 1.0 metre clearance at all bio-retention cell locations. However, monthly average groundwater levels suggest that groundwater levels are only within the 1 metre clearance during the spring freshet and late fall. Therefore, the infiltration capacity of the bioretention gardens would be limited during a limited period of time only.

Given the limited risk associated with the lack of clearance between the groundwater level and the bottom of the bio-retention cells, it was determined that a liner would not be required. The bio-retention cells will be equipped with a subdrain, which will allow the cells to drain during high groundwater conditions.

Chapel Hill Park & Ride

Location: Ottawa, ON

Hydrogeological Issue: High Groundwater

Solution: Focus on filtration-based LID

LID Type(s): Bioretention facilities

Design firm: Stantec Consulting

The Chapel Hill Park & Ride was proposed as a 3-ha OC Transpo transit and parking facility in the Chapel Hill neighbourhood. Various stormwater management options were considered including an infiltration trench with underground storage or wet pond, a wet pond, a dry pond with oil grit separator, underground storage, or infiltration measures.

The implementation of LID measures was the most preferred alternative, however, geotechnical investigations found that the groundwater table level was within 0.6m to 1.5m of the surface, with seasonal variance. Typical subsurface conditions for LIDs would require a minimum 1m clearance between the bottom of the trench bed to the groundwater table. Geotechnical investigations also identified the site as having a thin layer of sand up to approximately 1m below the ground surface, which is underlain with a thick deposit of sensitive silty clay. Therefore, the native soil also had a relatively low design infiltration rate of 5 mm/hr.

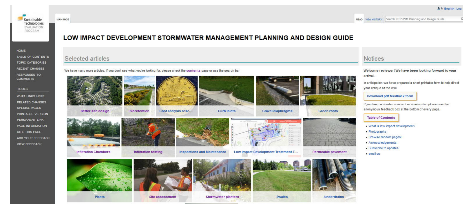
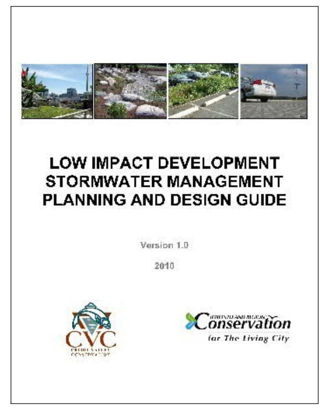
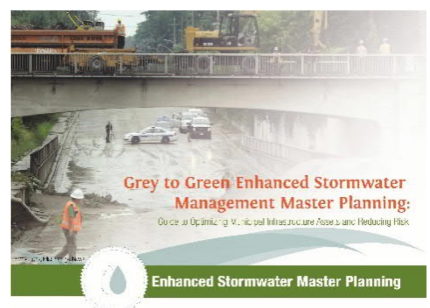
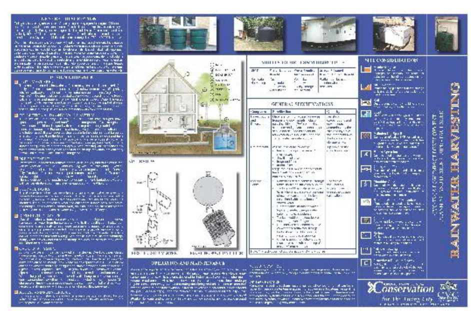
Due to the high groundwater table on-site, it was not possible to fully infiltrate the runoff from the site during high groundwater conditions, since the LIDs may not act as infiltration facilities. However, the LIDs may be incorporated to function as filtration and attenuation facilities.

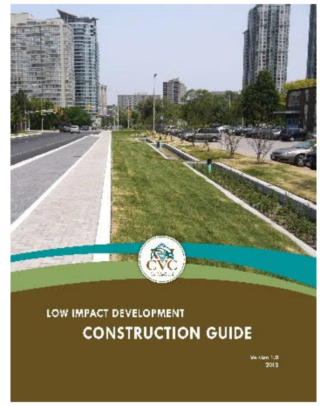
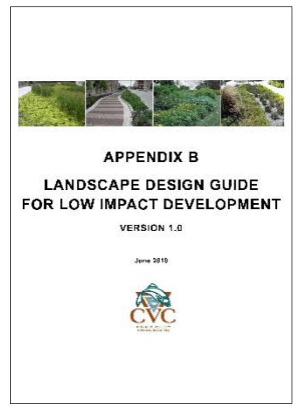
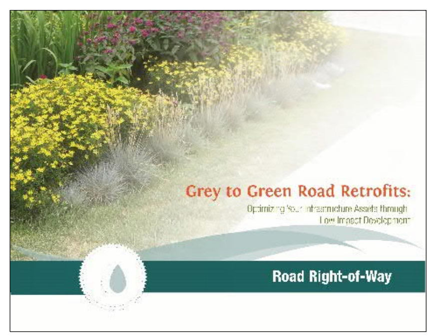
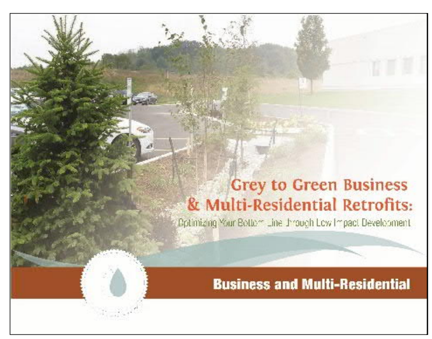
Five bioretention basins were incorporated into the site's SWM design plan, to maximize the benefits of runoff filtration and attenuation of the facility. Each bioretention basin included a deep layer of "amended soil" underlain by granular material was to be subdrained. The subdrains were provided to ensure that the filtration function of the LID was not adversely affected by the site's high groundwater table. The LID measures were maximized on-site where possible to minimize the loss of parking spaces.

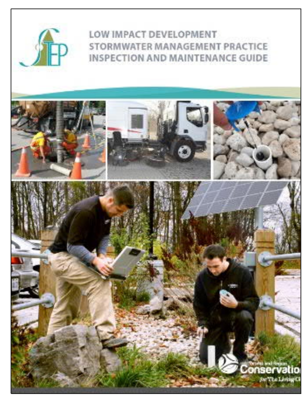
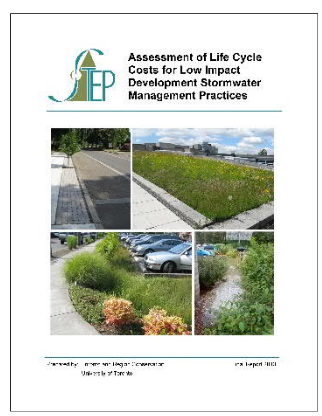
The bioretention basins were designed to provide sufficient storage to retain the 25mm 4-hour water quality event, detain the difference between the pre- and post-development 2-year peak design flow. Additionally, the bioretention basins were designed to accommodate the volume required to achieve a head that can pass the 100-year peak flow through the overflow weir at the two outlet control structures, and drain to Mud Creek. Five monitoring wells were installed on-site so that the performance of the LID could be monitored over time.

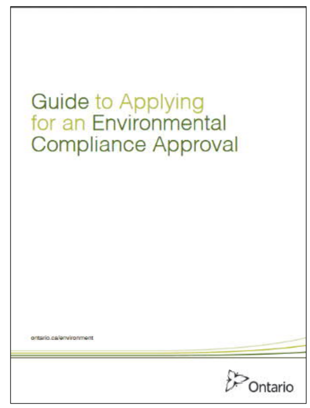
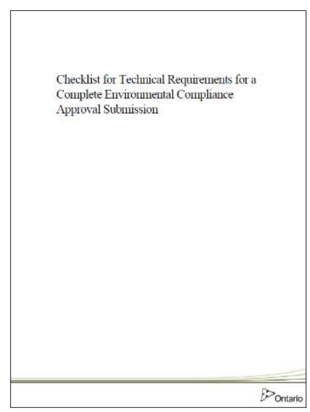
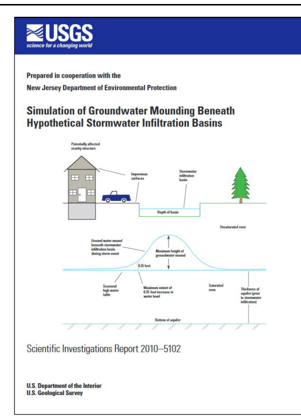
Appendix D

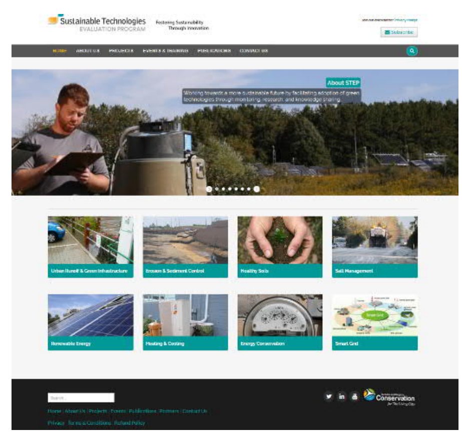
Resource Directory

Publication	Resource	Screen grab
Planning and Design Guide	**Low Impact Development Stormwater Planning and Design Guide (Wiki Document)** https://wiki.sustainabletechnologies.ca/wiki/Main_Page	
Planning and Design Guide	**Low Impact Development Stormwater Management Planning and Design Guide (TRCA/CVC, 2101, Version 1.0)** https://sustainabletechnologies.ca/home/urban-runoff-green-infrastructure/low-impact-development/low-impact-development-stormwater-management-planning-and-design-guide/	
Planning Guide	**Grey to Green Enhanced Stormwater Management Master Planning: Guide to Optimizing Municipal Infrastructure Assets and Reducing Risk (CVC)** http://www.creditvalleyca.ca/wp-content/uploads/2016/01/ORGuide.pdf	
Planning & Design Fact Sheets	**Low Impact Development Stormwater Management Planning and Design Guide, including Fact Sheets:** http://www.creditvalleyca.ca/low-impact-development/low-impact-development-support/stormwater-management-lid-guidance-documents/low-impact-development-stormwater-management-planning-and-design-guide/	

Construction Guide	**Construction Guide for Low Impact Development (CVC, 2012, Version 1.0)** http://www.creditvalleyca.ca/wp-content/uploads/2013/03/CVC-LID-Construction-Guide-Book.pdf	
Landscape Design Guide	**Landscape Design Guide for Low Impact Development (CVC – Version 1.0)** http://www.creditvalleyca.ca/low-impact-development/low-impact-development-support/stormwater-management-lid-guidance-documents/andscape-design-guide-for-low-impact-development-version-1-0-june-2010/	
Roads Retrofit Design Guide	**Low Impact Development Road Retrofits: Optimizing Your Infrastructure through Low Impact Development (CVC)** http://www.creditvalleyca.ca/wp-content/uploads/2014/08/Grey-to-Green-Road-ROW-Retrofits-Complete_1.pdf	
Business & Multi- Res. Retrofit Design Guide	**Grey to Green Business & Multi- Residential Retrofits: Optimizing Your Infrastructure through Low Impact Development (CVC)** http://www.creditvalleyca.ca/wp-content/uploads/2015/01/Grey-to-Green-Business-and-Multiresidential-Guide1.pdf	

Residential Retrofit Design Guide	**Low Impact Development Residential Retrofits: Engaging Residents to Adopt Low Impact Development in their Properties (CVC)** http://www.creditvalleyca.ca/wp-content/uploads/2015/01/Grey-to-Green-Residential-Guide1.pdf	
Public Lands Retrofit Design Guide	**Grey to Green Public Lands Retrofits: Optimizing Your Infrastructure through Low Impact Development (CVC)** http://www.creditvalleyca.ca/wp-content/uploads/2015/01/Grey-to-Green-Pulic-Lands-Guide.pdf	
Maintenance Guide	**Low Impact Development Stormwater Management Practice Inspection and Maintenance Guide (TRCA/ STEP, 2016, Version 1.0)** http://www.sustainabletechnologies.ca/wp/home/urban-runoff-green-infrastructure/low-impact-development/low-impact-development-stormwater-practice-inspection-and-maintenance-guide/	
Life Cycle Costs Report	**Assessment of Life Cycle Costs for Low Impact Development Stormwater Management Practices (TRCA, UofT, 2013)** https://sustainabletechnologies.ca/app/uploads/2013/06/LID-LCC-final-2013.pdf	

Costing Tool	**Low Impact Development Life Cycle Costing Tool (STEP)** http://www.sustainabletechnologies.ca/wp/home/urban-runoff-green-infrastructure/low-impact-development/low-impact-development-life-cycle-costs/	
Approval Guide	**Guide to Applying for an Environmental Compliance Approval** https://www.ontario.ca/document/guide-applying-environmental-compliance-approval-0	
ECA Submission Checklist	**Checklist for Technical Requirements for Complete Environmental Compliance Approval Submission** https://www.ontario.ca/page/checklist-technical-requirements-complete-environmental-compliance-approval-submission	
Groundwater Mounding Analysis	**Simulation of Groundwater Mounding Beneath Hypothetical Stormwater Infiltration Basins** **USGS** https://pubs.usgs.gov/sir/2010/5102/ spreadsheet Hantush_USGS_SIR_2010-5102-1110.xlsm	

LID Performance Resources	**Sustainable Technologies Evaluation Program available** https://sustainabletechnologies.ca/resource-library/water/?fwp_topics=low-impact-development **LID BMP monitoring plans, technical reports and case studies** http://www.creditvalleyca.ca/low-impact-development/lid-maintenance-monitoring/ **International Stormwater BMP Database** http://www.bmpdatabase.org/index.htm.	
	Other Resources and Reports	
	Sustainable Technologies Evaluation Program (STEP): www.sustainabletechnologies.ca/ **<u>Resources, Studies and Reports</u>** 1. Green Infrastructure Map 2. Stormwater Infiltration in Cold Climates Review (2009) 3. Stormwater Management and Watercourse Impacts: The Need for a Water Balance Approach 4. Preserving and Restoring Healthy Soil: Best Practices for Urban Construction 5. LID Discussion Paper 6. Urban Water Balance 7. LID “Barrier Buster” fact sheet series **<u>Features Studies and Resources:</u>** 8. Bioretention and Rain Gardens 9. Green Roofs 10. Soakaways, Infiltration Trenches and Chambers 11. Permeable Pavement 12. Swales and Roadside Ditches 13. Perforated Pipe Systems 14. Rainwater Harvesting 15. Residential Stormwater Landscaping 16. Water Balance for the Protection of Natural Features	

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