Low Impact Development Stormwater Management Guidance Manual

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Low Impact Development Stormwater Management Guidance Manual

PREFACE

Water from rainfall and other forms of precipitation circulates through the natural and urban environment and is essential to all living things. Too much or not enough water, water temperature and water pollution can impact the quality of life. With improved understanding over the years, there has been an evolution of stormwater management practices in Ontario and other jurisdictions. Stormwater management facilities and systems need to address a broad suite of issues including the maintenance of hydrologic processes and the natural water balance, as well as the enhancement of fish habitat, stream morphology, and terrestrial habitats and the mitigation of the observed and predicted impacts of climate change.

Green infrastructure and Low Impact Development stormwater management practices can be integrated into the very fabric of our communities to help protect Ontario's water resources, the natural and human environments, the ecological services already provided by existing natural systems, and the sustainability of communities.

This Low Impact Development Stormwater Management Guidance Manual provides information for municipalities, developers, consultants, agencies and others on the benefits of managing rain where it falls and snow melts, including performance guidance on controlling runoff volume.

This Manual is intended be read in conjunction with the 2003 Stormwater Management Planning and Design Manual and the 2008 Design Guidelines for Sewage Works. Together, these manuals provide flexible guidance to implement a holistic treatment train approach to stormwater management in Ontario using the full spectrum of source, conveyance and end-of-pipe controls that meet the needs and abilities of the local communities.

This manual is not intended to limit innovation. Rather, this manual encourages the development and application of innovative practices, designs and technologies that are supported by literature, research, and field studies. Where the proponent and designer can show that alternate approaches can produce the desired results or even better, such designs should be considered. The proponent along with the designer are responsible for the designs which are made with respect to stormwater management for any given site.

This guidance manual, along with the 2003 Stormwater Management Planning and Design Manual and the 2008 Design Guidelines for Sewage Works, will be used as a baseline reference document in the review of stormwater management applications for approval under Section 53 of the *Ontario Water Resources Act*, as administered by the Minister of the Environment, Conservation and Parks.

EXECUTIVE SUMMARY

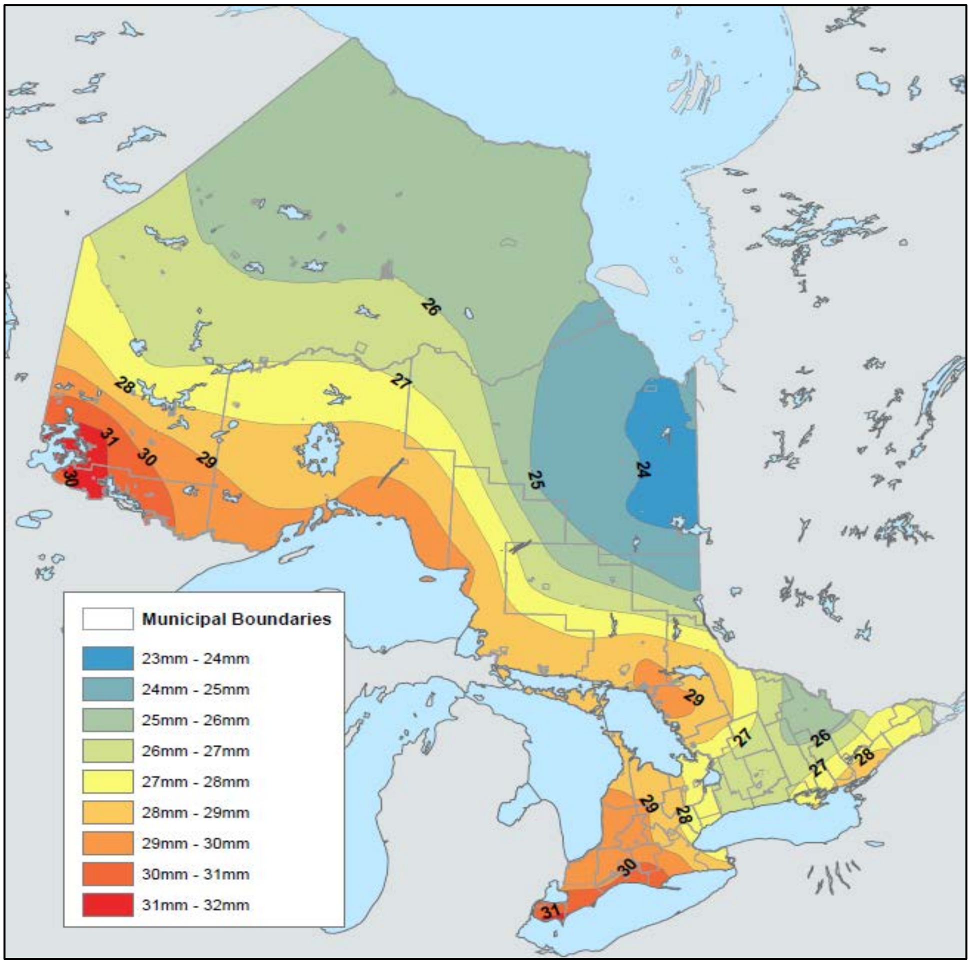
Low Impact Development (LID) is an innovative state-of-the-art approach to managing stormwater by controlling and treating precipitation where it falls, as a resource to be managed and protected rather than a waste. In this regard, the emphasis is to maintain the natural hydrologic cycle to the extent possible through the use of source (lot level) and conveyance measures in combination with end-of-pipe controls using what is referred to as a "treatment train" approach to stormwater management that meets the needs and abilities of the local communities. In keeping with these principles, a shift towards an ecosystem-based water balance approach to stormwater management has emerged and is being successfully applied. This approach has largely replaced the traditional stormwater management model based on rapid conveyance of runoff using only grey infrastructure (e.g., storm sewers) in combination with end-of-pipe controls.

In natural, undisturbed environments, precipitation (e.g., rain, snowfall) is initially intercepted by trees and vegetation. Most precipitation that is not intercepted ultimately infiltrates into the ground or is returned to the atmosphere by evapotranspiration. Very little precipitation becomes stormwater runoff under permeable ground conditions, and runoff generally only occurs with larger precipitation events or during snowmelt. Urban development practices cover large areas of the ground with impervious surfaces, such as roads, parking lots, sidewalks, and structures. Under impervious conditions runoff regularly occurs even during small precipitation events.

As impervious area increases within a watershed due to development, so do the impacts to the natural environment and the community, such as degradation of aquatic habitats, increased water-borne pollution (e.g., suspended solids, pathogens, plastics, litter, road salt), basement flooding, and combined sewer overflows. In recognition of these problems, stormwater practitioners have primarily used conveyance and detention methods (pipe-and-pond) to address the impacts. However, these practices may not fully protect the environment, public safety, and the sustainability of communities.

To strengthen protection and sustainability, an increased emphasis on maintaining the natural hydrologic cycle to the greatest extent possible is required. In order to achieve this, performance guidance on a Runoff Volume Control Target is provided in this Low Impact Development Stormwater Management Guidance Manual (LID Guidance Manual). The Runoff Volume Control Target for Ontario is the 90^{th} percentile precipitation event, that is, a rainfall depth ranging from 23 mm to 32 mm, based on local precipitation patterns across the Province of Ontario (see Figure on next page). Beginning with better site design practices and pollution prevention, the hierarchical approach to the application of measures to achieve the target begins with retention, followed by LID filtration, and then conventional stormwater management. Retention practices reduce runoff volume at the source and include practices that infiltrate, evapotranspire or harvest and reuse stormwater. LID filtration practices may reduce some runoff volume and provide full or partial water quality treatment at the site. In recognition of potential site conditions that pose challenges for LID practices, the concept of maximum extent possible is introduced for sites with restrictions in order to provide local flexibility.

Runoff Volume Control Target - 90th Percentile Precipitation Event (Precipitation Isohyets)



Adoption of the Runoff Volume Control Target is encouraged by the Ministry of the Environment, Conservation and Parks. The Runoff Volume Control Target for Ontario is science-based and was determined through hourly rainfall analysis using a 12-hour minimum inter-event time, and disregarding precipitation events smaller than 2 mm as these events typically do not produce measurable runoff (due to absorption, interception and evaporation).

MANUAL OUTLINE

Chapter 1: Introduction – Provides an overview of green infrastructure and low impact development practices, including key objectives of stormwater management and the benefits of LID.

Chapter 2: Environmental Planning Process – Provides an overview of the environmental planning framework for stormwater management in Ontario.

Chapter 3: Stormwater Design Criteria: Runoff Volume Control Target – Outlines guidance for the Runoff Volume Control Target and the hierarchical approach to the application of measures to achieve the target for new development, redevelopment, linear infrastructure and stormwater management retrofit projects in Ontario.

Chapter 4: Groundwater – Outlines the relationship between groundwater systems and watershed health, and the benefits of Low Impact Development best management practices in relation to groundwater resources.

Chapter 5: LID Modelling Approaches – Provides guidance regarding methodology and criteria for selecting a technical approach for predicting and assessing the performance of stormwater management plans on a long-term basis.

Chapter 6: Climate Change – Outlines the importance of assessing the impacts of climate change on development planning and design for stormwater management at the site and municipal scale.

Chapter 7: Erosion and Sediment Control During Construction – Discusses the importance of providing enhanced erosion and sediment control during LID construction.

Chapter 8: Operation and Maintenance – Describes operation and maintenance (O&M) practices, and the process by which O&M activities can be optimized as part of design and construction.

Chapter 9: Monitoring, Performance Verification and Assumption Protocols – Summarizes resources and approaches for monitoring, development of a monitoring plan, and assumption and performance verification protocols.

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1.0 INTRODUCTION

1.1 History of the Ministry Manuals

In Ontario, the evolution of stormwater management has been reflected in several provincial reports, guides and manuals, beginning in 1991 with the Interim *Stormwater Quality Control Guidelines for New Development.* This was followed by the *Stormwater Management Practices Planning and Design Manual* in 1994. And, in 2003, the Ministry of the Environment, Conservation and Parks (Ministry) completed and released the Stormwater Management Planning and Design Manual (2003 Stormwater Manual), which remains in effect.

Along with this Low Impact Development Stormwater Management Guidance Manual (LID Guidance Manual), the following Ministry guidelines and bulletin reflect the current direction of stormwater management in Ontario.

- 2003 Stormwater Manual – This manual provides a more integrated approach, as compared to its predecessors. The 2003 Stormwater Manual incorporates water quantity and erosion considerations and provides technical and procedural guidance for the planning and design of stormwater management practices. The focus of the manual was broadened to incorporate the current multi-objective approach to stormwater facility planning and design to address targets related to hazards, water quality, fish habitat and recreation.

  The 2003 Stormwater Manual advised the application of a "treatment train" approach to stormwater management that uses a combination of controls – source, conveyance and end-of-pipe controls - in an overall stormwater management system or strategy to ensure that objectives are achieved.

- 2015 Interpretation Bulletin - the Ministry released an interpretation bulletin to clarify expectations regarding stormwater management. Specifically, the bulletin clarified that the Ministry's existing policies and guidance and emphasized an approach to stormwater management that mimics a site's natural hydrology as the landscape is developed. The main tenet of this approach is to control precipitation as close to where it falls as possible by employing lot level and conveyance controls otherwise known as LID Best Management Practices (BMPs), and often as part of a treatment train approach. The bulletin also reinforced the Ministry's desire to implement LID BMPs as part of a holistic stormwater management approach and that LID BMPs are relevant to all forms of development, including new development, redevelopment, infill, and retrofit developments.

- 2008 Design Guidelines – The 2008 Design Guidelines for Sewage Works includes guidance on the design of separate storm sewer systems and control and treatment of combined sewer overflows.

1.2 Role of Ministry Guidance Documents

In order to effectively mitigate the impacts from urbanization, stormwater strategies need to include a means to reduce runoff volume with the objective of maintaining the natural water cycle to the extent possible. To meet the multiple objectives of stormwater management on a broad-scale, it is expected that a combination of source, conveyance and end of pipe controls will be employed.

This LID Guidance Manual was developed to complement the 2003 Stormwater Manual and the 2008 Design Guidelines. The LID Guidance Manual provides performance guidance for stormwater management, that is a Runoff Volume Control Target, and works together with the 2003 Stormwater Manual, 2008 Design Guidelines, and other ministry standards and guidance. The approach outlined in Chapter 3 - Stormwater Management Design Criteria: Runoff Volume Control Target applies to new development, redevelopment, linear infrastructure and stormwater management retrofit projects in Ontario. A general comparison of the guidance provided in the Ministry documents is provided in Table 1.1. Like the 2003 Stormwater Manual, this document should be viewed as a tool for understanding the performance criteria for stormwater management projects and not as a rulebook for stormwater management solutions.

The 2003 Stormwater Manual provides performance and detailed design guidance on lot level, conveyance and end-of-pipe stormwater management. While the terms Low Impact Development and green infrastructure are not explicitly used in the 2003 Stormwater Manual, design guidance for some infiltration and filtration practices are included. While much of the guidance remains valid, the LID Guidance manual updates and replaces certain infiltration and filtration guidance of the 2003 Stormwater Manual:

- End-of-pipe controls under Section 4.1.2 of the 2003 Stormwater Manual presupposes that lot level and conveyance controls will not, on their own, satisfy all of the stormwater management criteria, and that in all cases end-of-pipe facilities will be required. This is inaccurate, however, as it has been demonstrated that LID installations, when properly sited, designed and maintained, have met all of the performance requirements and no end-of-pipe controls were required for stormwater management.

- The 2003 Stormwater Manual specifies that the application of a number of infiltration-based management practices may not be suitable if the native soil has a percolation rate less than 15 mm/hr (see for example 2003 Stormwater Manual Table 4.1: Physical Constraints for Stormwater Management Practice Types - infiltration trenches, reduced lot grading, soakaway pits, rear yard ponding, and pervious pipes). 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. It has been demonstrated that infiltration-based practices can be implemented in tight soils provided the design has addressed the site conditions. Additionally, LID or green infrastructure practices such as bioretention and biofiltration use multiple treatment mechanisms including retention, filtration, evaporation and transpiration as well as infiltration and can help to achieve water balance and water quality goals (including reduced thermal impacts).

Aside from the minimum infiltration rates, the design guidance for lot level and conveyance controls in the 2003 Stormwater Manual remains valid.

Table 1.1 - Ministry Stormwater Guidance Manuals

Document	Lot or Source	Conveyance (e.g., road rights-of-way)	End-of-Pipe Treatment
LID Guidance Manual	Performance guidance (e.g., Runoff Volume Control Target)	Performance guidance (e.g., Runoff Volume Control Target)	Not Applicable
2003 Stormwater Manual	Detailed design guidance for some infiltration and filtration practices (e.g., soakaway pit)	Detailed design guidance for some infiltration and filtration practices (e.g., pervious pipe system, grassed swale, infiltration trench)	Detailed design guidance (e.g., stormwater pond, constructed wetland, infiltration trench, exfiltration basin) Performance guidance (e.g., erosion control, suspended solids removal)
2008 Design Guideline	Not Applicable	Detailed design guidance for storm sewers	Not Applicable

The 2008 Design Guideline includes detailed design guidance for separated storm sewers with focus only on conveying the stormwater. While the hydraulic capacity of storm sewers is an important design consideration, the 2008 Design Manual must work together with the 2003 Stormwater Manual and the LID Guidance Manual to protect public safety, the community and the environment.

The 1994 Protocol for Conducting A Storm Water Control Study originated as guidance for industrial facilities when conducting a Storm Water Control Study in accordance with the requirements of the former sector-specific Effluent Monitoring and Effluent Limits Regulations for industrial facilities in the following nine sectors: petroleum, pulp and paper, metal mining, industrial minerals, metal casting, organic chemical, inorganic chemical, iron and steel, and electric power generation. On the revocation of the regulations in 2021, these industrial facilities became subject to the same or equivalent requirements transferred from the regulations into their respective environmental compliance approvals (ECA). The protocol includes general and technical information that can inform any industrial facilities that are conducting a stormwater control study.

1.3 Objectives of Stormwater Management

Stormwater management is governed under the *Ontario Water Resources Act* which has the stated purpose to provide for the conservation, protection and management of Ontario's waters and for their efficient and sustainable use, in order to promote Ontario's long-term environmental, social and economic well-being. Urban development alters the natural hydrologic cycle. These alterations have risks to public health and safety and ecological impacts. Water in the environment supports and sustains life, including people (e.g., drinking water, agricultural use, tourism and recreation), animals, fish, plants and other valued ecosystem components. Therefore, the overall goal of stormwater management is to protect and improve our health, safety, property, economy, environment, and climate change resiliency.

The objectives of stormwater management established in the Ministry's 2003 Stormwater Manual continue to apply in the LID Guidance Manual, with the inclusion of climate change consideration. The objectives of stormwater management are:

- Maintain appropriate diversity of aquatic life and opportunities for human uses,
- Protect water quality,
- Preserve groundwater and baseflow characteristics,
- Reduce combined sewer overflow,
- Reduce occurrences of undesirable geomorphic change (e.g., stream erosion),
- Reduce flood damage potential (e.g., public safety, damage to property and infrastructure),
- Protect the ecosystem by maintaining the natural hydrologic cycle to the greatest extent possible,
- Increase resiliency of communities and associated stormwater infrastructure to climate change and contribute to mitigation of climate change.

1.4 Conventional Stormwater Management

The management of stormwater runoff was conceived to allow land use change, specifically urban development, to occur while mitigating the effects on the receiving channel associated with hydromodification, flooding and water quality. While significant progress has been made in this regard, it is increasingly apparent that current stormwater management practices do not provide sufficient mitigation to the identified impacts. Studies have repeatedly found that the current practices used to offset the hydrologic effects of urbanization are insufficient to prevent increased channel erosion, the deterioration of water quality and aquatic habitats (TRCA, 2006 and CVC, 2007).

Over most of Ontario's stormwater management history storm sewers were constructed to rapidly convey stormwater from urban communities to waterways. In the more recent past, Ontario has also relied on end-of-pipe control measures in the form of detention facilities (dry ponds, wet ponds and constructed wetlands). Originally, such facilities were designed for attenuating large flood flows. In the 1980s and early 1990s design standards for detention ponds were revised to provide water quality treatment through settling of suspended sediments. More recently (beginning in the late 1990s), ponds began to be designed for the management of increased erosion potential associated with hydromodification and in the mid-2000s for thermal protection of receiving waterbodies. However, there is a fundamental problem with the reliance on detention facilities as the sole basis for the management of hydrologic changes in watersheds, as they do not address or mitigate impacts to the water balance, and they do not provide volume reductions.

Detention facilities typically receive stormwater runoff from relatively large contributing areas such as an entire subdivision and are located at the outfall of a storm sewer system prior to release of stormwater runoff to the receiving watercourse or waterbody. They are detention-based measures intended to hold or store stormwater runoff and release it in a controlled manner to the receiving channel. Although water losses through evapotranspiration, and in some cases losses through infiltration through the bottom of the pond or constructed wetland occur, these losses are not generally significant in the majority of detention facilities. As such, runoff volumes are not reduced and without other stormwater management controls, the pre-development infiltration portion of water balance is significantly altered.

The significant impacts of the 'business as usual' approach to stormwater management and reliance on end-of-pipe control can be easily observed within many urban and suburban watersheds, watercourses and waterbodies in the province of Ontario and beyond.

1.5 Water Balance

Precipitation that falls onto the ground either flows over land as surface runoff which makes its way directly to a watercourse, soaks into the ground by infiltration, or is retained on vegetation and other surface materials as interception storage. Rainfall retained as interception storage is returned to the atmosphere through evaporation and never contributes to runoff. A portion of the water infiltrating into the soil recharges deep groundwater reserves and the remainder is stored near the ground surface where it is depleted through transpiration by plants. Some groundwater migrates laterally and is intercepted by valleys, ravines or the banks of watercourses where it emerges to become surface flow. This shallow groundwater discharge, known as baseflow, maintains flow in the channel during periods between precipitation events and consequently it is a very significant factor in the determination of habitat value and the maintenance of ecological flows. These processes and pathways are all part of the hydrologic cycle for undeveloped and developed lands.

The proportion of precipitation occurring as surface runoff versus infiltration and how rapidly the surface runoff is delivered to the receiver determines the impacts to the natural environment, habitats, and people. The basic components of a water balance include precipitation, evaporation, transpiration, infiltration, overland flow, streamflow and groundwater flow and can be represented by the following equation:

$$\boldsymbol{Equation\ 1}:$$

$$\boldsymbol{P = R + G + E + T + \Delta S}$$

Where:
P = Precipitation
R = Runoff
G = Groundwater Flow
E = Evaporation
T = Transpiration
ΔS = Change in Storage (surface or subsurface)

A simplified water balance equation is commonly applied by practitioners, which describes the proportions of precipitation (P) which enter the hydrologic pathways of runoff (R), infiltration (I) and the sum of evaporation (E) and transpiration (T) known as evapotranspiration (ET) and is represented by the following equation:

$$\boldsymbol{Equation\ 2}:$$

$$\boldsymbol{Precipitation\ (P) = Runoff\ (R) + Infiltration\ (I) + Evapotranspiration\ (ET)}$$

A water balance is a way of accounting for what portion of precipitation occurs as runoff versus infiltration or interception, how much water is returned to the atmosphere through evaporation and transpiration, supplied to deep groundwater reserves or to the watercourse through shallow groundwater discharge. The simplified equation focuses on water at the surface. Once water enters the ground, local conditions will determine whether it percolates through the soil and rock to recharge deep groundwater resources or move more laterally and re-emerge in local surface water features such as wetlands and watercourses. The Change in Soil Storage (ΔS) term in equation 1 and the Infiltration (I) term in Equation 2, are most commonly applied to represent the portion of precipitation that enters the subsurface system.

The portion of precipitation accounted for in each of these components of the water balance is determined by many factors which can be broadly classified as: climate, vegetation or geology. Climate refers to long term trends in meteorological conditions typically measured in units of decades to thousands of years. Although there may be short-term changes to the water balance as a result of climate variations, over the long term the water balance is constant, providing vegetation and geology are not altered.

1.6 Water Demand and Use

Ontario municipal drinking water plants produced 4.4 million cubic meters of potable water per day and the average per capita water usage from residential homes was approximately 201 liters per day in 2015 (Statistics Canada, 2015). The total daily water intake volume for all manufacturing industries in Ontario was approximately 4.1 million cubic meters in 2011 (Statistics Canada, 2014). Though less than municipal and manufacturing sectors, agricultural water use is also a vital component of water use in Ontario, but it varies significantly depending on weather conditions.

As of 2017, Ontario's population was estimated to be 14.2 million. By 2041, Ontario's population is expected to grow by 30.2% or almost 4.3 million people to a total of almost 18.5 million (Ontario Ministry of Finance, 2018). With increased population comes additional demand on our municipal and private water supply systems for residential, agricultural and industrial purposes. Although significant improvements have been made in water use efficiency, many ageing municipal water systems could require upgrades to meet increased demand while maintaining the necessary level of service. An innovative approach to stormwater management that treats runoff as a resource will help ensure the lakes, rivers and groundwater sources that feed these water systems provide clean and abundant water for Ontario's population, now and into the future.

1.7 Effects of Urbanization

The hydrologic cycle describes the continuous circulation of water between the surface water bodies, atmosphere, and land. Water is supplied to the atmosphere by evapotranspiration, which includes evaporation from all water, snow, vegetation, and other surfaces, plus transpiration from plants. It is returned to the land through precipitation. Within the hydrologic cycle, water may be stored by vegetation, snowpacks, land surfaces, water bodies, saturated subsurface zones, and unsaturated subsurface zones/soils. Water may be transported between these storages via overland runoff, streamflow, infiltration, groundwater recharge, and groundwater flow, among other processes.

Changes in land use that result in the loss of natural cover, such as clearing forests for cultivation, or the conversion of rural/agricultural land to urban forms, has an impact on water balance. When forest and farm lands are urbanized, porous soils are replaced or covered with impervious materials such as concrete and asphalt which yield high runoff during precipitation events. Consequently, land use changes can lead to a significant and sometimes radical alteration in the prevailing watershed hydrology and the associated water balance. Common environmental consequences of increased impervious surfaces that can be mitigated via improved stormwater management include the following:

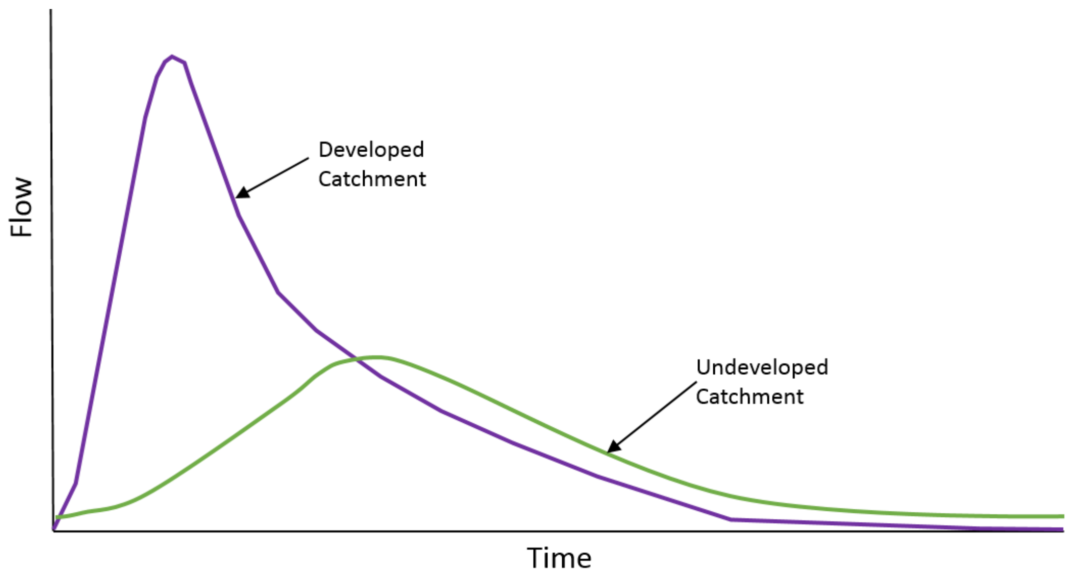
1. **Channel enlargement and increased erosion:** Streams in urban areas adjust to their altered hydrologic regime by enlarging their cross-sectional area to accommodate higher flows and/or by downcutting into the channel bed. This phenomenon can cause significant damage to property and infrastructure adjacent to or within the channel. Channel alignment and meander pattern may also vary because of changes to the hydrologic regime or the addition of hydraulic structures such as bridges and culverts. Channel erosion and input from land uses changes also cause increased sediment load in the stream. This sediment is deposited in slower moving reaches causing changes to the streambed substrate.

2. **Increased frequency and severity of flooding:** Urban catchments produce more runoff than natural areas and transport runoff to the downstream receiver faster. The combined effect of larger runoff volumes and increased drainage efficiency is an increase in peak flow rate and the duration of high flows in the receiving watercourse. These changes in the flow regime are referred to as hydromodification. Figure 1.1 show the response of an urban catchment to that of a rural catchment. Watercourses in urban catchments are more susceptible to flooding, especially from short duration, highly intense rainfall events.

3. **Impaired Water Quality:** As a catchment urbanizes, water quality deteriorates. While areas of the catchment are under development, eroded sediment washes off exposed soil at construction sites accumulating in watercourses. After development

has occurred, water quality continues to be impaired by runoff from impervious surfaces. Urban runoff may contain litter, plastics, and elevated levels of suspended solids, nutrients, bacteria, heavy metals, oils and grease, and sodium and chloride from the winter application of road salt.

Figure 1.1 - Flood Hydrographs for Undeveloped and Developed Catchments



4. **Degradation of habitat and associated biota:** Changes to hydrology, geomorphology and water quality can have a profound impact on local ecology. Impacts include:

   - A reduction in the diversity in fish, plant, animal and aquatic impact communities;
   - A reduction or loss of sensitive coldwater fish species due to thermal pollution;
   - A loss of wetlands, riparian buffers and springs; and
   - A general decline in aquatic habitat quality.

   Development often occurs in the headwaters of streams and rivers. These very small creeks and streams are home to many species that are sensitive to environmental changes and pollution. Urbanization alters headwaters by covering or ditching them, removing riparian vegetation, increasing water temperature, and altering water quality.

   Urbanization also indirectly alters forest ecosystems by modifying hydrology, altering nutrient cycling, introducing non-native species, changing atmospheric conditions, and modifying the historic patterns of natural processes.

5. **Decline in aesthetic value and recreational potential:** Recreational activities including fishing, paddling, and swimming rely on clean, healthy water bodies. People are less likely to participate in these activities where waterbodies are polluted, algae-chocked and lacking natural ecological features. Preserving natural stream functions is vital to keeping these valuable resources available for recreational purposes.

6. **Change in groundwater flow, volume and direction:** Generally, as development increases, the volume of precipitation contributed to shallow groundwater systems and deep groundwater reserves decreases. This is because impermeable surfaces and soil compaction provide a barrier to infiltration causing additional precipitation to runoff.

Combined with the effects of decreased infiltration volumes directed to shallow and deep groundwater aquifers, which supply baseflow to local watercourses and wetlands and is a source of drinking water for many Ontarians, the dramatic increase in water borne pollution such as litter, heavy metals and nutrients, in addition to increases in stream water temperature - the alteration to the hydrology of the watershed and the associated water balance can have a significant and often irreversible impact.

1.8 Introduction to Green Infrastructure and Low Impact Development

Green Infrastructure (GI) is a term that can encompass a wide array of stormwater management practices that control wet weather impacts and may provide many community benefits. For the purposes of this manual, the following definition of green infrastructure, which is consistent with the Provincial Policy Statement (PPS) applies:

Green infrastructure (GI): means natural and human-made (engineered) elements or systems 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, as well as LID BMPs (Figure 1.2). At its core, green infrastructure is a fundamental approach to rainwater management that protects, restores, or mimics the natural water cycle while delivering environmental, social, and economic benefits.

Low Impact Development (LID) is a stormwater management strategy, system, or facility, 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 human made or engineered elements or systems used for the management of rainwater and stormwater runoff (Table 1.2). Low Impact Development is the term used in this manual, but it can be alternately referred to as sustainable urban drainage systems, water sensitive urban design, or stormwater source controls. LID employs site design strategies that minimize runoff and distributed, small scale structural practices to mimic natural water cycle or predevelopment hydrology through the processes of infiltration, evapotranspiration, harvesting, filtration, detention and use of stormwater.

These practices can effectively remove contaminants, such as nutrients, pathogens and metals from runoff, and they reduce the volume and intensity of stormwater flows.

Table 1.2 - Green Infrastructure and Low Impact Development

Green Infrastructure	
Natural (Rainwater Management) • Natural heritage features and systems • Parklands • Street trees and urban forests • Natural channels and floodplains	Human-made or Engineered (Rainwater and Stormwater Management) • Naturalized end-of-pipe stormwater management systems • LID facilities • Street trees and urban forests

The underlying concept is that each LID and traditional practice within the treatment train provides successive attenuation, storage, and water quality benefits. Furthermore, LID source and conveyance practices may help to meet other objectives 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.

1.8.1 LID Approach and LID Practices

The LID approach begins at the earliest stage of site planning and design. Consideration of environmental goals during the layout of a development can result in better site design and pollution prevention. A LID stormwater management system may include many different types and combinations of LID approaches and practices to provide control and protection. Each LID approach or practice incrementally reduces the volume of stormwater runoff or filters the stormwater runoff on its way to the receiver.

The 2003 Stormwater Manual includes design guidance for some infiltration and filtration practices that should be reviewed. For example, it includes guidance on setback distance from a building for the location of soak away pits, infiltration trenches, surface ponding areas as well as land slope within the proximity of a building to mitigate potential for basement flooding. For more information on LID BMPs and other considerations, please see the Resource Directory in Appendix 3.

1.8.1.1 Better Site Design

Low impact development begins with the application of the principles of 'better site design'. From a stormwater management perspective, better site design involves considering site-level opportunities and constraints to stormwater management infrastructure from the beginning of the site design process. On-site conditions such as topography, soil composition, depth to bedrock, and depth to groundwater table should inform the design of stormwater infrastructure. For redevelopment projects, existing infrastructure may also result in opportunities and constraints. There are many better site design techniques which can be applied early in the design process at development sites. While not all of the techniques will apply to every development, the goal is to apply as many of them as possible to maximize stormwater reduction benefits before the use of structural LID BMPs.

The application of better site design techniques is the most cost-effective means of achieving stormwater management targets, as many of the techniques are no-cost approaches, and some may in fact represent a potential cost savings. Better site design techniques include:

- Preserving natural areas and natural area conservation;
- Site reforestation;
- Stream and shoreline buffers;
- Open space design;
- Disconnecting and distributing runoff;
- Disconnection of surface impervious cover;
- Rooftop disconnection;
- Disconnection of foundation drainage disposal from a municipal stormwater collection system;
- Efficient land use and dual land use of stormwater features (e.g., parks, sports field);
- Stormwater/ absorbent landscaping;
- Reducing impervious cover via innovative site design where municipal and provincial standards allow:
    - Narrower streets
    - Slimmer sidewalks
    - Smaller cul-de-sacs
    - Shorter driveways
    - Optimally sized parking lots

1.8.1.2 Pollution Prevention

Following the application of better site design principles, the implementation of effective non-structural and structural pollution prevention approaches, also represent an important first step in the design of LID BMPs. Pollution prevention approaches are a cost-effective means of achieving stormwater management targets. Many pollution prevention techniques are no-cost approaches, and some may in fact represent a potential cost savings.

The *Canadian Environmental Protection Act, 1999* (CEPA, 1999) defines pollution prevention as “the use of processes, practices, materials, products, substances or energy that avoid or minimize the creation of pollutants and waste and reduce the overall risk to the environment or human health”.

Pollution prevention is a key component of stormwater management on all sites. Pollutants that are prevented from mixing with runoff do not have to be treated by LID BMPs (source & conveyance) or end-of-pipe controls that rely on filtration and settling. This can reduce the capital costs of structural stormwater management controls (LID BMPs and end-of-pipe controls), can improve operational efficiency and reduce long-term operation and maintenance burdens.

On project sites that contain catchment areas with high risk site activities (Section 4.2.1), pollution prevention should be used to eliminate the risk of certain pollutants from contaminating site runoff.

Pollution prevention methods include but are not limited to:

- Replacing material and products that generate pollutants with those with less of an impact;
- Modifying equipment and/or processes to reduce the risk of contaminant releases;
- Spill and leak prevention;
- On-site reuse, recycling or recovery of waste and waste by-products; and
- Inventory management and storage technique improvements.

Better site design, pollution prevention and LID BMPs, together with traditional BMP’s as part of a treatment train approach can be applied to achieve an overall stormwater management system which when compared to conventional stormwater practices alone:

- Provides better performance (see the Resource Directory);
- Is more cost effective (see Appendix 4 and the Resource Directory);
- Has lower maintenance burdens (see Chapter 9 and the Resource Directory); and
- Is more protective during extreme storms (see the Resource Directory).

LID stormwater management practices include source controls and conveyance controls. Source controls at the lot or property include physical measures that retain runoff, encourage the infiltration of water into the ground and reduce runoff volumes before water enters the subsurface or surface drainage systems. The flexible design nature of source controls allows them to be incorporated into a wide-variety of site types and configurations. Stormwater conveyance systems are linear stormwater transport features and are generally located within the road Right-of-Way (ROW). Conventionally stormwater conveyance systems were designed only to move runoff from one area to another. LID approaches to stormwater design allow for infiltration and filtration of stormwater within a linear conveyance network.

Low Impact Development stormwater management BMPs are listed in Table 1.3, including their general location as either a source control, conveyance control or both and their control mechanisms.

Table 1.3 - LID Practices, Location and Control Mechanisms

LID Practices	**Lot or Source**	**Conveyance**	**Infiltration (Retention)**	**ET (Retention)**	**Reuse (Retention)**	**Filtration**	**Detention**
Rain water harvesting (irrigation)	✓	✓	☑	☑	☑	x	x
Rain water harvesting (other reuse)	✓	✓	x	x	☑	x	x
Green Roofs	✓		x	☑	x	☑	☑
Downspout disconnection	✓		☑	☑	x	☑	☑
Foundation drain disconnection	✓		☑	☑	x	☑	☑
Soakaways, Infiltration Trenches and Chambers	✓	✓	☑	x	x	x	☑
Bioretention (rain gardens)	✓	✓	☑	☑	x	☑	☑
Vegetated Filter Strips	✓	✓	☑	☑	x	☑	☑
Permeable Pavements	✓	✓	☑	x	x	☑	☑
Enhanced Grass Swales (vegetated swales)	✓	✓	☑	☑	x	☑	☑
Dry Swales (bioswales)	✓	✓	☑	☑	x	☑	☑
Perforated Pipe Systems		✓	☑	x	x	x	☑
Tree BMPs	✓	✓	☑	☑	x	☑	☑
Soil Amendments	✓	✓	☑	☑	x	☑	☑

Notes: ET – Evapotranspiration, ✓ or ☑ – Yes, x – No

1.8.1.3 Rainwater Harvesting

Rainwater harvesting is the process of collecting, treating and storing rainwater for use. Harvesting rainwater for domestic purposes has been practiced in rural Ontario for well over a century. Roof runoff is an ideal source for this practice due to the large surface area and minimal exposure to contaminants. Rainwater harvesting not only reduces the volume of runoff that is conveyed offsite, but also reduces the use of municipally treated water. Rainwater harvesting systems convey runoff to a storage tank or cistern. Prefabricated storage units can range in size from a simple rain barrels that tie into downspouts to precast concrete tanks capable of storing tens of thousands of litres or more from much larger catchment areas. Cisterns can be located inside a building or outside.

Rainwater that is collected in a cistern can be used for non-potable indoor or outdoor uses. Sufficient pre-treatment options include gravity filtration or first flush diversion. The irrigation of landscaped areas and washing of site features and vehicles are common uses of harvested rainwater. The 2006 Ontario Building Code explicitly allows the use of harvested rainwater for toilet and urinal flushing (See Section 7.1.5.3 of the Code). The Canadian Standards Association has standards B.128.1 and B.128.2 that address the design, installation, maintenance and field testing of non-potable water systems.

Note that potable uses of harvested rainwater or stormwater will require considerations outside the scope of the LID Guidance Manual as there are additional standards, guidance or requirements for potable water including approval requirements for drinking water systems.

1.8.1.4 Green Roofs

Green rooftops, also known as "living roofs" or "rooftop gardens" consist of a thin layer of vegetation and growing medium installed on top of conventional flat roofs or modestly sloped roofs. Green roofs are touted for their multiple benefits to cities, as they improve energy efficiency, reduce heat island effects, and can create urban green space for passive recreation, aesthetics and habitat. To a water resources manager, they are attractive for their water quality, water balance, and geomorphic benefits. Hydrologically speaking, a green roof acts like a lawn or meadow by storing rainwater in the growing medium and ponding areas. Excess rainfall enters an underdrain and is conveyed in a typical building drainage system to the next LID BMP in the treatment train or outfall. After the storm, stored water is transpired by the plants or evaporates. Green roofs are particularly useful in developments with a high percentage of lot coverage sites where space for ground level BMPs is limited.

1.8.1.5 Downspout disconnection

Downspout disconnection involves directing flow from downspouts to the lawn or another pervious area. This prevents stormwater from directly entering the drainage system or flowing across a "connected" impervious surface such as a driveway or parking lot. Downspout disconnections are typically used in combination with other LID BMPs but can be used as standalone techniques if appropriate quantities of pervious area are present. Please note the 2 metre setback distance guidance from a building for roof leader discharge to the yard under the 2003 Stormwater Manual.

1.8.1.6 Soakaways, Infiltration Trenches and Chambers

Soakaways, infiltration trenches and chambers and can be used to reduce runoff volume and maintain or enhance recharge. Most surface areas can be directed to infiltration practices without pre-treatment. Roads and parking lots should be provided with pre-treatment devices to prevent clogging, extend their lifecycle, and protect groundwater quality.

This practice is also known as infiltration galleries, french drains or dry wells, are excavations in the native soil that are lined with geotextile fabric and filled with clean granular stone. They are typically designed to accept runoff from a relatively clean water source such as a roof or pedestrian area. Where possible, they should be installed where native soils allow for infiltration; however, like other infiltration techniques, underdrains can be installed where poorly drained soils are present. These practices can be designed in a broad range of shapes and sizes.

Infiltration chambers are a variant that use prefabricated modular plastic or concrete structures (rather than only aggregates) installed over a granular base to provide maximum void space (up to 90%) and provide structural support. These systems provide more storage capacity than equivalently sized soakaways and have minimal footprints. Infiltration chambers are ideal for heavily urbanized sites because they can be installed below parking lots or other impervious surfaces without compromising available vehicle parking. Infiltration chambers have also been successfully installed below recreational fields and public urban courtyards. They can be designed in many configurations to suit site constraints. Please note the 4 metre setback distance guidance from a building for soak away pits, infiltration trenches and practices under the 2003 Stormwater Manual. In situations where the Ontario Building Code applies, please refer to the Code for setback distance for a “dry well” (e.g., 5 metres) from the building foundation.

1.8.1.7 Bioretention (Rain Garden)

As a stormwater filtration and infiltration practice, **bioretention** temporarily stores, treats and infiltrates runoff. The primary component of the practice is the bioretention soil media. This component is comprised of a specific ratio of sand, fines and organic material. Another important element of bioretention practices is vegetation, which can be either grass or a more elaborate planting arrangement such as an ornamental garden.

Bioretention can be integrated into a diverse range of landscapes including as roadside practices, open space, and as part of parking lots and landscaped areas a perimeter control. Perimeter controls are placed adjacent to the impermeable surface (i.e. parking lot) typically at the low point where it can efficiently collect runoff.

Bioretention practices are commonly referred to as "rain gardens". Depending on the native soil infiltration rate and site constraints, bioretention practices may be designed without an underdrain for full infiltration, with an underdrain for partial infiltration, or with an impermeable liner and underdrain for filtration only (commonly called a biofilter) where infiltration is not desired or where contaminated soils are encountered. Please note the 4 metre setback distance guidance from a building for infiltration practices under the 2003 Stormwater Manual. Bioretention can also be configured as bioretention planter or bumpout.

Rain Garden – an open area landscaped feature or garden. Rain gardens are typically on of the most common LID BMP and are typically applied within park setting, parking lots, at commercial and institutional buildings as well as on residential properties.

Bioretention Planter - have vertical sidewalls and are often narrow and rectangular in shape. The walls allow bioretention planters to maximize the amount of stormwater retention within a small footprint. The self-contained structure of bioretention planters permits them to be installed in close proximity to utilities, buildings, trees, light standards and other landscape features. Bioretention planters can be constructed immediately adjacent to the roadway, in the boulevard, or as a green feature within the pedestrian area (i.e. sidewalks and pathways) and are ideal for highly urbanized areas.

Bioretention Bump-Out (also known as curb extensions) are bioretention areas that extend into the asphalt surface of a roadway and are separated from the paved area by perimeter curbing. Bioretention bump outs are a very flexible LID and can be constructed during resurfacing or reconstruction projects. The location, size and spacing of bioretention bump outs can be adjusted as needed to meet existing conditions.

1.8.1.8 Vegetated Filter Strips

Vegetated filter strips (buffer strips and grassed filter strips) are gently sloping, densely vegetated areas that treat runoff as sheet flow from adjacent impervious areas. They function by slowing runoff velocity and filtering out suspended sediment and associated pollutants, and by providing some infiltration into underlying soils. Originally used as an agricultural treatment practice, filter strips have evolved into an urban stormwater management practice. Vegetation may be comprised of a variety of trees, shrubs and native plants to add aesthetic value as well as water quality benefits. With proper design and maintenance, filter strips can provide relatively high pollutant removal. Vegetated filter strips can also be designed as pre-treatment step to a bioretention facility. Maintaining sheet flow into the filter strip through the use of a level spreading device (e.g., pea gravel diaphragm) is essential.

1.8.1.9 Permeable Pavements

Permeable pavement is an alternative pavement system to conventional asphalt or concrete pavement. A permeable pavement system has pore spaces or joints that allow stormwater to pass down through the pavement layer such that surface runoff is reduced or eliminated. The stormwater then enters a stone base for infiltration into underlying native soil or is temporarily detained for flood control purposes. It should be noted that permeable pavement infiltrates during winter months and has the potential to reduce salt use. Typical types of permeable pavement include:

- pervious concrete;
- porous asphalt;
- permeable interlocking concrete pavers (PICP) (i.e., block pavers);
- plastic or concrete grid systems (i.e., grid pavers or grass pavers); and
- rubberized granular surfaces, bricks and pads.

Permeable Pavements can be implemented as sidewalks, driveways, multi-use pathways, on-street (lay-by) parking, alleyways, road shoulders and even minor or local roadways themselves but are most commonly applied in parking lots.

Pervious Concrete Parking Lot

Permeable Interlocking Concrete Paver (PICP) Driveway

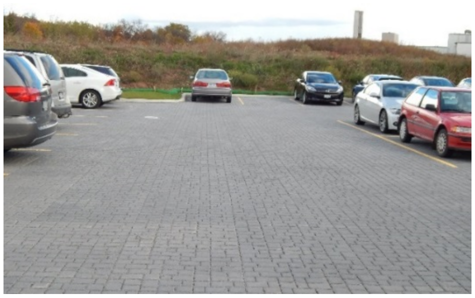
Porous Asphalt Roadway

Permeable Plastic Grid System

PICP Parking Lay-by and Sidewalk

When implemented within a parking lot, permeable pavement can be implemented partially or fully across the parking lot.

Partial permeable pavement parking surface has permeable pavement that is strategically constructed within the parking stall areas only and the central drive-lanes remain as conventional asphalt. In this manner, the permeable pavement systems can accept runoff from impervious areas (i.e. drive lanes).



Full permeable pavement parking surface has permeable pavement for drive lanes and parking stalls.

1.8.1.10 Enhanced Grass Swales (Vegetated Swales)

Enhanced grass swales are vegetated open channels designed to convey, treat and attenuate stormwater runoff (also referred to as enhanced vegetated swales). Check dams and vegetation in the swale slows the water to allow sedimentation, filtration through the root zone and soil matrix, evapotranspiration, and infiltration into the underlying native soil. Simple grass channels or ditches have long been used for stormwater conveyance, particularly for roadway drainage. Enhanced grass swales incorporate design features such as modified geometry and check dams that improve the contaminant removal and runoff reduction functions of simple grass channel and roadside ditch designs. A dry swale is a design variation that incorporates an engineered soil media bed and optional perforated pipe underdrain system. Enhanced grass swales are not capable of providing the same water balance and water quality benefits as dry swales, as they lack the engineered soil media and storage capacity of that best management practice.

1.8.1.11 Dry Swales (Bioswales)

A **dry swale** can be thought of as an enhanced grass swale that incorporates an engineered soil (i.e., filter media or growing media) bed and optional perforated pipe underdrain or a bioretention cell configured as a linear open channel. They can also be referred to as infiltration swales or bioswales.

Dry swales are similar to enhanced grass swales in terms of the design of their surface geometry, slope, check dams and pre-treatment devices. They are similar to bioretention cells in terms of the design of the filter media bed, gravel storage layer and optional underdrain components. In general, they are open channels designed to convey, treat and attenuate stormwater runoff. Vegetation or aggregate material on the surface of the swale slows the runoff water to allow sedimentation, filtration through the root zone and engineered soil bed, evapotranspiration, and infiltration into the underlying native soil. Dry swales may be planted with grasses for simple maintenance or have more elaborate landscaping for higher aesthetic appeal. Dry Swales are implemented to provide water quality treatment and water balance benefits beyond those of a conventional ditch. Dry Swales are sloped to provide conveyance, but due to their permeable soil media and gravel, surface flows are only expected during intense rainfall events. Sites with existing swales or ditches are ideal candidates for retrofitting with dry swales. Dry swales are the most commonly applied LID as part of complete streets and parking lots.

1.8.1.12 Perforated Pipe Systems

Perforated pipe systems, also called exfiltration systems, can be thought of as long infiltration trenches that are designed for both conveyance and infiltration of stormwater. They are underground stormwater conveyance systems composed of perforated pipes installed in gently sloping granular stone beds lined with geotextile fabric that allows exfiltration of runoff into the gravel bed and infiltration into the underlying native soil.

Perforated pipe systems can be used in place of almost any conventional storm sewer pipes where topography, water table depth, and runoff quality conditions are suitable. Perforated pipe systems employ many of the same materials and construction practices as conventional storm sewer pipes. They are capable of handling runoff from roofs, walkways, parking lots, and roads. For roads applications, these systems can be located within boulevard areas or beneath the roadway surface itself.

1.8.1.13 Tree BMPs

The **use of trees** to manage stormwater runoff has been shown to be a highly effective approach. Mature trees and forest canopy, reduces stormwater runoff volume and peak flow and improve water quality, generate organic soils, absorb greenhouse gases, create wildlife habitat, and provide shading to mitigate temperature increases at development sites. Tree BMPs can encompasses several practices including tree conservation (during and post-construction), tree trenches, tree boxes and tree pits often combined with soil support systems and can be incorporated anywhere in the stormwater treatment train but are most often located in upland areas of the treatment train or within roadway and parking lot contexts. Tree BMPs can mimic certain physical, chemical, and biological processes that occur in the natural environment. The strategic distribution of tree BMPs help control runoff close to the source where it is generated.

Tree BMPs are one component of urban forestry. Urban forestry is a broad term that applies to all publicly and privately-owned trees within an urban area, including individual trees along streets and in backyards, as well as stands of remnant forest (Nowak et al. 2001). Urban forests are an integral part of community ecosystems, whose numerous elements (such as people, animals, buildings, infrastructure, water, and air) interact to significantly affect the quality of urban life. Trees are already part of virtually all development and can be integrated anywhere in the treatment train, even into the densest urban areas. Many cities already have tree planting requirements and supporting by-laws which can be effectively leveraged as part of a holistic stormwater management approach. However, the potential of these trees to provide significant stormwater benefits is largely untapped to date. (Minnesota, 2017).

1.8.1.14 Soil Amendments

Compost or **soil amendments** are tilled or mixed into existing soils thereby enhancing or restoring soil properties by reversing the loss of organic matter and compaction. They also are used to make Hydrologic Group C and D soils suitable for on-site stormwater BMPs such as downspout disconnection, filter strips, and grass channels, etc. Soil amendments benefits include increased infiltration, stormwater storage in the soil matrix, survival rate of new plantings, root growth and stabilization against erosion, improved overall plant health and decreased need for irrigation and fertilization of landscaping. Amended soils are suitable for any pervious area where soils have been or will be compacted by the grading and construction process. While soil amendments will never be used solely to meet stormwater management objectives, they are effective in reducing the overall runoff volume, will contribute to a lower peak discharge, and can help improve water quality by reducing contaminate loads.

1.8.2 Benefits of Low Impact Development

LID techniques mimic natural systems as rain travels from the runoff source to the receiver by applying a series of practices across the entire subwatershed, development area, and or site before discharging. Real-world LID designs typically incorporate a series of BMPs in a 'treatment train' approach to provide integrated treatment of runoff from any and all sites.

LID BMPs used together with conventional stormwater BMPs as part of an overall holistic treatment train approach have been shown to better meet stormwater management targets and objectives, provide better performance, are more cost effective, has lower maintenance burden, and are more protective during extreme storms than conventional stormwater practices alone.

As discussed previously, LID is an approach to stormwater management that uses simple, distributed and cost-effective engineered landscaped features and other techniques to infiltrate, store, filter, evaporate, detain, and use rainfall where it falls. The principles of LID are part of the evolution of stormwater management whereby rainwater is managed as a resource. A comparison of the benefits of stormwater management approaches is provided in Table 1.4.

Table 1.4 - Benefits of Low Impact Development

Objectives/Outcomes for Stormwater Management	Conventional Storm Sewer - with No Treatment	Conventional Infrastructure - with Treatment	LID or Green Infrastructure
Maintain appropriate opportunities for human uses	○ Less	○ Less	● More
Maintain appropriate diversity of aquatic life	○ Less	◘ Effective	● More
Protect water quality	○ Less	● More	● More
Preserve groundwater and baseflow characteristics	○ Less	○ Less	● More
Reduce combined sewer overflow	○ Less	○ Less	● More
Reduce flooding risk	◘ Effective	● More	● More
Reduce occurrences of excessive stream erosion	○ Less	● More	● More
Protect the ecosystem by maintaining the natural hydrologic cycle to the greatest extent possible	○ Less	○ Less	● More
Increase resiliency of infrastructure and ecosystem to climate change	○ Less	◘ Effective	● More

○ Less Effective ◘ Effective ● More Effective

Each element of the treatment train (LID and conventional BMPs) incrementally reduces the volume of stormwater on its way to the receiver. In doing so, LID BMPs have the potential to achieve a broader range of benefits including:

- maintaining the pre-development water balance;
- conserving, restoring, and enhancing natural features;
- maintaining and enhancing shallow groundwater levels and interflow patterns resulting in the preservation of base flow;
- maintaining predevelopment drainage divides and catchment discharge points;
- moderating runoff velocities and discharge rates;
- improving water quality;
- enhancing evapotranspiration;
- maintaining soil moisture regimes and hydroperiods to support the viability of vegetation communities;
- maintaining surface and groundwater supplies to support existing wetland, riparian and aquatic habitats;
- reducing the peak flow intensity and runoff volume from a wide range of storm events;
- reducing the frequency of flow events;
- reducing channel degradation and in-channel erosion;
- minimizing impacts and increase resiliency to urban flooding;
- reducing combined sewer overflows through runoff volume reductions (via increasing infiltration and evaporation) and slower release rates to overstressed or at capacity sewer networks; and
- climate change resilience

It should be noted that while LID can reduce flooding risk, it is not the primary control for flooding. Guidance on planning for or managing flooding is beyond the scope of the LID Guidance Manual for stormwater management.

1.8.3 Economic impact of Low Impact Development

Many stormwater economic analyses involve cost analysis - capital, operating or life cycle cost without sufficient recognition that municipal stormwater management provides protection of Ontario's environment and provides valuable services to the people and businesses in the community. Achieving outcomes associated with the objectives of stormwater management discussed in Section 1.3 can have economic benefits that may be appropriate to consider as part of benefit-cost analysis for stormwater management systems.

Although individual LID BMPs may increase the capital cost of a development or re-development project, there are several long-term benefits beyond improved stormwater management performance. Experience in Ontario, Canada and the United States have repeatedly shown that implementing well-chosen, planned and sited LID BMPs can save money for developers, property owners, and communities while protecting and restoring water quality (EPA, 2007; CMHC, 2017 and CVC, 2014 with more information provided in Appendix 4 LID Economics). Additionally, the use of LID can improve climate change resiliency and mitigate urban heat island effects. Overall, municipalities have primary responsibility for stormwater management services for their communities and would benefit from a long-term planning approach, including redevelopment and retrofit opportunities, that considers needs of their communities and economic feasibility. While economic benefit and cost information of other jurisdictions and organizations is relevant to consider, case specific benefit-cost analysis on a system and community-wide basis may be useful for a municipality or other proponent to understand the environmental impacts, socio-economic benefits and costs to inform long term planning for stormwater management services.

All of the costs of a development should be considered including the costs of not providing adequate stormwater controls. This is sometimes referred to as a "triple bottom line” analysis. To achieve sustainable development and climate change resilience, developers must address the economic, social, and environmental aspects of their projects. The analysis should employ a systematic evidence-based economic business case framework that uses best practice life cycle cost analysis and cost benefit analysis techniques to quantify and attribute monetary values to the impacts resulting from the development. This type of analysis expands the traditional financial reporting framework (such as capital, and operations and maintenance costs) to also consider social and environmental performance.

In Ontario, the City of Kitchener completed an analysis of the impacts of climate change and the adaptation benefits of LID on their stormwater management system (storm sewers and facilities) as part of their Integrated Stormwater Management Master Plan (Aquafor Beech, 2016). Based on the analysis of climate change scenarios, the City’s 1:5-year rainfall event (standard for storm sewer design) was predicted to increase by 17.4% based on localized climate projections prepared for the Region of Waterloo. This was acknowledged in the city’s climate change hydrologic modelling scenarios. To assess the impact of city’s LID implementation policies on existing conditions and climate change scenarios, the city’s volume retention policy was applied to appropriate urban catchments. Table 1.5 indicates the results of this analysis. Of note is that using LID as an adaptation strategy is expected to reduce total length of surcharged pipes in a future climate, thereby greatly decreasing the capital asset replacement cost.

Table 1.5 - City of Kitchener 1:5-year Design Storm Flooding Summary with Climate Change and Low Impact Development

Scenarios	Total Length of Pipe at Full Capacity (m)	Total Length of Surcharged Pipes (m)	Cost Implications ($ millions) †
Existing Conditions	10,723	13,763	$15.8
Climate Change on Existing Conditions	13,934	19,566	$22.5
LID Volume Control on Existing Conditions:	4,585	5,842	$6.7
Climate Change & LID Volume Control	10,685	14,691	$16.9

† Assumes a unit replacement cost of $1,150/linear metre

Municipalities and other proponents of stormwater management facilities and systems are encouraged to consider economic benefits of services in addition to cost analysis. Since municipal stormwater management is a municipal service that benefits the people and businesses in the community, it would be valuable to recognize the monetary value of these benefits for the people and businesses as part of the benefit-cost analysis of long term planning and implementation for stormwater management and to support dialogue with local public and businesses. Some have quantified the economic benefits associated with LID stormwater management that relate to reduced conventional stormwater management infrastructure, reduced reliance on combined sewer infrastructure, increased recreational opportunity, improved air quality, increased property value, reduced flooding risk or reduced energy use (CNT, 2020; CNT, 2010; Marbek, 2010; USEPA, 2014).

1.9 Supporting Resources

Within the province, several organizations have established themselves as leaders in the field of innovative stormwater management by authoring supporting documents and resources informed through the installation, monitoring and support of private sector implementation of LID BMPs. For example, LID resources are provided by the Sustainable Technologies Evaluation Program (STEP). STEP is currently operated collaboratively by Toronto and Region Conservation Authority (TRCA), Credit Valley Conservation (CVC), and Lake Simcoe Region Conservation Authority (LSRCA). These resources may be considered as appropriate during the following phases of LID implementation:

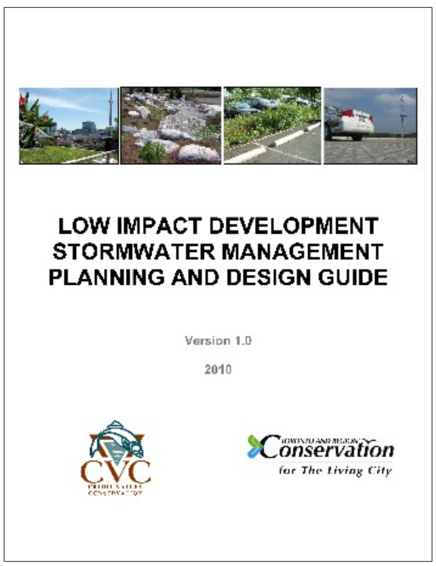
- Planning and design;
- Construction; and
- Assumption, maintenance and lifecycle activities.

The STEP website, sustainabletechnologies.ca, is also a publicly available source of comprehensive LID monitoring data and performance studies.

The following LID resource documents and other resources may be considered as appropriate, including those listed in the Resource Directory in Appendix 3. The Resource Directory includes links where resources can be downloaded. The resources are listed as a convenience and not as an endorsement. The documents identified may not be up-to-date and those interested in consulting the documents are encouraged to go to the source.

LID Resources for Planning & Design

The CVC/TRCA Low Impact Development Stormwater Management Planning and Design Guide was co-released by CVC and the TRCA to provide engineers, ecologists and planners with up-to-date information and direction on landscape-based stormwater management planning and Low Impact Development stormwater management BMPs for new or existing development areas.



The Design Guide provides design criteria for source and conveyance stormwater management practices including:

- Rainwater harvesting;
- Green roofs;
- Roof downspout disconnection;
- Soakaways, infiltration trenches and chambers;
- Bioretention;
- Vegetated filter strips;
- Permeable pavement;
- Enhanced grass swales;
- Dry swales; and
- Perforated pipe systems.

The CVC/TRCA LID Stormwater Management Planning and Design Guide currently exists as both a traditional document and as a curated website that encourages feedback from experts and users and which is found at https://wiki.sustainabletechnologies.ca/wiki/Main_Page. References to CVC/TRCA 2010 also include the curated website (wiki).

The CVC/TRCA LID Stormwater Management Planning and Design Guide describes the key principles for Low Impact Development Design 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;
- 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; and
- 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.

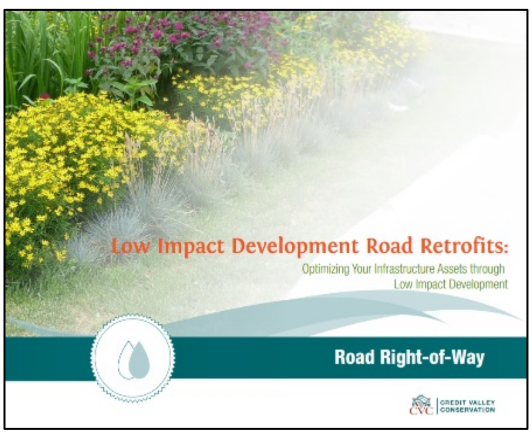
5. Educate and maintain.
- Provide adequate training, funding, or legal agreements to monitor and maintain lot level and conveyance stormwater management practices on public property;

- Teach property owners, managers and their consultants how to monitor and maintain source and conveyance control stormwater management BMPs on private property;
- Establish legal agreements to ensure long-term operation and maintenance (See Chapter 9).

The CVC/TRCA LID Stormwater Management Planning and Design Guide also includes the following information:

- Fact Sheets for LID BMPs that provide quick technical references for general design guidance, applications, construction considerations, common concerns, ability to meet stormwater management objectives, and site considerations.
- A Landscape Design Guide for LID that provides land managers and professional practitioners with an understanding of the guiding principles of LID planting design, selection, implementation and management.
- A Site Evaluation and Soil Testing Protocol for field testing protocol for infiltration-based LID BMPs.

LID Resources for Planning & Design (Retrofits)



The Grey to Green Road Right of Way Retrofit Guide, released by CVC, provides guidance for municipal retrofits of road right of ways (ROWs) with innovative LID BMPs. The guide provides municipal planners, engineers and technical staff with guidance from screening LID options through lifecycle activities. Implementation in the guide has nine phases:

- Building the project team
- Background review
- Screening the LID options
- Pre-design
- Detailed design
- Approvals
- Tender & contract documents

- Construction supervision & administration
- Lifecycle activities

The Grey to Green Low Impact Development Residential Retrofits Guide, released by CVC, provides guidance for engaging residents to adopt LID BMPs on their private properties. This guide presents:

- Residential LID options
- Strategies for targeting neighbourhoods with LID
- Municipal retrofit project team requirements
- Methodology for conducting neighbourhood-level market research
- Marketing Plan Options
- Tips for rolling out a marketing plan

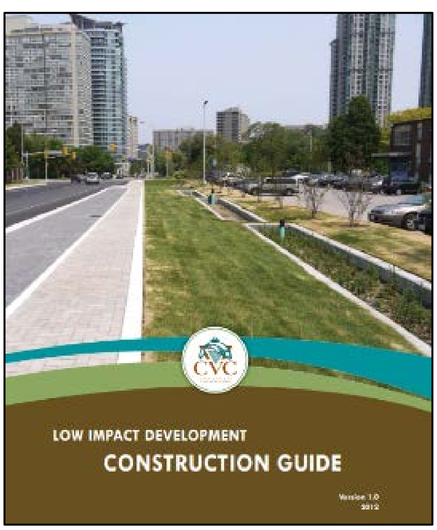
The Grey to Green Low Impact Development Business and Multi-Residential Guide, released by CVC, provides guidance for implementing LID retrofits on businesses, colleges, universities and multi-residential properties of all sizes. The guide presents:

- LID options
- Upfront requirements

- Site screening for opportunities and constraints
- Pre-design
- Detailed design
- Approvals
- Tender & contract documents
- Construction supervision & administration
- Lifecycle activities
- Tracking and reporting the LID project

The Grey to Green Public Lands Retrofit Guide, released by CVC, provides guidance for LID retrofits of public realm properties. The guide discusses LID options and implementation strategies for the following property types such as parks, municipal facilities, schools, and places of worship. The guide focuses on project team requirements and summarizes the implementation process as well as necessary lifecycle activities.

LID Resources for Construction, Maintenance, Assumption and Lifecycle Activities

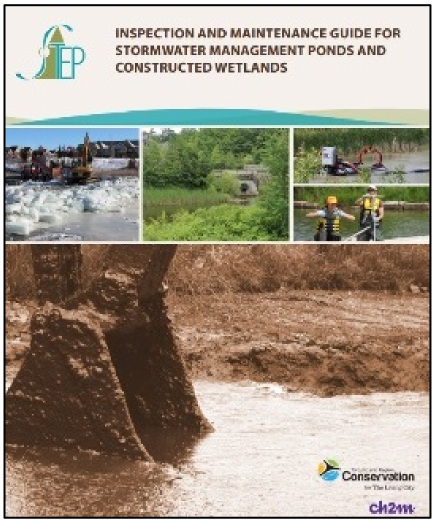


The Low Impact Development Construction Guide was released by CVC to provide guidance to design consultants, municipal engineers, plan reviewers, and construction project managers regarding common LID construction failures and how to avoid them. The goal of this document is to guide the proper construction of LID designs, and ultimately, the success of LID throughout Ontario. It includes:

- A discussion of common LID construction errors;
- Information on how to protect LID BMPs through all phases of construction; and
- Recommendations on improving contracts, plans, specifications and communication.

The Low Impact Development Stormwater Inspection and Maintenance Guide, released by TRCA, provides guidance for municipalities and property managers with developing their capacity to integrate LID BMPs into their infrastructure asset management programs. The document provides guidance on designing an effective inspection and maintenance program and recommends standard protocols for inspection, testing and maintenance.

The Sustainable Technologies Evaluation Program (STEP) Life Cycle Costing Tool allows users to generate realistic, reasonably accurate costs estimates for LID stormwater practices. The tool along with a user guide allows users to evaluate the capital and life cycle costs of LID BMPs over a long term (e.g., 50-year) horizon based on a detailed assessment of local input costs, maintenance, rehabilitation costs and design scenarios relevant to Canadian climates. Note that this is a cost analysis tool and not a comprehensive benefit-cost analysis tool.



The Inspection and Maintenance Guide for Stormwater Management Ponds and Constructed Wetlands, released by TRCA, serves as guideline to address fundamental elements that should be considered in routine stormwater management facility inspection and maintenance and sediment removal and disposal decision making processes.

Resources for LID Performance

The STEP website is a publicly available source of LID monitoring data performance studies. LID technical reports and case studies are also available on the Credit Valley Conservation website. On a broader level, several American organizations including the Environmental Protection Agency, the American Public Works Association, the American Society of Civil Engineers, and the U.S. Department of Transportation in collaboration with non-governmental organizations and consulting engineers have created an International Stormwater BMP Database which is available online including some Ontario data. (see Resource Directory)

A technical brief, Comparative Performance Assessment of Bioretention in Ontario (STEP, 2019), compares the performance of nine different bioretention facilities monitored by TRCA and CVC in Ontario. The following are some of the findings of the study:

- Bioretention facilities designed for infiltration of stormwater into the native soil were found to reduce runoff volumes by 60 to 92% over the monitoring period. These facilities were not lined.

- The combined benefit of runoff volume reductions and water quality improvements resulted in suspended solids (SS) load reductions of between 88 and 99% for the unlined facilities, and 73% and 79% for the two lined facilities.

- Phosphorus removal rates and effluent concentrations exhibited significant variation both seasonally and between sites. However, phosphorus load reductions in unlined facilities were impressive (e.g., 68 to 93%), despite evidence of phosphorus leaching from the filter media. As with SS, these load reductions were largely due to the reduction in runoff volumes.

2.0 ENVIRONMENTAL PLANNING PROCESS

Planning that integrates stormwater management and infrastructure resilience at the outset with protection of the ecological and hydrological attributes and functions of the watershed, provides the fundamental basis for achieving the key stormwater management objectives identified in Section 1.3 of this manual.

There are several policies, acts, regulations, and plans that have been developed by local, provincial and federal authorities that relate to the management of stormwater in Ontario. While municipal land use and environmental planning for stormwater management might vary from one municipality to another, the intent of this section is to provide a general overview of the planning process. Proponents should refer to the source agencies and their documents to ensure complete and accurate information.

2.1 Planning for Stormwater in Ontario

The provincial policy-led land use planning system recognizes and addresses the complex inter-relationships among environmental, economic and social factors in land use planning. It is governed by the *Planning Act*, the Provincial Policy Statement, 2020, and geographic-specific plans such as A Place to Grow: The Growth Plan for the Greater Golden Horseshoe (2019) and the Greenbelt Plan (2017). Municipalities and planning boards implement the province's land use planning policy framework through their official plans and other planning documents, and decisions on land use planning matters.

In Ontario, municipalities are responsible for land use and infrastructure planning, and stormwater management for their communities (e.g., planning, design, establishment, operation and maintenance) which accommodate the component of the urban surface run-off that is or would commonly be collected by means of separate municipal storm sewers. Many ministries and agencies provide oversight for stormwater management and surface drainage. Municipal stormwater management is complex, partly due to the multi-functional purpose of the infrastructure system and the many different agencies involved. Resilience to climate change is an additional factor contributing to the complexity.

Planning Act

The *Planning Act* is provincial legislation that sets out the ground rules for land use planning in Ontario. It describes how land uses may be controlled, and who may control them. The Act recognizes that municipal councils, landowners, developers, planners and the public play an important role in shaping a community.

The *Planning Act* gives municipalities the ability to create official plans and zoning by-laws, which in turn provide direction to various officials, staff and other authorities involved in the planning and development decision making process. Municipalities express their planning goals and policies for future land use through their official plans, which describe how land in the community should be used. It is prepared with input from the community and helps to ensure that future planning and development meet specific needs of the community. Zoning by-laws are used to put the policies in an official plan into effect and provide for its day-to-day administration. Among other things, the *Planning Act* also contains procedures for amending the official plan, for zoning bylaw amendments, and approval of plans of subdivision. It is important to note that municipal official plans, and planning decisions must be consistent with the PPS and must conform to or not conflict with any applicable provincial plans.

In Northern Ontario, some of the steps involved in land use planning differ from those in the rest of the province. As a result, land use planning in some northern municipalities and in areas that have no municipal organization may be shared by three authorities – Minister of Municipal Affairs and Housing (MMAH), planning boards, and the Ministry of Northern Development, Mines, Natural Resources and Forestry (MNDMNRF). It is the Minister of MMAH who approves official plans and amendments, as well as development applications except in areas where approval is granted by other planning authorities, such as planning boards. Where planning boards are established, they develop policies on land use planning that reflect the interests of the entire planning area and coordinate over-all future growth. With respect to the planning and management of Crown land in Northern Ontario, the MNDMNRF is the responsible authority. Before Crown land is developed, the ministry consults with affected municipal councils and planning boards and takes into consideration existing municipal official plans and policies, to help guide development activities.

Provincial Policy Statement

The Provincial Policy Statement (PPS) is issued by the Minister of MMAH under the *Planning Act* and provides provincial direction to municipalities and other planning approval authorities on land use planning, infrastructure planning, natural resource and environmental protection, economic development, protection of water resources, and safe and sustainable communities.

It provides for a land use planning system led by provincial policy and integrates matters of provincial interest into planning decisions by requiring that all decisions be consistent with the PPS. This means that planning authorities must ensure that the policies in the PPS are applied as an essential part of the land use planning decision-making process. Decision makers implement the PPS in the context of other planning objectives and local circumstances.

The goal of stormwater management planning in the PPS is to maintain the health of streams, lakes and aquatic life by mitigating the effects of development. The infrastructure policies in the PPS state that infrastructure, including stormwater management systems, shall be provided in a coordinated, efficient and cost-effective manner that considers impacts from climate change while accommodating projected needs. In addition, planning authorities are encouraged to promote stormwater best management practices, including stormwater attenuation and re-use, LID and green infrastructure in their planning processes in order to complement infrastructure. The PPS recognizes that strengthening stormwater management requirements are important components of broader infrastructure planning.

In addition, the PPS includes general water policies that strive to maintain the health of streams, lakes and aquatic life by mitigating the effects of development. In this regard, planning authorities shall ensure that stormwater management practices are provided in a coordinated, efficient and cost-effective manner that considers impacts from climate change. To support development and infrastructure planning, the PPS includes clear direction to planning authorities regarding the protection, improvement and restoration of the quality and quantity of water resources, including:

- using the watershed as the ecologically meaningful scale for integrated and long-term planning, which can be a foundation for considering cumulative impacts of development;
- minimizing potential negative impacts, including cross-jurisdictional and cross-watershed impacts;
- evaluating and preparing for the impacts of a changing climate to water resource systems at the watershed level;
- identifying water resource systems consisting of ground water features, hydrologic functions, natural heritage features and areas, and surface water features including shoreline areas, which are necessary for the ecological and hydrological integrity of the watershed;
- maintaining linkages and related functions among ground water features, hydrologic functions, natural heritage features and areas, and surface water features including shoreline areas; and
- implementing necessary restrictions on development and site alteration to:
    - protect all municipal drinking water supplies and designated vulnerable areas; and
    - protect, improve or restore vulnerable surface and ground water, sensitive surface water features and sensitive ground water features, and their hydrologic functions.
- planning for efficient and sustainable use of water resources, through practices for water conservation and sustaining water quality;
- ensuring consideration of environmental lake capacity, where applicable; and
- ensuring stormwater management practices minimize stormwater volumes and contaminant loads, and maintain or increase the extent of vegetative and pervious surfaces.

The PPS further recognizes that in addition to land use approvals under the *Planning Act*, stormwater management infrastructure may also require approvals and permits issued under other legislation, regulations, policies and plans.

Provincial Plans

The following provincial plans work together to manage growth, build complete communities, curb sprawl and protect the natural environment and water resources, and support economic development in Ontario:

- Growth Plan for the Greater Golden Horseshoe, 2019,
- Greenbelt Plan, 2017,
- Oak Ridges Moraine Conservation Plan, 2017, and
- Niagara Escarpment Plan, 2017

These plans build upon the policy foundation provided by the PPS and convey additional, or geographically-specific, land use planning policies, such as the need for integrated and long-term planning for stormwater management infrastructure (e.g., stormwater master plans), which include consideration of LID and green infrastructure. Some policies also seek to provide improved protection for water resource systems and natural heritage features, while other policies address municipal asset management planning through the assessment of the vulnerability and resilience of infrastructure to climate change risks (e.g., flooding).

In addition to the provincial plans identified above, the Growth Plan for Northern Ontario (2011) recognizes that a holistic approach is needed to plan for growth in Northern Ontario. It contains policies to guide decision-making about growth that promote economic prosperity, sound environmental stewardship, and strong, sustainable communities that offer northerners a high quality of life. With respect to stormwater management and planning, the policies are intended to:

- grow and diversify emerging opportunities in water, wastewater and stormwater technologies; and
- coordinate the planning for potable water, stormwater, and wastewater systems between communities that share inland water sources and/or receiving water bodies.

As well, the designated policies in the Lake Simcoe Protection Plan and the policies in source protection plans should be read in conjunction with other provincial plans, policies and acts. These plans may provide useful information on local hydrologic and hydrogeologic conditions that can inform site-specific retention and infiltration practices.

2.2 Planning for Stormwater in a Watershed Context

Watershed planning provides a framework for establishing goals objectives and actions to protect, restore or enhance the health of a watershed. It may be undertaken at many scales (e.g. subwatershed, tributary), with the level of analysis and specificity increasing for smaller geographic areas. Watershed planning helps to identify key hydrologic and natural features, understand and identify the conditions of a watershed and to identify measures to protect, restore or enhance the health of the watershed.

Watershed/Subwatershed Plans

Watershed planning is an effective tool to ensure that stormwater management solutions are based on an appropriate scale and consider cumulative effects of urbanization and growth. As outlined in the 2003 Stormwater Manual, watershed planning should inform environmentally sound land use and infrastructure decision-making within the context of municipal planning and growth management. Areas of focus of watershed and subwatershed plans may include (but are not limited to):

- watershed characterization;
- a water budget and conservation plan;
- nutrient loading assessments;
- consideration of climate change impacts and severe weather events;
- land and water use management objectives and strategies;
- scenario modelling to evaluate the impacts of forecasted growth, servicing options and mitigation measures;
- environmental monitoring plan;
- requirements for the use of environmental best management practices, programs and performance measures;
- criteria for evaluating the protection of quality and quantity of water; the identification and protection of hydrologic features, areas, and functions and the inter-relationships between or among them; and
- targets for the protection and restoration of riparian areas.

In general terms, a Watershed or Subwatershed Plan evaluates the integrated effect of land use scenarios (development, terrestrial linkages preservation, stream buffer preservation, environmentally sensitive/significant area preservation), and urban stormwater management on water balance, stream erosion, water quality, temperature, baseflow, flooding, terrestrial and fisheries habitats and life. These plans set multidisciplinary goals, objectives and targets, while the level of detail required for design comes from site specific proposals.

With a broad range of input received and with the proper technical and implementation steps undertaken, it should be possible to carry out subsequent studies at a much smaller scale (e.g., tributary or Secondary Plan level).

Stormwater Master Plans

Stormwater master plans are long-range plans that assess existing and planned stormwater facilities and systems and outline stormwater infrastructure needs for new and existing development with objectives that align with the key stormwater management objectives identified in Section 1.3 of this manual. These plans can integrate, among other things, aspects of urban flood control, groundwater and surface water quality, stormwater retrofit opportunities, LID and green infrastructure; and system drainage issues into a cohesive municipal-wide strategy. As such, watershed and subwatershed studies can be used to inform stormwater master plans and infrastructure needs. Master Drainage Studies may also be completed at this level of detail but focus more closely on identifying existing drainage deficiencies and developing solutions to address the deficiencies.

Many plans, including master plans, include analysis of estimated costs to build and operate the system over time. Given that municipal stormwater management is a municipal service that benefits the people and businesses in the community, a benefit-cost analysis can be a useful tool for supporting dialogue with local public and businesses and to inform planning decisions. Municipalities and other proponents of stormwater management facilities and systems are encouraged to consider economic benefits of services in addition to cost analysis.

Environmental Management Plans

Environmental Management Plans (also referred to as Environmental Impact Report or Master Environmental Servicing Plans) are typically completed at a level of detail that will allow individual subdivision plans to proceed pending completion of the plan, and prior to consideration of Draft Plan Approval. The scale for undertaking an Environmental Management Plan generally coincides with a tributary subcatchment boundary or Secondary Plan boundary, or portion thereof. Where a watershed or subwatershed plan is available, the plan will summarize and refine the findings of the previous plans at a higher level of resolution.

It is important to ensure that the Environmental Management Plan is of sufficient detail that all remaining environmental and/or stormwater management work may be completed as conditions of the Draft or Site Plan stage.

Environmental/Stormwater Management Reports

On a smaller scale, an Environmental/Stormwater Management Report is generally prepared in order to meet conditions set at the Draft Plan or Site Plan stage of the municipal planning process. These plans are both completed by a proponent of development and submitted to review agencies to demonstrate that the stormwater management measures meet municipal, agency and provincial standards, and may be submitted along with other plans (e.g., grading and erosion). At this stage, applicable requirements or actions outlined in higher level plans should be demonstrated, prior to approval.

Proponents are encouraged to use the Runoff Volume Control Target guidance outlined in Chapter 3 of this manual, however, locally developed targets for stormwater management informed by plans or studies, such as watershed and subwatershed plans, stormwater master plans, environmental management plans and master environmental servicing plans may be used as alternatives, provided they achieve the key stormwater management objectives identified in the Section 1.3.

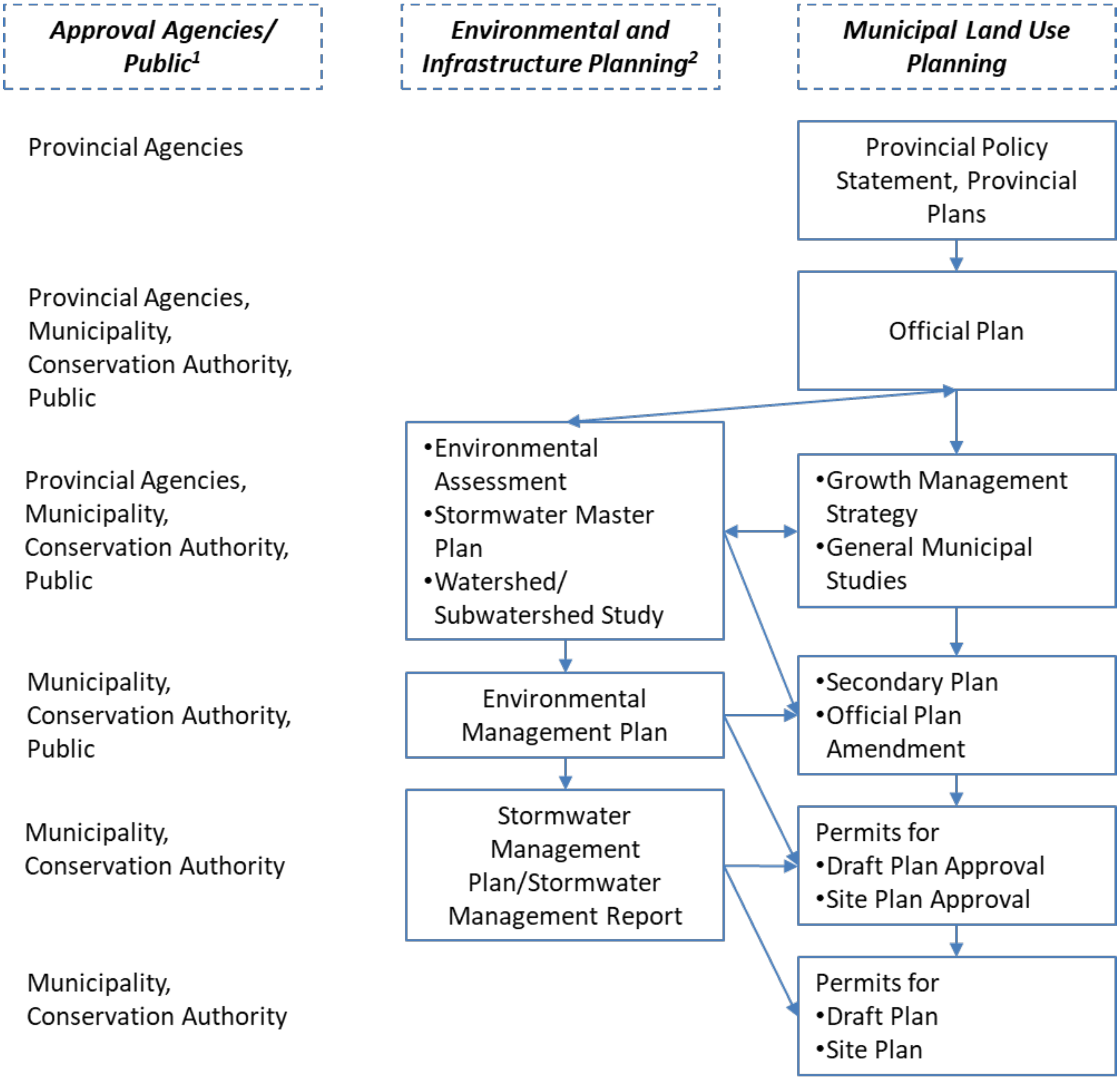
Major System for Surface Drainage
The major system is comprised of overland flow paths for runoff along roadways and open channels to provide safe conveyance of major storm events to nearby stream or river systems.

For urban areas, the major system includes natural streams, valleys, swales, artificial channels, roadways, stream road crossings and ponds. The major system conveys runoff from infrequent events that exceed the capacity of the municipal stormwater management system. The major system may be unplanned with high volume of overland flow (or floodwater) following existing natural or development topography and pathways to a water course, including through properties occupied by houses, buildings or infrastructure. A well designed major system will reduce the risk to life and property damage by providing overland flow routes to a safe outlet.

Although the primary of function of roads is to convey vehicular traffic, roads can be used to convey runoff. Standards for using the roadway as a floodway are set by the local municipality.

Figure 2.1 illustrates the stormwater management planning process within the context of land use planning in Ontario. It should be noted that this information is general for all levels of stormwater planning.

Figure 2.1 - Environmental and Municipal Planning Process



1 Approval agency / public involvement will vary from jurisdiction to jurisdiction.
2 For a given jurisdictional area one Environmental Planning component would generally be associated with one Municipal Land Use component. Multiple arrows leading from the Environmental Planning component to the Municipal Land Use signify different approaches which are used in different jurisdictions.

2.3 Environmental Assessment

An environmental assessment is an environmental planning and decision-making process that studies and documents the potential environmental effects of a project and allows interested persons to comment on projects that may affect them. Once an environmental assessment is complete, the applicant uses this information to make decisions on the project and moves on to any subsequent environmental permits or approvals required.

In Ontario, environmental assessments may be carried out as an individual/comprehensive environmental assessment (Comprehensive EA) or a streamlined environmental assessment. Comprehensive EAs are the most rigorous type of assessment in terms of planning and public consultation requirements; they are intended to be prepared for large-scale, complex projects where environmental impacts cannot be easily anticipated or mitigated and require approval by the Minister and Cabinet. Streamlined environmental assessments are conducted for projects that are considered to routine in nature and have predictable environmental effects that can be readily managed. These projects complete a prescribed assessment and consultation process.

Each streamlined process outlines which projects must follow it and categorizes them based on their potential for environmental effects (e.g., low, medium, or high). The level of assessment required for these projects corresponds with the category; the greater the potential for environmental risk, the higher the level of assessment. There are different types of streamlined assessment processes, including class environmental assessments (Class EA), and regulated environmental assessment processes. The Municipal Class EA process is an example of a Class EA process and is commonly used by municipalities for planning water and wastewater infrastructure projects, such as stormwater management. A brief description of the environmental assessment approach commonly used for municipal infrastructure is presented in this section.

Environmental Assessment for Municipal Infrastructure

The Municipal Engineers Association's (MEA) Municipal Class Environmental Assessment (EA) is the principal "tool" used by municipalities for assessing water, wastewater and transportation infrastructure projects in accordance with the Act. It is a streamlined, proponent-driven planning process approved for specified types of undertakings by municipalities (and some private sector developers). The Municipal Class EA process allows municipalities to plan, design, construct, maintain, rehabilitate, and/or retire municipal stormwater management facilities.

Stormwater management projects undertaken by municipalities vary in their environmental impacts and are classified into four schedules (A, A+, B, and C). Schedule A/A+ projects may have environmental effects that are minimal and more easily managed, whereas Schedule B and C projects have a greater potential for adverse environmental impacts that require assessment and consultation.

Completing the Municipal Class EA process does not replace or exempt a project from the formal processes of other applicable federal and provincial legislation (e.g., *Ontario Water Resources Act*, *Environmental Protection Act*) and municipal by-laws, such as permits or approvals, and the specific public and agency consultation that they may require.

In addition to assessing the environmental effects of infrastructure projects, the Municipal Class EA approach is also suited for long-term planning of large geographic areas where independent decisions that impact the servicing and land use are being made. Examples of planning applications that can be integrated with the Municipal Class EA process include official plans (and amendments), Secondary Plans, Plan of Subdivisions and Plan of Condominiums.

Master Plans

Master plans are long range plans that integrate infrastructure requirements for existing and future land use with environmental assessment planning principles. A master plan should complement the municipal official plan and is an important tool for examining a municipal infrastructure system or group of related projects in order to guide planning and development. The development of a master plan, or the review of an existing plan, provides an opportunity to adopt LID BMPs for new development or retrofits to existing areas. It may also help to enhance infrastructure resilience to climate change and the increased impacts of runoff by better managing precipitation at the source.

Municipalities may prepare master plans to address groups of projects, an overall infrastructure system, a number of integrated systems or to coordinate the requirements of both the *Environmental Assessment Act* and the *Planning Act* through the development of long range multi-disciplinary plans. For example, when conducted through the Municipal Class EA, a stormwater master plan should address (at a minimum) the identification of the problem or opportunity and identifying alternative solutions (i.e., Phase 1 and Phase 2 of the Class EA). Individual stormwater management systems, facilities or practices that are identified in the master plan may be required to meet any additional applicable requirements of the Municipal Class EA process.

Master planning helps to ensure clarity and transparency of long-range infrastructure planning, such as the potential for cumulative outcomes and benefits as well as cost savings. Long range infrastructure planning enables the proponent to comprehensively identify need and establish broader infrastructure options. The combined impact of alternatives is also better understood which may lead to other and better solutions. In addition, the opportunity to coordinate or integrate with land use planning enables a proponent to look at the full impact of decisions from a variety of perspectives.

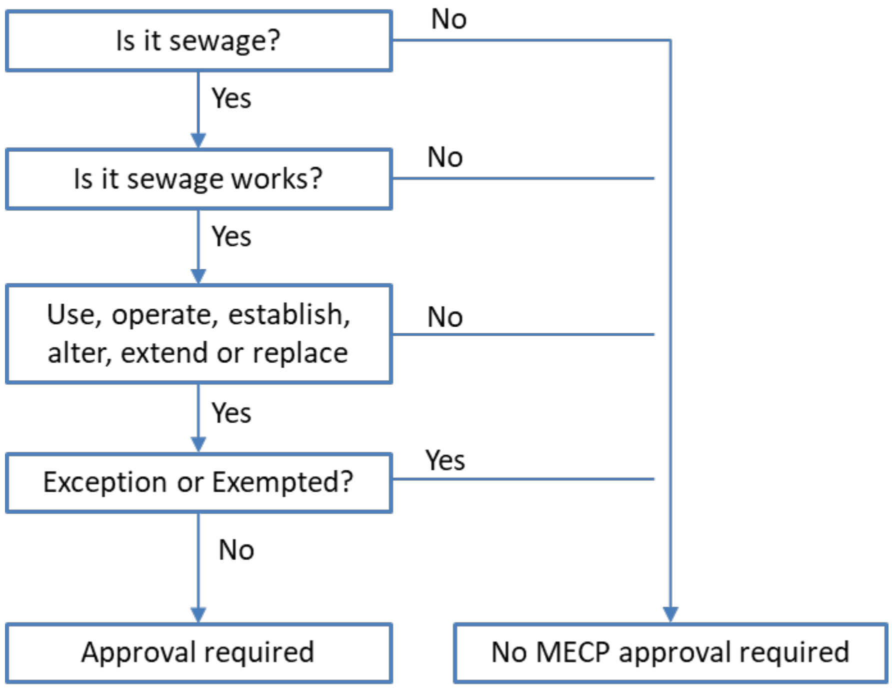
2.4 Stormwater Approvals and Permissions

While the Ministry of the Environment, Conservation and Parks is the provincial lead for the protection, improvement and sustainability of the environment, stormwater management is a shared responsibility with municipalities, the developers, property owners (residents, businesses), local public sector organizations (i.e., conservation authorities), other provincial ministries, federal departments, and non-governmental organizations, and others all playing important roles.

Ministry Role

The *Ontario Water Resources Act* (OWRA) and the *Environmental Protection Act* (EPA) provide a legislative framework for key objectives of stormwater management (see Section 1.3), such as protecting water quality and water quantity. The OWRA states that "no person shall use, operate, establish, alter, extend or replace new or existing sewage works except under and in accordance with an environmental compliance approval", such as stormwater management facilities and storm sewers, unless specifically exempted. Environmental compliance approvals for sewage works may be issued by the appointed Director to applicants under Part II.1 of the EPA. The aim of such approvals is to set rules for these activities in a way that helps protect the natural environment and is in keeping with the purpose of the OWRA, namely to provide for the conservation, protection and management of Ontario's waters and for their efficient and sustainable use, in order to promote Ontario's long-term environmental, social and economic well-being. See Figure 2.2 for a simplified decision tree illustrating the need for a sewage works approval.

Figure 2.2 - Sewage Works Approvals



The Water Management: Policies, Guidelines, Provincial Water Quality Objectives (Blue Book) provides overall guidance for water management in Ontario. Applications for a stormwater management approval under the OWRA are considered by the MECP on a case-specific basis. Applications should be informed by the design and technical guidance provided in the LID Guidance Manual, the 2003 Stormwater Manual, the 2008 Design Guidance for Sewage Works, and applicable approvals program guidance.

It is important to note that proponents may also need to follow an approved environmental assessment process prior to obtaining an environmental compliance approval for stormwater management systems/LID facilities (see Section 2.3).

Examples of MECP guidelines and documents relevant to stormwater management are listed in Table 2.1. Many of the MECP documents provide guidance on water management or environmental protection in general but have relevance to stormwater management. The other ministries such as the Ministries of Northern Development, Mines, Natural Resources and Forestry, Municipal Affairs and Housing, or Transportation should be contacted for guidance or requirements that may apply. (e.g., Redside Dace, MTO's Stormwater Management Requirements for Land Development Proposals)

Table 2.1 – MECP Guidelines and Documents Relevant to Stormwater Management

Guideline or Document	Notes
Stormwater Management Planning and Design Manual (2003)	Provides performance and detailed design guidance on lot level, conveyance and end-of-pipe stormwater management. Also refer to Section 1.2 https://www.ontario.ca/document/stormwater-management-planning-and-design-manual-0
Design Guidelines for Sewage Works (2008)	Includes design guidance for storm sewers. https://www.ontario.ca/document/design-guidelines-sewage-works-0
Water Management: Policies, Guidelines and Provincial Water Quality Objectives, updated 1999 (Blue Book)	Provides policies and guidelines for the management of the province's water resources. Surface water quality is to be preserved to ensure that the water is satisfactory for aquatic life and recreation and that water uses which require more stringent water quality be protected on a site-specific basis. Ground water quality is to be preserved to protect the greatest number of uses. https://www.ontario.ca/page/water-management-policies-guidelines-provincial-water-quality-objectives
Lake Simcoe Protection Plan	Comprehensive plan to protect and restore the ecological health of Lake Simcoe and its watershed. https://www.ontario.ca/page/lake-simcoe-protection-plan
Lake Simcoe Phosphorus Reduction Strategy	Strategy which is intended to safeguard the health of the lake. https://www.ontario.ca/page/lake-simcoe-phosphorus-reduction-strategy
Guidelines for Evaluating Construction Activities Impacting on Water Resources	These guidelines were developed to protect the receiving environment according to the physical, the chemical and the biological quality of the material being dredged. https://www.ontario.ca/page/b-6-guidelines-evaluating-construction-activities-impacting-water-resources
Incorporation of the Reasonable Use concept into MOEE Groundwater Management Activities	Provides guidance on the reasonable use of groundwater on property adjacent to sources of contaminants and for determining the acceptable levels of contaminants. https://www.ontario.ca/page/incorporation-reasonable-use-concept-moee-groundwater-management-activities-guideline-b-7
Guidelines for Identifying, Assessing and Managing Contaminated Sediments in Ontario	The purpose of the Provincial Sediment Quality Guidelines is to protect the aquatic environment by setting safe levels for metals, nutrients (substances which promote the growth of algae) and organic compounds. https://www.ontario.ca/document/guidelines-identifying-assessing-and-managing-contaminated-sediments-ontario/identification-and-assessment

Guideline or Document	Notes
Evaluation of Construction Activities Impacting Water Resources (Guidelines B-6)	Aid in the assessment of the environmental impact of construction activities. https://www.ontario.ca/page/b-6-guidelines-evaluating-construction-activities-impacting-water-resources
Sewer and Watermain Installation: Separation Distance Requirements (Guideline F-6)	Guideline for reducing/minimizing the potential for health hazards to water users in the event of a watermain or sewer line rupture that could result in contamination of the water distribution system. https://www.ontario.ca/page/f-6-sewer-and-watermain-installation-separation-distance-requirements https://www.ontario.ca/page/f-6-1-procedures-govern-separation-sewers-and-watermains
Lakeshore Capacity Assessment Handbook: Protecting Water Quality in Inland Lakes	This handbook was developed to guide municipalities carrying out lakeshore capacity assessment of inland lakes on Ontario's Precambrian Shield. https://www.ontario.ca/document/lakeshore-capacity-assessment-handbook-protecting-water-quality-inland-lakes
Determination of treatment requirements for municipal and private combined and partially separated sewer systems (Procedure F-5-5)	Provides guidance for treating municipal and private combined and partially separated sewage systems. https://www.ontario.ca/page/f-5-5-determination-treatment-requirements-municipal-and-private-combined
Management of Excess Soil - A Guide for Best Management Practices	Provides best management practices for managing excess soil in a manner that promotes sustainability and protects the natural environment. https://www.ontario.ca/page/management-excess-soil-guide-best-management-practices
Protocol for Conducting a Storm Water Control Study	Provides information and guidance for industrial facilities conducting a stormwater control study. https://www.ontario.ca/page/protocol-conducting-storm-water-control-study

Regional and Local Role

At the local-level, municipal and private stormwater management is approved and implemented primarily through subdivision and site planning. Integrated subdivision/site planning is an effective means to ensure that parallel social, environmental, economic and functional objectives are achieved. Regional and municipal governments may set stormwater management policies and standards that are to be followed by developers and property owners, such as:

- Design criteria (e.g., IDF data and acceptable rainfall distributions);

- Design level of service (e.g., convey at least 1:5-year in minor system and no surcharging during regulatory event);
- Spacing and depth requirements for inlet and for conveyance systems;
- Ownership and access requirements (e.g., easements, setbacks, etc.);
- Lot grading, drainage pattern and property requirements;
- Acceptable devices; and
- Municipally-accepted water quality devices.

Through conditions of plan of subdivision approval, a planning approval authority may require the proponent to provide to the satisfaction of and at no expense to the municipality the provision of appropriate stormwater management. At this stage, water quality, water balance and water quantity control measures should reflect provincial guidance (e.g., Runoff Volume Control Target) and/or local guidance (e.g., water balance targets, flood control targets, subwatershed specific water quality targets). Also, at this stage, municipalities may review the plan of subdivision for conformance with the official plan, zoning, and lot grading, drainage and property standards by-laws. Site plan control bylaws are used by a municipality to ensure that specific site details conform to the official plan policies, such as stormwater management calculations and design.

It is important to understand that subdivision/site planning is a fundamental determinant of the overall change in the hydrologic cycle for a given development. The landowners and the planners/designers prepare the plan based on the performance standards set by the municipal by-laws or guidelines (e.g., setbacks, density, height), and the business objectives set by the landowners (e.g., number of units for sale, parking spaces).

Conservation authorities work with municipalities to regulate natural hazards (including riverine and waterbody flooding and erosion risk) and natural heritage features (including wetlands, creeks, rivers and lakes). They also provide guidance and advice in the planning and design of stormwater management infrastructure to developers, consultants, municipalities, and landowners. Permits may be required to undertake specific types of development in areas regulated by conservation authorities.

Environment and Climate Change Canada (ECCC)

The following documents provide information or guidance from the federal ECCC. The list is not intended to be exhaustive and proponents are advised to contact the federal agency or website for information or guidance.

- Canadian Water Quality Guidelines for the Protection of Aquatic Life
- Canadian Water Quality Guidelines for the Protection of Agricultural Water Uses
- Guidelines for Canadian Drinking Water Quality
- Guidelines for Canadian Recreational Water

Code of Practice for Environmental Management of Road Salts (2004) Code of Practice for Environmental Management of Road Salts (2004)

3.0 STORMWATER DESIGN CRITERIA: RUNOFF VOLUME CONTROL TARGET

The chapter outlines the guidance for stormwater runoff volume control for new development, re-development, linear development and stormwater retrofits in Ontario. The overall approach is to manage rain where it falls and where snow melts in order to maintain or restore the natural hydrologic cycle to the greatest extent possible to meet the key objectives of stormwater management outlined in Section 1.3.

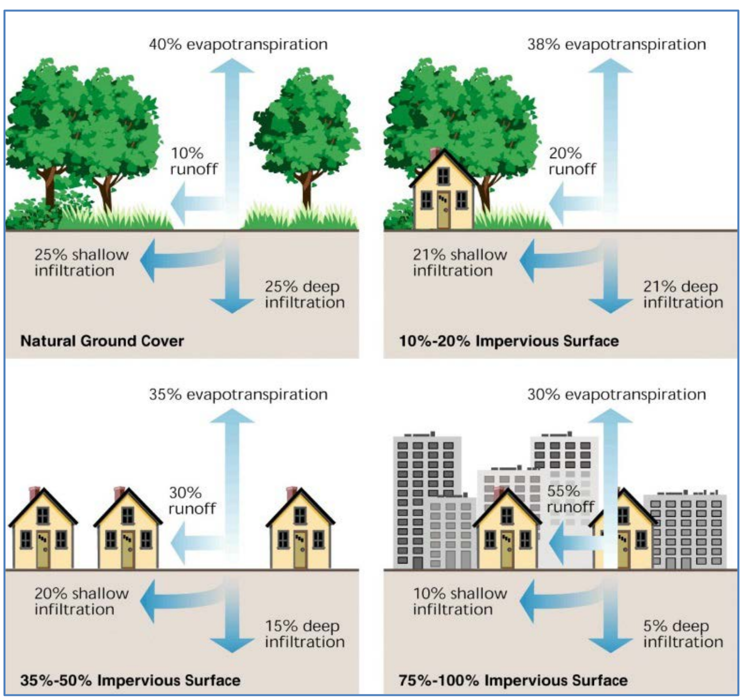
3.1 The 90th Percentile Precipitation Event

The following sections provide context and background regarding the effects of urbanization on watershed impervious area; the history of the 90th percentile control approach in North America; and how the Runoff Volume Control Target has been developed.

3.1.1 Watershed Impervious Area

The hydrologic cycle describes the continuous circulation of water between the surface water bodies, atmosphere, and land (e.g., through infiltration, evapotranspiration, runoff). With conventional urban stormwater management (e.g., catchbasins and storm sewers), surface drainage efficiency is enhanced, resulting in a significant shift in hydrology and associated water balance toward a regime with high runoff yield, rapid flow response, and decreased infiltration; as illustrated in Figure 3.1.

Figure 3.1 – Relationship Between Impervious Cover and Surface Runoff



(Source: FISRWG, 1998)

Even at low levels of urbanization within a watershed, an increase in impermeable surfaces of just 4% can result in changes to stream channel characteristics and aquatic communities (TRCA, 2006). These impacts have been shown to follow a continuum of impacts and environmental degradation as total watershed impervious area increases due to development, as supported by:

- As total watershed impervious area changed from 5% to 10%, the physical and biological measures within a watershed generally change most rapidly (B.C., 2002). With more intensive urban development in the watershed, habitat degradation and loss of biological productivity continues, but at a slower rate (Horner and May, 1998);
- At approximately 10% total watershed imperviousness channel adjustments of local watercourses (primarily as enlargement) will occur (CVC, 2007); fisheries biodiversity and abundance are initially and significantly impacted (B.C., 2002);
- When the impervious area of watersheds with traditional ditch and pipe systems reaches the 10% threshold, about 10% of the total rainfall volume becomes runoff that enters receiving waters; this runoff volume is the root cause of aquatic habitat degradation. Note that there is virtually no surface runoff from the naturally vegetated portion of a watershed, but nearly all rain that falls on directly connected impervious surfaces becomes runoff. (B.C., 2002)
- A 30% total watershed imperviousness has been shown to increase the flood flow peaks of the 100-year event by a factor of 1.5. In contrast, events occurring on average once in 2 years or annually, increased by factors of 3.3 to 10.6 respectively (Hollis, 1975);
- In addition, at 30% total watershed imperviousness, urban watershed may be unable to sustain abundant self-supporting populations of coldwater fish (B.C., 2002);
- At urbanization levels between 25% and 55% (built form) serious irreversible degradation has been predicted and shown to take place (CVC, 2007); and
- At 50% total watershed imperviousness, poor water quality and concentrations of metals in sediments begin to show significant impact to aquatic biological communities (B.C., 2002).

To offset impacts, an increased emphasis on maintaining the natural hydrologic cycle to the greatest extent possible is required. The approach supported by many Canadian, US and international jurisdictions is the selection of a performance target which can maintain the form and function of the natural systems and avoid the 'initial and significant impacts' associated with urbanization which is correlated with a total watershed imperviousness of 10% as detailed above. A total watershed imperviousness of 10% has been suggested as a tipping point beyond which significant and sometimes irreversible impacts are expected to occur.

Acknowledging that at 10% total watershed imperviousness of watersheds with traditional ditch and pipe systems, about 10% of the total rainfall event volume becomes runoff that enters receiving waters and that this runoff volume is the root cause of aquatic habitat degradation (B.C., 2002), a performance target for the management of runoff volume should be to control 90% of the total annual rainfall volume. This has the potential to mitigate the impacts of urbanization discussed in Section 1.4.

As such, an appropriate performance target is to control the runoff generated from 90% of the average annual rainfall, commonly determined through the use of the 90th percentile event.

3.1.2 Background of the 90th Percentile Precipitation Event

One of the earliest references to the 90th percentile precipitation event (or storm) can be found in a 1979 publication by the USEPA, as part of a stormwater management system case study in Salt Lake City (US EPA, 1979). The system was analyzed for varying storm events (50, 64, 80, and 90th percentile storms) along with their respective pollutant reductions and dissolved oxygen content. The case study concluded that the 90th percentile storm just met the water quality guidelines being evaluated. While the concept was first introduced in 1979, it took many more years for the concept to re-emerge and gain widespread acceptance.

The origins of the 90th percentile precipitation event are most commonly traced back to The Design of Stormwater Filtering Systems (Claytor, 1996). Chapter 2 of this document entitled Runoff and Water Characteristics for Small Sites suggests that based on an analysis of the rainfall frequency spectrum for Washington, D.C. that a BMP sized to capture and treat the three (3) month storm frequency of 1.25 inches (31.8mm) will effectively treat 90% of the annual average rainfall (Schueler, 1992). Stating further, that while such a practice will also capture and at least partially treat the first 1.25 inches (31.8mm) of larger events, therefore resulting in a capture efficiency greater than 90% annual average rainfall volume.

In 1992, many jurisdictions required treatment of only the first 0.5 inch (12.5mm) or 'first-flush', however at the time little research on the cumulative pollutant load bypassing facilities sized on that principle had been completed, with the exception of Chang et al., 1990. Research in Texas (Chang et al., 1990) found that the total annual load capture using the 0.5 inch (12.5mm) decreased significantly as impervious areas approached 70% (i.e. a highly-urbanized environment). Subsequent studies such as the Michigan Department of Environmental Quality 2014 Post-Construction Storm Water Runoff Controls Program, subsequently confirmed that "all the pollutants washed off in the first flush of runoff from impervious surfaces are contained in the first 25 mm of runoff" (MDEQ, 2014).

Further analysis by Claytor for an 11-year period for four locations within the Chesapeake Bay area, found that one-inch (25 mm) rainfall provided an average capture percentage of 85% to 91% of the rainfall volume. This analysis provided justification for using the one-inch rainfall event and became known as the "One-inch-rule", the "90% Rule" or the "90% Capture Rule".

The Claytor study also emphasized that regional rainfall characteristics will differ from location to location and that additional rainfall frequency analysis is required in order to have more reliance on the 90% Capture Rule value suggesting that a rainfall frequency spectrum (RFS) analysis be conducted using local precipitation data using a longer data set (Claytor, 1996). The data set length or analysis techniques should be selected such that extreme events and drought periods become less statistically significant on the capture value derived.

Since that time numerous jurisdictions have developed regional Rainfall Frequency Spectrum (RFS) curves, adopted and modified the 90% Capture Rule approach, including many US jurisdictions and some Canadian and Ontario jurisdictions, including the Lake Simcoe Watershed which implemented its own 90th percentile precipitation event control target in September 2016. The technical basis for the 90% Capture Rule is that the stormwater practice is explicitly designed to capture and treat 90% of the annual rainfall events.

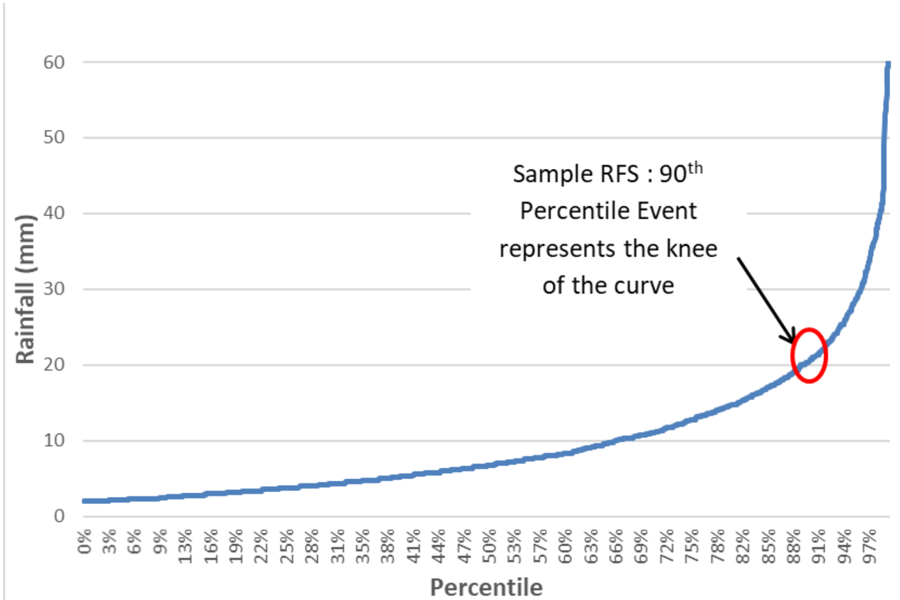
3.1.3 Rainfall Frequency Spectrums (RFS)

Rainfall Frequency Spectrum (RFS) curves (also known as “rainfall distribution plots”) are useful tools to assist with the development of stormwater management criteria, particularly the criteria that relate to smaller storm events (runoff reduction or recharge, water quality). The RFS can link the various criteria with particular rainfall events (Center for Watershed Protection, 2008). A Rainfall Frequency Spectrum (RFS) is a tool that can be used to analyze and develop local stormwater management criteria and to provide the technical foundation for the criteria. Over the course of a year, many precipitation events occur within a community. Most events are quite small, but a few can create significant rainfall. An RFS illustrates this variation by describing how often, on average, various precipitation events (adjusted for snowfall) occur during a normal year (Center for Watershed Protection, 2008).

The development of an RFS is generally a first step in the creation of stormwater criteria relating to the 90% Capture Rule. Data used to generate the RFS and ultimately the capture depth of the 90% Capture Rule are based on an analysis of the regional rainfall patterns. Figure 3.2 is a representative RFS derived from hourly rainfall data. The example RFS developed from hourly rainfall totals (excluding all events less than 2 mm) illustrates the theoretical 90th percentile rainfall event and its location on the curve at the “knee” of the curve. “It is at this point that the theoretical optimization of treatment occurs” (EOR and SWMP, 2005) as such as the target percentile moves past the “knee” of the curve diminishing returns can be expected, meaning that the size of size and cost of the BMP increases significantly while the total number of storms treated increases only marginally. This is often referred to as the ‘law of diminishing returns’ which is used to refer to point at which the benefit gained is less than the amount of effort (money or energy) invested.

The rainfall depth associated with the “knee” of the curve equates to the 90th percentile event of approximately 22 mm in this example. A similar result was reported for the Minneapolis/St. Paul Airport for the period of 1971 through 2000 as part of the MIDS development, which reported that both the 90th and 94th percentile “represent valid interpretations of the knee of the precipitation depth curve” (EOR and SWMP, 2005).

Figure 3.2 - Representative RFS which Represents the Knee of the Curve



3.2 Runoff Volume Control Target for Ontario

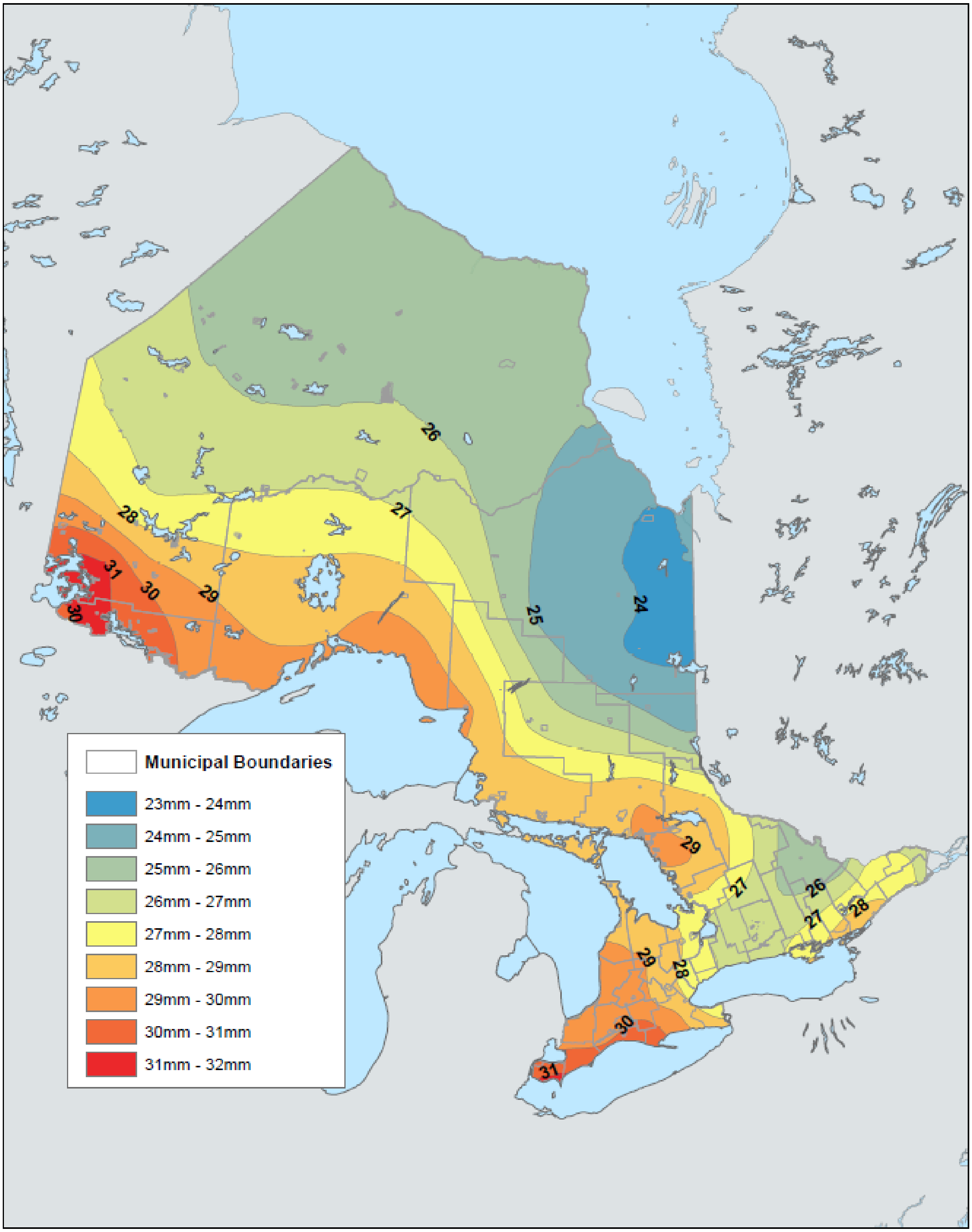
The Runoff Volume Control Target for Ontario is the 90th percentile precipitation event as indicated in Figure 3.3 that shows rainfall depth ranging from 23 mm to 32 mm across Ontario.

The Runoff Volume Control Target has been determined through the hourly rainfall analysis using a 12-hour minimum inter-event time (MIT), disregarding events smaller than 2 mm as these events typically do not produce any measurable runoff (due to absorption, interception and evaporation). Additional information can be found in a report prepared to inform the development of LID guidance for Ontario (Aquafor Beech Ltd., Earthfx Inc, October 2016, *Runoff Volume Control Targets for Ontario Final Report*).

To increase the spatial resolution across the province in order to identify and capture geographically significant trends the 95th percentile <u>daily</u> rainfall series (disregarding days with less than 2 mm of rainfall) has been used to represent the 90th percentile hourly runoff control volume targets in Ontario based on the results of the comparative analysis performed. Daily rainfall volumes have been evaluated between April 1st and October 31st for weather stations with a minimum of 15-years of data within the 36-year historical record period of 1970-2005. This allows for a consistent period to be employed in the analysis year over year, and ensures that the largest number of climate stations have been used in the analysis (many stations do not collect precipitation data outside these months.) The daily rainfall records from April 1st to October 31st show little variance as compared to all rainfall events (full year); as in all cases the average 90th percentile events as compared to the average 95th percentile events of rainfall collected from April to October showed only a 0.8 and 0.6 mm deviation in the Runoff Volume Control Target applying a 2 mm cut-off respectively. Figure 3.3 illustrates the 90th percentile precipitation event Runoff Volume Control Target guidance for Ontario using percentile contours (isohyet) mapping which represents regional rainfall variations.

The Runoff Volume Control Target for Ontario is science based. The derivation of the target has been developed to be repeatable, geographically specific, and flexible. The intent is to promote a consistent level of performance of stormwater management systems.

Figure 3.3 - Regionally Specific 90th Percentile Precipitation Event Runoff Volume Control Target – Precipitation Isohyets



For the purposes of this guidance, retaining the runoff that could be generated by all storms up to and including the 90th percentile precipitation event is analogous to maintaining or restoring the natural hydrologic cycle. This 90th percentile precipitation event represents the volume that appears to best represent the volume that is intercepted, evapotranspirated, or infiltrated in a natural condition before construction of urban form and infrastructure (e.g., building, roads, parking lots, driveways).

The following concepts and factors are recognized in the establishment and application of the Runoff Volume Control Target for Ontario:

- Runoff is generated from all surfaces (not exclusively from impervious surfaces).
- Precipitation should be regarded as a resource to be managed as close to where it falls and where snow melts as possible (i.e. on-site) using approaches which focus on mimicking the natural hydrologic cycle and preventing rapid, excessive runoff responses associated with urbanization.
- The application of landscaped based and volume based stormwater controls, such as LID BMPs, should be incorporated, wherever feasible, in all new developments, areas of redevelopment, undertakings for linear infrastructure, and stormwater retrofits as a key component of climate change adaptation and mitigation strategies.
- LID systems and facilities are designed and implemented to meet the key objectives of stormwater management outlined in Section 1.3.
- Site-specific restrictions (or constraints) may limit stormwater retention and filtration practices for a particular location requiring a flexible approach as discussed in Section 3.2.5 Flexible Treatment Options for Sites with Restrictions.
- It is important for the proponent to engage municipalities, conservation authorities, the public and others to ensure a common understanding of the stormwater planning and design process and how the Runoff Volume Control Target and the hierarchy was applied especially where there exist site-specific restrictions that require a flexible approach.
- Capturing and treating the runoff generated from the 90th percentile precipitation event will also capture and at least partially treat an equivalent volume during larger rainfall events in excess of the 90th percentile precipitation event.
- Capturing and treating the runoff generated from the 90th percentile precipitation through retention and filtration practices will reduce suspended solids and other contaminants in the treated stormwater as discussed in Section 3.3 Water Quality Expectations.
- Urban flooding risk (resulting from poor surface drainage of runoff) can be reduced with a surface drainage plan or strategy complemented by LID and conventional stormwater management systems.
- A runoff reduction approach necessitates the use of practices that will typically address the issue of maintaining predevelopment surface water temperatures.

3.2.1 Hierarchical Approach

The following describes a hierarchical approach to the application of measures to achieve the Runoff Volume Control Target for new development, redevelopment, linear development, and stormwater retrofit projects in Ontario.

The planning approach should begin with consideration of the stormwater management objectives outlined in Section 1.3. Next the proponent could undertake public outreach, engagement, and pre-consultation with the approving authorities to confirm any development constraints and performance criteria as necessary. A design charrette may be considered at this stage. Better site design principles (see Section 1.5.1.1) and pollution prevention (see Section 1.5.1.2) should be applied to the design for the site. The subsequent selection of stormwater control measures should be guided by the hierarchy outlined below. The hierarchy is specified to provide flexibility in the implementation of measures to meet the Runoff Volume Control Target, to ensure measures are applied consistently across the province, and that a treatment train approach is utilized as needed. The Runoff Volume Control Target hierarchy has the following order:

- Control hierarchy priority 1 (Retention),
- Control hierarchy priority 2 (LID filtration), and
- Control hierarchy priority 3 (Conventional treatment).

The Runoff Volume Control Target hierarchy for application of measures to achieve the Runoff Volume Control Target for Ontario include the following priorities in keeping with the above noted rationale. While the Control Hierarchy provides inherent flexibility in the types of stormwater management BMPs which can be used, practitioners should document the selection rationale from priority 1 approaches to priority 3 approaches, explicitly describing the site restriction or constraints which prevent the implementation including all relevant supporting documentation, as required. Information on LID practices including their respective control mechanisms (e.g., retention, filtration) are described previously in Section 1.8.1. Figure 3.4 illustrates the steps for applying the Runoff Volume Control Target.

1. **Control Hierarchy Priority 1 Retention** – LID retention practices which utilize the mechanisms of infiltration, evapotranspiration and/or re-use to recharge shallow and/or deep groundwater; return collected rainwater to the atmosphere and/or use harvested rainwater. (Note that potable uses will require considerations outside the scope of the LID Guidance Manual as there are additional standards, guidance or requirements for potable water including approval requirements for drinking water systems.) The target volume is controlled and not later discharged to the municipal sewer networks (with the exception of water re-use activities) or surface waters and does not therefore become runoff. See Table 3.1 for examples of Priority 1 LID BMPs as well as Section 1.8.1 for examples and descriptions of LID practices that can provide retention.

2. **Control Hierarchy Priority 2 LID Filtration** – LID technologies which utilize appropriate filter media (e.g., per the TRCA, CVC, 2010, LID Stormwater Planning and Design Guide). The controlled volume is filtered and released to the municipal sewer networks or surface waters at a reduced rate and volume (a portion of LID Filtration may be infiltrated or evapotranspired). See Table 3.1 for examples of Priority 2 LID BMPs as well as Section 1.8.1 for examples and descriptions of LID practices that can provide filtration.

3. **Control Hierarchy Priority 3 (Conventional Treatment)** – Other stormwater technologies which utilize filtration, hydrodynamic separation and or sedimentation (i.e. end-of-pipe facilities) to detain and treat runoff using an appropriate filter media per industry standard verification protocols; separate contaminants from runoff; and/or facilitate the sedimentation and removal of contaminants respectively. The controlled volume is treated and released to the municipal sewer networks or surface waters at a reduced rate. Typically, the precipitation is not controlled on-site, and the volume of runoff is not reduced by these measures. See Table 3.1 and the 2003 Stormwater Manual for applicable Priority 3 BMPs.

Priority 1 and Priority 2 measures reflect management of stormwater at the source where rain falls and snow melts through prevention, on-site volume control and on-site quality control as illustrated by Table 3.1.

Table 3.1 – Stormwater Control Hierarchy

Hierarchy	Runoff Volume Control	Quality Control	Examples
Better Site Design and Pollution Prevention	**On-site** - Significantly reduce run-off volume from the site*	**On-site** - Reduced contaminant loading and improved stormwater quality from the site	Narrow streets, preserve natural systems, preserve natural drainage pathways and forest cover (see Sections 1.8.1.1 and 1.8.1.2)
Priority 1 Retention	**On-site** - Eliminate run-off volume from the site*	**On-site** - Reduced contaminant loading and improved stormwater quality from the site	Bioretention, rain garden, green roof, permeable pavement, rain water harvesting (see Section 1.8.1) Priority 1 BMPs: • Reduce runoff volumes • Provide less variable pollution control as pollutant loads to receivers are reduced through runoff volume reductions (infiltration, evapotranspiration and re-use)

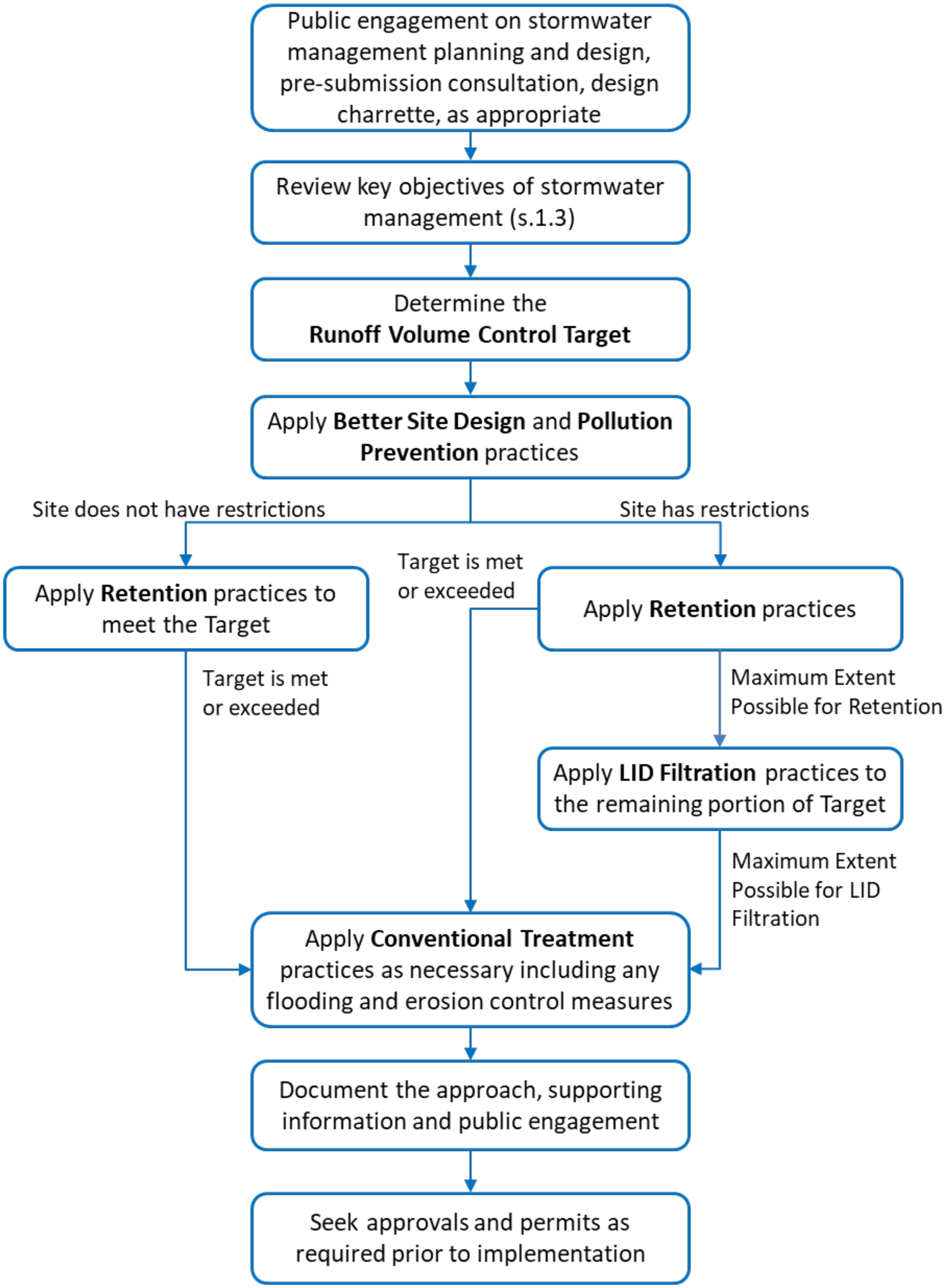
Hierarchy	Runoff Volume Control	Quality Control	Examples
			as compared to approaches which rely on removal efficiencies (i.e. percentage removal) • Prevent urban flood and combined sewer overflows (CSO) by increasing the sewer capacity by reduced volume and peak flows, as well as delayed time-to-peak; • Maintain the natural hydrologic cycle to the greatest extent possible; • Contribute to stream baseflow and mitigation of thermal impacts to urban streams; • Preserve groundwater quantity and levels.
Priority 2 **LID Filtration**	Potential for some run-off volume reduction from the site	**On-site** - Improved quality of surface run-off from the site	Biofiltration, enhanced grass swale, manufactured filter (see Section 1.8.1) Priority 2 BMPs: • Reduce some runoff volumes (LID filtration controls have been demonstrated to provide runoff volume reductions irrespective of the ability to infiltrate through absorption, material wetting and increased depression storage). • Provide less variable pollution control as pollutant loads to receivers are reduced through runoff volume reductions as compared to approaches which rely on removal efficiencies (i.e. percentage removal) • Provide additional water quality benefits result from treatment process of filtration which may also include pollution adsorption and sedimentation.
Priority 3 **Centralized/** **Conventional Treatment**	No run-off volume reduction from the site	Treatment is typically off-site	Extended detention wet ponds, dry ponds, constructed wetlands (see 2003 Stormwater Manual) Priority 3 BMPs:

Hierarchy	Runoff Volume Control	Quality Control	Examples
			• Provide additional water quality benefits from treatment process of sedimentation; • Contribute to erosion and flood control.

* Note: Reduced run-off volume as compared to development with conventional stormwater management approach. The table highlights volume and quality control, but additional control and benefits exist.

The following Figure 3.4 illustrates the basic steps of applying the Runoff Volume Control Target, including the flexible approach for sites with restrictions. The figure also acknowledges the need to consider the key objectives for stormwater management discussed under Section 1.3 and the importance of public engagement in applying the Runoff Volume Control Target hierarchy and documenting the findings. As such, some steps may be iterative in order to address all objectives and concerns.

Figure 3.4 - Steps for Applying the Runoff Volume Control Target Hierarchy



3.2.2 Runoff Volume Control Target for Development

Stormwater runoff volumes generated from the geographically specific 90th percentile precipitation event (Figure 3.3) from all surfaces on the entire site are targeted for control. The pre-development water balance (i.e., at the project onset or a natural undisturbed condition) should be maintained or restored (i.e., match the pre-development infiltration volume on an annual basis based on a site-specific assessment, acknowledging that evapotranspiration is variable pre to post development and that full control may not always be possible). For development, the basic steps for applying the Runoff Volume Control Target follow the steps in Figure 3.4.

For sites without restrictions (see Section 3.2.5) the approach to control stormwater runoff volumes should be to manage all of the volume associated with the Runoff Volume Control Target (i.e., 100% of the geographically specific 90th percentile precipitation event as determined under Figure 3.3) over all surfaces on the entire site using Better Site Design, Pollution Prevention and Control Hierarchy Priority #1 measures.

For a new development, redevelopment or linear development site with restrictions (see Section 3.2.5) where management of 100% of the geographically specific 90th percentile precipitation event isn't feasible by way of Better Site Design, Pollution Prevention, and Control Hierarchy Priority #1 measures, the alternative is to:

a) Manage 100% of the geographically specific 90th percentile precipitation event (Figure 3.3) over all surfaces on the entire site per a combination of Better Site Design, Pollution Prevention and Control Hierarchy Priority #1 and Control Hierarchy Priority #2 measures. All opportunities for Better Site Design, Pollution Prevention and Priority #1 measures should be exhausted before Priority #2 measures are considered.
b) Options considered and presented should examine the merits of relocating project elements to address, varying soil conditions and other constraints across the site.

For a new development, redevelopment or linear development site with restrictions (see Section 3.2.5) where management of 100% of the geographically specific 90th percentile precipitation event isn't feasible by way of a combination of Better Site Design, Pollution Prevention and Control Hierarchy Priority #1 and Control Hierarchy Priority #2 measures, the alternative is to:

a) Achieve volume control to the maximum extent possible (MEP). All opportunities for Better Site Design, Pollution Prevention and, Priority #1 and Priority #2 measures should be exhausted before MEP is considered to have been attained.
b) Options considered and presented should examine the merits of relocating project elements to address, varying soil conditions and other constraints across the site.

Maximum Extent Possible (MEP) - the maximum achievable runoff volume control, using all known available and reasonable approaches, including the methods as described within this manual, given the site restrictions as discussed in Section 3.2.5. The specific scope of MEP may be proposed by the proponent of the project on a case specific basis with a description of site conditions, a rationale and supporting data and information, as well as any comments about the proposed MEP from municipalities, conservation authorities, the public or others.

After the application of LID retention and filtration practices to the maximum extent possible, if there remain stormwater control requirements that have not been met (e.g. peak flow control) then apply Control Hierarchy Priority #3 measures. Control Hierarchy Priority #3 measures are centralized/conventional stormwater controls.

Please note that the application of the Runoff Volume Control Target hierarchy also requires consideration of the following:

Section 3.2.4 Additional Considerations for Linear Infrastructure,
Section 3.2.6 Direct Discharge to Waterbodies, Watercourses or Wetlands,
Section 3.3 Water Quality Expectations, and
Section 3.4 Water Quantity Expectations.

In order to assign stormwater management criteria that are appropriate for different development circumstances, the following terminology apply for the purpose of this manual.

New Development: The creation of a new lot, a change in land use, or the construction of buildings and structures commonly requiring approval under the *Planning Act*. New development includes actions that result in the alteration of the landscape during construction of buildings or other infrastructure such as parking lots, roads, etc., (e.g., grading, removal of vegetation, soil compaction, etc.) such that the changes affect runoff volumes, rates, duration of flow, water quality and/or temperature.

Redevelopment: The creation or alteration of buildings, land uses or lots on land where development has previously occurred. Redevelopment includes actions that result in the alteration of the landscape during construction of buildings or other infrastructure such as parking lots, roads, etc., (e.g., grading, removal of vegetation, soil compaction, etc.) such that the changes affect runoff volumes, rates, duration of flow, water quality and/or temperature. It may also involve the wholesale change or conversion of an area, often involving some form of land assembly and/or the partial or full demolition of a building and/or structure.

Redevelopment may include:

- Redevelopment of brownfield sites or greyfield sites.

- Infill Development: development on vacant parcels of land within an area that is predominately built-out.
- Intensification: the development of a property, site or area at a higher density than currently exists, through development, redevelopment, and revitalization, and includes:
  - redevelopment, including the redevelopment of brownfield sites;
  - the development of vacant or underutilized lots within previously developed areas;
  - infill development - new development on formerly vacant land;
  - the conversion or expansion of existing industrial, commercial and institutional buildings for residential use; and,
  - the conversion or expansion of an existing residential building or buildings to create new residential units or accommodation, including accessory apartments, second dwelling units and rooming houses.

Linear Development: The construction or reconstruction of roads, rail lines and transit infrastructure that are constructed or reconstructed separate from a new development or re-development project or common plan of development or sale.

Linear development includes:

- Projects which are composed of construction or reconstruction of stormwater systems, combined or partially combined systems, including combined sewer separations, are considered linear developments.
  - Projects which are composed of construction or reconstruction of only sanitary systems or the construction or reconstruction of only water distribution systems, that do not include a significant change to the right-of-way are not considered linear development for the purposes of this manual.

- Linear developments which propose a conversion of a rural cross-section into an urban cross-section are considered linear developments (i.e. defined as a reconstruction). Urban cross-section conversions may include, but are not limited to, such project elements as the installation of storm sewers and appurtenances, base and asphalt replacement, and concrete curb placement, etc.
  - Projects which have an existing rural cross-section and are proposed to maintain the rural cross-section, without expansion of the impervious surfaces, are considered a Stormwater Retrofit and not linear development for the purpose of this manual.

Conversion of rural cross section to curb and gutter

Roadways with an existing rural design (drainage ditches, gravel shoulder, no curbs) often come under consideration for urbanization (curbs, catch basins, and stormsewers) which result in increased impervious area and greater runoff. Where urbanization proceeds the impact of the increased runoff and the new stormsewer must be considered.

Under rural conditions runoff from the street usually flows onto vegetated roadsides where the water can infiltrate, evapotranspirate, or is filtered as it flows through the catchment. For the majority of precipitation events there is no discharge to streams, rivers or lakes.

Changes brought on by urbanization usually include:

- Wider streets that generate more runoff than the rural streets;
- The runoff is collected by catchbasins and enters the stormsewer and any interception, evapotranspiration, infiltration, and/or filtration previously provided by the ditches is no longer provided;
- Flow from the stormsewer may empty into a stormwater treatment pond but in older developed areas typically empties directly into a stream, river or lake.

This new discharge of urban runoff directly into streams, rivers, and lakes has the potential for adverse effects on flows (flooding and erosion), water quality and water temperature (aquatic habitat and fisheries).

Where urbanization proceeds attention should be paid to the potential impacts and runoff volume controls and runoff quality controls should be implemented.

3.2.3 Runoff Volume Control Target for Stormwater Retrofits

Managers, planners, designers, and builders of new and/or reconstructed municipal or non-municipal stormwater infrastructure within an existing urban area including as part of road resurfacing project and / or trails and sidewalks construction, that is not considered a development, redevelopment or linear development project, are encouraged to achieve volume control to the maximum extent possible. For stormwater retrofits, the basic steps for applying the Runoff Volume Control Target follow the steps in Figure 3.4 with control by retention and filtration on a maximum extent possible basis. Proponents are encouraged to review the feasibility of meeting the Runoff Volume Control Target and to meet it where possible.

The following terminology applies for the purpose of this manual:
Stormwater Retrofits: A stormwater project can be considered a retrofit provided all of the following conditions are met:

- The project does not include a new stormsewer system or outlet.

- The project does not increase the volume of runoff or pollutant loadings.
- The project can be implemented and is in compliance with the approved source protection plan.

A stormwater retrofit should not:

- Be part of a common plan of development (i.e., subdivision, site plan, plan of condominium, etc.).
- Require approval under the *Planning Act*.
- Be linear development. Note: Linear projects which have an existing rural cross-section and are proposed to maintain the rural cross-section after development, without expansion, are considered a Stormwater Retrofit (see 3.2.4 Additional Considerations for Linear Infrastructure).

Retrofit projects can include, but are not limited to, LID implementation within parks, municipal properties (community centres, arenas, and administrative buildings), private properties (commercial, institutional, or residential), private or public parking lots, road resurfacing projects, trails, and sidewalk establishment or refurbishment.

3.2.4 Additional Considerations for Linear Infrastructure

Linear Infrastructure Feasibility and Prioritization Studies

Owners (municipalities and agencies) are encouraged to comprehensively and holistically assess stormwater and LID implementation opportunities and constraints within their respective rights-of-way networks and public properties to improve cost effectiveness, environmental performance and overall benefit to the receiver and the community.

Planning level studies align planned or forecasted capital or maintenance works within linear developments following a Class EA-type approach that transparently considers Social, Environmental, Financial, and Technical considerations consistent with this manual and the supporting resources as outlined in Section 1.6. Such planning level studies which include stakeholder and community consultation, can provide a framework for implementation, define future study needs, allocate available funding sources and define future funding needs. In this manner, municipalities would be able to assess their infrastructure and prioritize upgrades in a prudent and economically feasible manner. This would entail prioritizing areas in greatest need, providing long-term capital works schedules, developing rigorous inspection and maintenance programs and providing ongoing monitoring as part of an adaptive management approach.

The planning level studies are intended to prioritize the linear developments which provide the greatest overall benefit and to identify the linear developments which may qualify for the exceptions listed below or qualify for the flexible treatment options for sites with restrictions per Section 3.2.5.

Minor Projects

The following are examples of linear infrastructure volume control exceptions:

1) Roadway resurfacing (i.e. roadway projects which are primarily mill and overlay and other resurfacing activities which do not involve the removal and replacement of the existing impervious surface) as well as trails and sidewalks, are not subject to the Runoff Volume Control Target guidance but the proponents are encouraged to undertake stormwater management retrofits to the activities to the maximum extent possible (MEP).

2) Minor roadway developments that involve changes to the roads that would result in minor changes to the impervious surfaces are not subject to the Runoff Volume Control Target guidance, but the proponents are encouraged to undertake stormwater management retrofits to the activities to the maximum extent possible (MEP). Examples include the following:
   a) Sliver widening (e.g., 3.66 m lanes being adjusted to 3.75 m width)
   b) Addition of turning lanes and interchange/intersection improvements
   c) Addition of entrance accesses
   d) Shoulder paving for short cycling network connections
   e) Culvert replacements

3.2.5 Flexible Treatment Options for Sites with Restrictions

Meeting the Runoff Volume Control Target through retention practices (Control Hierarchy Priority 1) or LID filtration practices (Control Hierarchy Priority 2) should be attempted for all sites. However, this may not be feasible for every site as a result of site-specific constraints. If such is the case, runoff volume control to the maximum extent possible (MEP) should be planned and implemented, using all known available and reasonable approaches, including the methods as described within this manual, given the site restrictions. For example, volume control is achievable on these sites via re-use and evapotranspiration practices even when partial or no infiltration is possible (see Table 1.3).

Treatment options for sites with restrictions have been included in this manual to provide flexibility in the application of the Runoff Volume Control Target and LID BMPs. The individual site conditions will vary across the province and may restrict the implementation of LID BMPs.

It is the responsibility of the proponent to provide a concise and defensible explanation and necessary documentation of the site restrictions.

Should pre-design investigation (case specific analysis) undertaken by the proponent or consultation by the proponent with the subject municipality, conservation authority, or the

MECP as part of the environmental approval pre-consultation and/or pre-design investigation identify that volume targets are not achievable; the proponent should consider and present to the responsible authority the merits of relocating project elements to address varying soil conditions and other constraints. As well, runoff volume control to the maximum extent possible (MEP) should be planned and implemented.

It is noted that opportunities for the relocation of project elements within linear development are limited. As such the proponent is encouraged to relocate project elements to address varying soil conditions and other constraints only where possible. The constraints that may result in the application of alternatives to the above prescribed volume targets include:

a) Shallow bedrock[†] and Karst;
b) High groundwater[†] or 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 (e.g., susceptible to flooding);
c) Swelling clays or unstable sub-soils;
d) Contaminated soils (e.g., Brownfields);
e) High Risk Site Activities including spill prone areas;
f) Prohibitions and or restrictions per the approved source protection plans and where impacts to private drinking water wells and /or Vulnerable Domestic Well Supply Areas cannot be appropriately mitigated;
g) 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;
h) For existing Linear infrastructure where reconstruction is proposed and where surface and subsurface areas are not available based on a site-specific assessment completed by a qualified person.
i) 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:
    1. Increase private property flood risk liabilities that cannot be mitigated through design,
    2. Impact pumping and treatment cost that cannot be mitigated through design,
    3. Increase risks of structural collapse of sewer and ground systems due to infiltration and the loss of pipe and/or pavement support that cannot be mitigated through design,
j) Surface water dominated or dependant 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 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 MECP and local agencies is encouraged;

k) Existing urban areas where risk to water distribution systems has been is 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;

l) Existing urban areas where risk to life, human health, property or infrastructure has been is 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;

m) Water reuse feasibility study has been completed to determine non-potable reuse of stormwater for onsite or shared use. Potable reuse of water is beyond the scope of the LID Guidance Manual but may be considered on case specific basis.

† May limit infiltration capabilities if bedrock and groundwater is within 1m of the proposed facility invert per Table 3.4.1 of the LID Stormwater Planning and Design Guide (2010, V1.0 or most recent). Detailed assessment or studies are required to demonstrate infiltration effects and results may permit relaxation of the minimum 1m offset.

Where the term flooding is used, it is useful to recognize that there are different types of flooding which may be affected by LID BMPs in different ways, such as riverine flooding (LID BMPs may reduce risk), urban flooding due to groundwater impacts (LID BMPs may increase risk), urban flooding due to I/I related sewer surcharge and backup (LID BMPs may increase risk), overland flooding and seepage (LID BMPs may reduce risk), and urban flooding due to sump pump failure risk (LID BMPs may increase or decrease risk). Practitioners should consider the various types of flooding when evaluating the various flooding constraints.

It should be noted that many of the constraints identified above may primarily impact the infiltration of runoff, but do not necessarily limit the use of other mechanisms such as evapotranspiration, re-use, filtration, detention, hydrodynamic separation and or sedimentation (Table 3.2).

Table 3.2 – Opportunities for Implementation of LID Practice or Treatment for Different Constraints

Constraint	Implementation Opportunities						
Control Hierarchy Priority	1	1	1	2	2	3	3
	Infiltration	ET	Re-use	LID Filtration	Filtration	Hydro-dynamic Separation	Sedimentation
a) Shallow bedrock† and Karst	L	M	S	S	S	S	S
b) High groundwater† or 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)	L	M	S	S	S	S	S
c) Swelling clays or unstable sub-soils	S	M	M	M	M	M	S
d) Contaminated soils (i.e. Brownfields)	L	M	M	M	M	M	S
e) High Risk Site Activities including spill prone areas	L	M	M	M	M	M	M
f) Prohibitions and or restrictions per the approved source protection plans and where impacts to private drinking water wells cannot be appropriately mitigated	L	M	M	M	M	M	M
g) 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	S	M	M	M	M	M	M
h) For existing Linear Developments where reconstruction is proposed and where surface and subsurface areas are not available based on a site-specific assessment completed by a qualified person	S	S	n/a	S	S	S	L

Constraint	Implementation Opportunities						
Control Hierarchy Priority	**1**	**1**	**1**	**2**	**2**	**3**	**3**
	Infiltration	**ET**	**Re-use**	**LID Filtration**	**Filtration**	**Hydro-dynamic Separation**	**Sedimentation**
i) 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, c) Increase risks of structural collapse of sewer and ground systems due to infiltration and the loss of pipe and/or pavement support that cannot be mitigated through design,	L	M	M	M	M	M	M
j) Surface water dominated or dependant 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 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 MECP and local agencies is required	S	S	S	S	M	M	M
k) Existing urban areas where risk to water distribution systems has been is 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	S	M	M	M	M	M	M
l) Existing urban areas where risk to life, human health, property or infrastructure has been is identified and substantiated by a qualified person through an appropriate area specific study and where the risk	S	S	S	S	S	S	S

Constraint	Implementation Opportunities						
Control Hierarchy Priority	1	1	1	2	2	3	3
	Infiltration	ET	Re-use	LID Filtration	Filtration	Hydro-dynamic Separation	Sedimentation
cannot be reasonably mitigated per the relevant design guidelines							
m) 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	M	M	M	M			

M - Most opportunity S - Some opportunity L - Least opportunity

† May limit infiltration capabilities if bedrock and groundwater is within 1m of the proposed facility invert per Table 3.4.1 of the LID Stormwater Planning and Design Guide (2010, V1.0 or most recent). Detailed assessment or studies are required to demonstrate infiltration effects and results may permit relaxation of the minimum 1 metre offset.

It is in the proponent's interest to identify constraints as early in the planning process as possible and to address them in planning or the design of the stormwater management system. If there are other site constraints not identified above, they may be raised with the appropriate approval authority on a project specific basis.

3.2.6 Direct Discharge to Waterbodies, Watercourses or Wetlands

Sites which discharge stormwater directly to waterbodies, watercourses or natural wetlands present challenges for stormwater practitioners. The reduction of pollutant loads is essential before stormwater is discharged to these features in order to preserve or enhance ecological habitat as proximity to the receiver typically may not provide any alternative off-site or centralized treatment options. The objectives for stormwater management discussed in Section 1.3 could be achieved on these sites through the application of a combination of Control Hierarchy Priority 1, 2 and 3.

It should be noted that surface water dominated or dependant features are acknowledged as potential site restrictions for LID (see Section 3.2.5) including but not limited to marshes and/or riparian forest wetlands which derive all or the majority of their water from surface water, including streams, runoff, and overbank flooding. If, surface water dominated or dependant features are identified through approved site-specific studies and/or hydrologic/ hydrogeologic studies completed as part of the land use review and approvals process, environmental assessment process, or an Environmental Impact Statements (EIS), these areas may be considered for a modified/reduced volume control target for retention or filtration, however, an appropriate level of treatment may be required through the use of conventional end-of pipe facilities. Guidance for conventional end-of pipe facilities is provided through the 2003 Stormwater Manual. Pre-consultation with the MECP and local agencies is required.

For sites that directly discharge, the proponent should ensure the site achieves complete volume control of runoff that is generated from the geographically specific 90^{th} percentile precipitation event from all surfaces on the entire site.

Direct discharges to waterbodies, watercourses or wetlands are subject to the approval of the respective municipality or agency.

3.3 Water Quality Expectations

Stormwater may pick-up various contaminants as it runs off and is conveyed downstream via the urban drainage system. While suspended solids have been the primary target for control, it is important to recognize that other contaminants may be present requiring control. Please refer to Section 4.2 and Table 9.2 for potential stormwater contaminants. Further, water quality expectations should be consistent with objectives for stormwater management discussed under Section 1.3.

Suspended Solids (SS) have been the primary targeted contaminant, as studies indicated that other contaminants of concern adhere to the surface of suspended sediments and therefore the capture and removal of suspended solids from stormwater runoff would also result in pollutant loading reduction to receiving surface water bodies. In this context, it is important to consider how the Particle Size Distribution (PSD) characteristics of suspended solids can play a significant role in the concentration of pollutant loading. The effectiveness of stormwater best management practices that rely, at least in part, on sedimentation for treatment of runoff is strongly influenced by the size distribution of particles (TRCA 2012). The smaller particles, such as silts and clays (e.g. 'fines') have greater combined surface area than do the coarser sediments such as sands and gravel per the same total volume of solids. Designers of stormwater management and LID BMPs need to consider the PSD characteristics of a given suspended solids removal target. In terms of the treatment train approach, stormwater management practitioners should consider the PSD of the sediments in the runoff which will be flowing into the proposed stormwater management and LID BMPs and the effect of the PSD on the overall efficiency, operation and maintenance. For example, consideration should be given to the various stormwater management and LID BMPs and their ability to capture and /or filter coarse vs. fine sediments and how this can impact the satisfaction of the stated stormwater management target, the protection of the receiver and the impact to habitats.

The 2003 Stormwater Manual specifies three levels of protection, with the goal to maintain or enhance existing aquatic habitat, based on the suspended solids removal performance. Enhanced Protection as defined by the 2003 Stormwater Manual is the long-term average removal of 80% of suspended solids. Often, this level of protection is the target for stormwater quality facilities along with other locally important pollutant loading reduction strategies including phosphorus reductions. Per the 2003 Stormwater Manual, any stormwater management practice that can meet the required long-term suspended solids removal for the selected level (Enhanced, Normal, or Basic Protection) under the conditions of the site is acceptable for water quality objectives. With the application of the Runoff Volume Control Target, it is necessary to account for and provide acknowledgement of the beneficial effects to water quality from runoff volume reduction provided by LID BMPs, in addition to the benefits resulting from the mechanisms of filtration, adsorption, uptake and re-use. For LID BMPs, it is more appropriate to examine water quality from a load (mass/unit time such as kg/yr) reduction perspective, which accounts for both flow reduction (volume per unit time such as m^3/s) and the concentration (mass per unit volume such as mg/L).

Stormwater management BMPs which achieve the Runoff Volume Control Target (the control of the regionally specific 90th percentile precipitation event) may be considered to have achieved Enhanced Protection (sometimes referred to as Level 1) for the respective contributing drainage area. Treating the runoff from one hundred percent of the 90th percentile precipitation events (and an equivalent rainfall depth for all events larger than the 90th percentile precipitation event) from a respective contributing drainage area will provide a high level of contaminant load reduction. With LID BMPs, it can be assumed that essentially all suspended solids are being captured for all events up to the 90th percentile precipitation event.

Partial control of runoff generated from the 90^{th} percentile precipitation event from all surfaces on the entire site through a combination of Priority 1 and Priority 2 BMPs will have achieved the relative portion of the full Enhanced Protection. For example:

- For a site where the Runoff Volume Control Target is 25 mm, the complete control of runoff that is generated from 12.5 mm of rainfall from all surfaces on the entire site using Control Hierarchy Priority 1 (Retention) and Control Hierarchy Priority 2 (LID Filtration) will be considered to have achieved half of the site's required Enhanced Protection. As such, in order to achieve Enhanced Protection, the proponent may design other stormwater quality BMPs using Control Hierarchy Priority 3 (Centralized/Conventional Treatment) to treat the remaining runoff volume.

- Where sites cannot achieve the full Runoff Volume Control Target using a combination of Priority 1 and Priority 2 BMPs, Priority 3 BMPs should be sized by applying the principles as outlined in the 2003 Stormwater Manual, including such that they provide water quality control using an appropriate extended detention volume with a 12 to 24-

hour detention time (24 hours is preferred) for the remaining runoff volume. Caution is advised in the direct application of guidance for sizing end-of-pipe controls under Table 3.2 of the 2003 Stormwater Manual, specifically wet ponds, wetlands, hybrid and end-of-pipe infiltration facilities, for the remaining Runoff Volume Control Target when a treatment train approach (i.e., upstream Priority 1 and Priority 2 BMPs) is planned. The direct application of Table 3.2 from the 2003 Stormwater Manual in a treatment train approach without consideration of upstream LID retention may result in excessive facility size, poor performance, aesthetic concerns, cumbersome operation and maintenance requirements and excessive costs. Practitioners are encouraged to utilize modelling tools (e.g., the Low Impact Development Treatment Train Tool (LID TTT) - See Section A5.1.2) to verify the sizing of end-of-pipe controls in this regard.

- Where LID BMPs are used in conjunction with other stormwater quality BMPs using Control Hierarchy Priority 3 (Centralized/Conventional Treatment) to meet water quality requirements (e.g. use of a hydrodynamic separator, filter, catch basin insert or other, upstream of LID BMPs as pre-treatment), the PSD should be a design factor for assessing the long-term average suspended solids capture and removal. It is therefore critical that the practitioner understand both the site's general soil characteristics, winter maintenance practices and the related PSD in order to design a treatment train system using both conventional and LID BMPs in a 'treatment train' approach.

The practitioner will select a rainfall intensity for use in design (see A5.4.2). The rainfall intensity may be prescribed within local standards or can be developed by practitioners through examination of historical rainfall records for corresponding or representative rainfall events of similar magnitude. It should be noted that, regardless of the selected rainfall intensity used to represent the Runoff Volume Control Target in design, bypass of the system may occur when intensities of rainfall events (smaller than or equal to the Runoff Volume Control Target) exceed the design rainfall intensity. This situation, while infrequent, is to be reasonably expected and does not necessarily indicate a deficiency in design or that the Runoff Volume Control Target has not been fully achieved. Practitioners are required to document the selection rationale for the rainfall intensity applied in each design.

Industrial, Commercial and Institutional Properties

LID practices can be implemented at most industrial, commercial and institutional (IC&I) properties (e.g., community centres, schools, retail shopping centres and malls, business centres, warehouses and manufacturing facilities). While the stormwater runoff from all properties pose water quality risks, the runoff from IC&I properties may pose additional water quality risk that require site specific considerations in planning and designing LID retention and filtration practices. Additional information is provided in Section 4.2.1 - High Risk Site Activities.

3.4 Water Quantity Expectations

The Runoff Volume Control Target does not change water quantity control requirements related to flood control or erosion control identified through watershed, subwatershed, stormwater management / master drainage plans completed following the Municipal Class Environmental Assessment Master Planning process. Proponents are advised to seek guidance or information from other agencies, organizations or documents such as the Municipal Engineers Association , Environmental Impact Statements (EIS), Provincial Policy and Guidelines or other area specific studies which have been duly reviewed and approved by the relevant agencies and authorities or as defined by the relevant municipality or conservation authority. While flood (quantity) control facilities may have a specific purpose, the design and operation of stormwater management facilities or systems should be consistent with objectives for stormwater management discussed under Section 1.3.

A portion of the volume detention and/or peak flow reduction requirements as outlined in local plans and policies for water quantity control may be fulfilled through the satisfaction of the Runoff Volume Control Target and the application of volume control LID BMPs as part of Control Hierarchy Priority 1 (Retention) and Control Hierarchy Priority 2 (LID Filtration).

Practitioners should demonstrate through calculations and / or hydrologic modelling the storage quantity and the peak flow reductions associated with achieving or partially achieving the Runoff Volume Control Target and the application of volume control LID BMPs as part of a new development, redevelopment, linear infrastructure project, or retrofit project. Acceptance and approval will be subject to the approval of the respective municipality or agency.

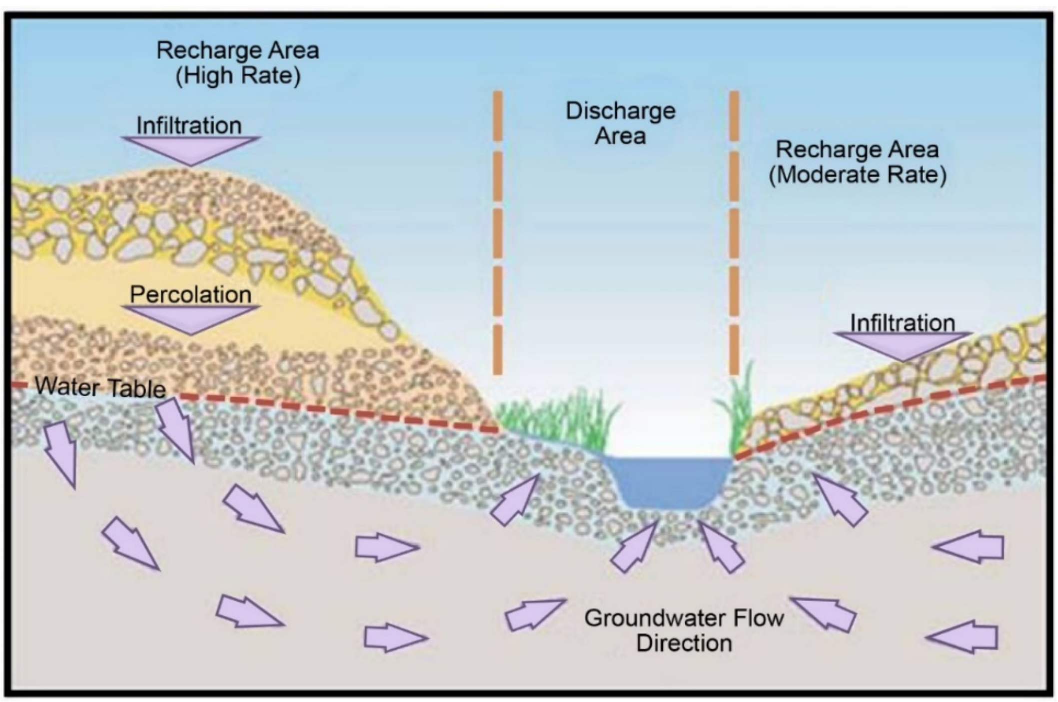
4.0 GROUNDWATER

Many of the LID BMPs that can be used to meet Control Hierarchy Priority 1 (Retention) rely on infiltration to reduce runoff volume from a project site. To safely and effectively infiltrate stormwater, it is important to understand the interaction between surface water, shallow and deep groundwater zones. This section focuses on groundwater and the infiltration of stormwater including the potential risk of contamination. It is important to remember that source and conveyance controls that do not rely on infiltration are generally unlikely to pose a risk of groundwater contamination.

4.1 Groundwater Considerations

Groundwater is a vital component of the natural hydrologic system and a source of municipal, domestic or rural water for 28.5% of Ontarians (Environment and Climate Change Canada, 2013). As shown in Figure 4.1, rain and snow melt infiltrates into the soil in recharge areas. Water is held up between the soil grains but when the volume of water exceeds the field capacity of the soil, the excess water percolates down to the water table, in a process referred to as groundwater recharge. Infiltration and groundwater recharge rates can vary from place to place based on the soil conditions. Infiltration and groundwater recharge rates can also vary seasonally and from year to year, depending on annual rainfall and antecedent moisture conditions.

Figure 4.1 - Groundwater-Surface Water Interaction



Groundwater and surface water systems are linked in the natural water cycle. The exchange of water between groundwater systems and surface water features is dependent on water table and surface water elevation. Where the surface of the water table is higher than the water level in the surface water feature, the groundwater system discharges to streamflow as water moves through the soil zone to reach surface water features (Winter et al. 1998). Baseflow is the streamflow that persists in between rainfall events when there is no runoff. Baseflow *can* include the slow release of water from lakes, wetlands and snowpack but in many Ontario streams, baseflow primarily results from the slow discharge of shallow groundwater into streams through the streambed and/or stream banks and is an important source of clean cool water necessary to sustain aquatic life. During dry periods, baseflow may be the only source of flowing water in many creeks. Groundwater can also discharge directly into wetlands and lakes. Focussed groundwater discharge is visible as seeps and springs but diffuse seepage is more common. Figure 4.1 illustrates the interaction between groundwater and surface water in discharge areas.

In Ontario, most infiltration and groundwater recharge occur in the spring when the soil has thawed, and rainfall and snowmelt is plentiful. As precipitation decreases and evapotranspiration increases during the summer, the soil begins to dry out. Less excess water is available for recharge and groundwater levels generally decline. Recharge rates typically increase in the autumn in Ontario as evapotranspiration decreases and autumn rains set in, gradually declining into the winter months as rain transitions to snow.

Urbanization reduces groundwater recharge in Ontario's watersheds by replacing soft pervious surfaces that allow for surface abstractions and connections to shallow groundwater systems with paved surfaces. Generally, as new roads, housing, and commercial areas are developed without mitigation, impervious surfaces and soil compaction significantly reduces infiltration by directing precipitation to the rapid runoff pathways of urban stormwater conveyance systems. Reduction in groundwater discharge to streams during summer months has resulted in warmer stream temperatures with higher pollutant concentrations and lower dissolved oxygen content when compared to creeks in less developed watersheds. Natural areas that depend on groundwater discharge to sustain aquatic species diversity include riparian areas, wetlands, ponds, and coldwater streams.

Changes to the volume or temporal distribution of precipitation caused by climate change (see Chapter 6) will likely also have a direct impact on the availability of groundwater resources and the connections between surface and groundwater features. For example, warmer wetter winters may increase recharge in January and February, but the longer and hotter summer season will severely affect streamflow from July through September.

As discussed in more detail in previous sections of this manual, the use of volume retention stormwater management solutions, such as infiltration-based LID BMPs, help to reduce runoff and maintain and restore natural hydrologic processes. LID BMPs retain more rainfall on-site, allowing it to infiltrate and be filtered by soil as it percolates down to shallow groundwater systems or to the groundwater table. This can reduce contaminants present in stormwater. LID BMPs are crucial to maintaining the viability of local stormwater infrastructure and contribute to climate change adaptation and mitigation strategies in urbanizing areas.

4.2 Groundwater Risks from LID BMPs

As the implementation of infiltration-based LID BMPs becomes more prevalent, stormwater practitioners have a duty to protect local groundwater resources by implementing stormwater infiltration controls in consideration of identified and future risks. Ultimately, these risks need to be balanced with the benefits of LID implementation such as preserving Ontario's groundwater resources and protecting aquatic habitat while minimizing the threat of groundwater contamination.

To understand the potential impact of stormwater infiltration on groundwater resources, it is essential to identify the key constituents of stormwater runoff. As runoff flows across urban landscapes and through conveyance networks, it picks up dissolved and suspended impurities. Potential groundwater contaminants are, for example, the product of land maintenance, the degradation of vehicles or even natural processes. Urban stormwater runoff may contain litter, plastics, suspended solids, nutrients, bacteria, heavy metals, oil and grease, and pesticides, as well as sodium and chloride from road salt, and other substances. Table 4.1 identifies some of the constituents of stormwater, the Provincial Water Quality Objectives associated with these constituents, and typical observed concentrations in urban stormwater runoff.

Table 4.1 - Some Parameters Typically Found in Urban Stormwater Runoff and Their Provincial Water Quality Objectives (PWQOs)

Parameter	Unit	PWQO	Observed Concentrations
Escherichia coli	CFU/100 mL	-	10,000 - 16 x 10^6
Suspended Solids (SS)	mg/L	-	87 - 188
Total Phosphorus (TP)	mg/L	0.03 (interim)	0.3 - 0.7
Total Kjeldahl Nitrogen (TKN)	mg/L	-	1.9 - 3.0
Phenols	mg/L	0.001	0.014 - 0.019
Aluminum (Al)	mg/L	-	1.2 - 2.5
Iron (Fe)	mg/L	-	2.7 - 7.2
Lead (Pb)	mg/L	0.005 (interim)	0.038 - 0.055
Silver (Ag)	mg/L	0.0001	0.002 - 0.005
Copper (Cu)	mg/L	0.005	0.045 - 0.46
Nickel (Ni)	mg/L	0.025	0.009 - 0.016
Zinc (Zn)	mg/L	0.020 (interim)	0.14 - 0.26
Cadmium (Cd)	mg/L	0.0002	0.001 - 0.024

(Source: Aquafor Beech, 1993)

The US EPA has sponsored several studies on the potential groundwater quality impact of infiltrating stormwater. Of significance are the series of papers on groundwater contamination potential by Pitt, Clark and Parmer (Pitt et al., 1994), Pitt, Field, Lalor & Brown (Pitt et al., 1995) Pitt, Clark Parmer & Field (Pitt et al., 1996), Pitt, Robertson, Barron, Ayyoubi & Clark (Pitt et al., 1999), and Clark & Pitt (Clark et al., 1999). The purpose of these multi-year studies was to identify common stormwater constituents and their potential to adversely impact groundwater. Categories of stormwater constituents analyzed and discussed included nutrients, pesticides, other organics, pathogens, metals and dissolved minerals. Common sources of groundwater contaminants are discussed below. While risk to groundwater is discussed under Chapter 4, contaminants or parameters found in stormwater can also pose risk to surface waters and habitat.

Nutrients

- Nitrate is one of the most frequently encountered contaminants in groundwater, but phosphorus is not a common groundwater contaminant (AWWA, 1990).
- Based on extensive testing conducted in the United States, agricultural areas commonly have the highest nitrate contamination of groundwater (Ritter, Humenik & Skaggs, 1989).
- Roadway runoff can be a major source of groundwater nitrogen contamination from vehicle exhaust and roadside fertilization (Hampson, 1986; Schiffer 1989; German, 1989).

- Leakage and spillage from sanitary sewers or septic tanks can cause significant groundwater contributions of nitrate.

Pesticides

- Pesticide contamination of groundwater is more common in agricultural settings where large volumes are used on crops.
- Weed and insect control along roadsides, high-voltage transmission lines and railway tracks is a potential source of these contaminants.
- Due to the cosmetic pesticide ban in Ontario, residential land uses are not a significant contributor of pesticides.

Other Organic Compounds

- Organic compounds can be naturally occurring or anthropogenic.
- Of concern to groundwater systems are Polycyclic Aromatic Hydrocarbon (PAH) and Halogenated Hydrocarbons.
- Sources of organic compounds include runoff from landfills, sewage systems, highway runoff, agricultural runoff and urban stormwater runoff.
- Organic contaminants in urban stormwater runoff include gasoline and oil drippings, tire residuals, exhaust by-products, mechanical lubricants, animal droppings and decomposing plant matter (Pitt et al., 1999).

Pathogens

- Fecal waste from pets and urban wildlife is the primary source of bacteria and viruses found in urban stormwater (Pazwash, 2016).
- Pathogens can also end up in groundwater resources from malfunctioning septic tanks and sanitary sewage overflows.

Metals

- Metals that can commonly be found in urban stormwater include Cadmium, Zinc, Lead, Copper, Manganese, Nickel, Chromium and Iron (Burton and Pitt, 2002).
- Sources of metal contamination in urban stormwater include vehicle wear, building materials, exhaust, lubricants, metal plating as well as industrial leaks and spills.

Dissolved Minerals

- Chloride, sodium and sulfate can contaminate groundwater resources.
- In Ontario, chlorides used during winter de-icing of pavement surfaces has caused increased chloride levels in municipal and private wells.

Although the stormwater constituents listed above have the potential to contaminate groundwater, the risk of contamination from many of these can be reduced by removal processes that occur as stormwater percolates through soils. Table 4.2 identifies whether urban stormwater constituents are attenuated as they move through soils. The ability of soils to reduce contaminant concentrations to an acceptable level before they reach an aquifer is dependent on many variables including the concentration of contaminant, soil texture, soil composition, soil pH, depth to the water table and other local hydrogeologic conditions. In general, tighter soils tend to provide more stormwater contaminant attenuation but lack the fast draining abilities of sands and loams. Infiltration-based LID BMPs are commonly installed in Hydrologic Soil Groups A (sand, loamy sand or sandy loam) and B (silt loam or loam) due to their ability infiltrate quickly but can be installed in any soil type with additional design considerations such as the addition of a perforated underdrain.

Table 4.2 - Pollutant Attenuation Mechanisms in Soil

Stormwater Constituent	**Attenuation Mechanisms in Soil**	**Groundwater Contamination Potential†**	
		no pre-treatment	**with pre-treatment**
Nitrate	Nitrate is highly soluble and is not filtered readily by soils. Nitrates are used by plants but below the root zone, there is limited nitrate mitigation in the unsaturated (vadose) zone" (Pitt et al., 1999) Nitrate can be reduced through the process of denitrification under certain conditions (e.g. where the oxygen in the soil is depleted), thereby limiting its effect of on groundwater.	Low-Moderate	Low-Moderate
Phosphorus	Phosphorus is largely removed from percolating stormwater by sorption to soil particles. Once the sorption capacity of the soil is reached, phosphorus can percolate to groundwater or flow directly into watercourses via interflow.	-	-
Pesticides	Pesticides include a wide range of chemical compounds, some of which decompose or are transformed into innocuous forms by chemical and biologic processes in the soil. These processes are dependent on many factors including type of pesticide and residence time in the soil before reaching the groundwater table (Jury, Spencer & Farme, 1983). Some can also be attenuated by the processes of volatilization and sorption.	Low-Moderate	Low

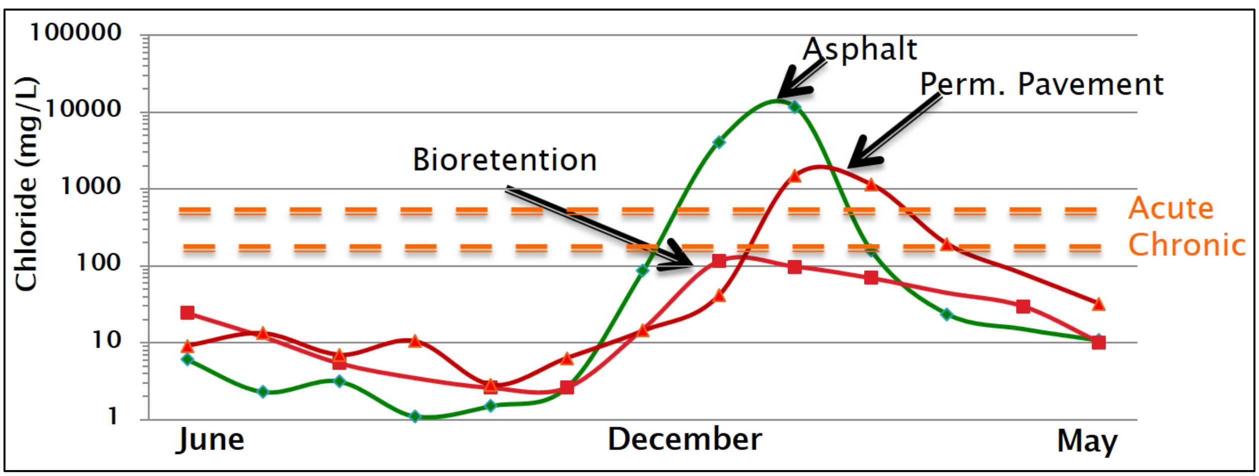
Stormwater Constituent	Attenuation Mechanisms in Soil	Groundwater Contamination Potential†	
		no pre-treatment	with pre-treatment
Other Organic Compounds	Many organic compounds (including Hydrocarbons and VOCs) are attenuated as they percolate through soils by the processes of volatilization, sorption, degradation and decomposition.	Low-Moderate	Low
Pathogens	Bacteria are removed from percolating stormwater by filtration when attached to sediment or are immobilized in soils by sorption to soil particles. Once immobilized in the soil they are inactivated by natural processes. Viruses are more resistant to environmental factors than bacteria but may be adsorbed and inactivated under the right conditions. Virus and bacterial survival is affected by factors including temperature, pH, metal concentration, and nutrient availability (Pitt et al., 1993).	Moderate	Moderate
Heavy Metals	Most metals that are constituents of urban stormwater will bind to sediment. Sorption and sediment filtration are effective techniques for the removal most metals in trace amounts. Metals removal can also be accomplished through soil surface association, precipitation, occlusion with other precipitates, diffusion into soil minerals, and uptake by biological soil components (Crites, 1985). Soils with high Cation Exchange Capacity are generally better at reducing metal concentrations.	Low	Low
Dissolved Minerals incl. Salt (Chloride)	Unlike most stormwater contaminants, many dissolved minerals, including sodium and chloride, are not attenuated as stormwater percolates through soils. In some cases, the leaching of salts from soils can occur as the lower-concentration stormwater water percolates through soil, thereby increasing concentrations by the time the water enters the groundwater system.	High	High

†Pitt et al., 1994

As stormwater constituents are reduced by removal processes that occur as stormwater percolates through soils, concerns have been raised as to whether contaminants will accumulate in the underlying soils, leading to soil contamination. Studies performed by TRCA in 2008 on seven older permeable paver installations and five older swales and / or ditches suggest that "long term accumulation of contaminants in soils beneath the pavement and swales was not a significant concern". Contaminant levels were generally below Ontario soil 'background' concentrations for non-agricultural land uses. In the few exceptions where concentrations exceeded background levels, they were still well below the level which would trigger the need for remediation.

In Ontario, specific groundwater quality concerns arise due to the cold climate and winter maintenance of paved surfaces. As noted in Table 4.2, pavement de-icing salt constituents, especially chloride, are not filtered by soils and present a common risk of water contamination on most urban sites. On sites that use infiltration-based LID BMPs, chloride ions tend to accumulate in filter media during the winter when salt laden runoff enters these facilities. As cleaner water percolates through the filter media in the spring, chloride that has accumulated during the winter months leaches out. Figure 4.2 shows chloride loading determined from monitoring conducted by the Sustainable Technologies Evaluation Program (STEP). As shown in the chloride plots, conventional paved surfaces tend to release chloride in high concentrations during the winter runoff events. Bioretention and permeable pavement practices were shown to have lower chloride concentrations at their discharge points during the winter but elevated chloride levels throughout the remainder of the year.

Figure 4.2 - Groundwater-Surface Water Interaction



(Source: Sustainable Technologies Evaluation Program)

Clean Water Act, 2006

In Ontario, municipal drinking water sources are protected through the *Clean Water Act, 2006*. Through this Act, source protection plans have been developed to outline policies to reduce the risks posed by drinking water threats. The province of Ontario has identified 22 prescribed drinking water threats under the *Ontario Regulation 287/07*. Of these threats, five (5) water quality threats and one (1) water quantity threat relate directly to sites with infiltration-based LID BMPs.

Water Quality Threats

1) "*The establishment, operation or maintenance of a system that collects, stores, transmits, treats or disposes of sewage*." This threat includes stormwater management facilities designed to discharge to groundwater or surface water.

2) "*The handling and storage of road salt; the application of road salt; and, the management of runoff that contains chemicals used in the de-icing of aircraft*." Infiltration practices are typically used to capture runoff from impervious surfaces such as parking lots and roadways. These surfaces are treated with de-icers such as sodium chloride during the winter season. De-icers can also be stored on sites within areas potentially exposed to precipitation or to runoff from precipitation or snow melt, impacting drinking water sources.

3) "*The storage of snow*." Snow is often plowed into low areas surrounding paved surfaces. LID BMPs are often located adjacent to paved surfaces. Snow plowed from urban locations includes several contaminants of interest including chloride, sodium, and petroleum hydrocarbons.

Water Quantity Threats

1) "*An activity that reduces the recharge of an aquifer*." Infiltration-based LID BMPs are designed to mitigate the impact of impervious surfaces on aquifer recharge by mimicking natural hydrologic processes.

Separation Distance for Sewer and Watermain

The primary purpose of Guideline F-6 Sewer and Watermain Installation: Separation Distance Requirements is to reduce/minimize the potential for health hazards to water users in the event of a watermain or sewer line rupture that could result in contamination of the water distribution system. The guideline is supported by Procedure F-6-1 Procedures to Govern the Separation of Sewers and Watermains. Sewers/sewage works and watermains located parallel to each other should be constructed in separate trenches maintaining a minimum clear horizontal separation distance of 2.5 metres.

This is considered a good engineering and construction practice and will reduce the potential for health hazard in the event of the occurrence of conditions conducive to possible contaminated ground water flow into the water distribution system.

Contaminated ground and surface water may enter the water distribution system at leaks or breaks in piping, vacuum air relief valves, blowoffs, fire hydrants, meter sets, outlets, etc. with the occurrence of a negative internal or positive external pressure condition. Water pressure in a part of the system may be reduced to a potentially hazardous level due to shutdowns in the system, main breaks, heavy fire demand, high water usage, pumping, storage, or transmission deficiency.

In cases where it is not practical to maintain separate trenches or the recommended horizontal separation distance cannot be achieved, the Ministry, in accordance with the above-noted procedure, may allow deviation from the separation requirements.

4.2.1 High Risk Site Activities

Not all stormwater runoff contains the same levels of contaminants. Roads and parking lots are subject to vehicular traffic as well as winter sanding and salting operations. In contrast, the primary source of contaminants on roofs comes from atmospheric deposition. The identification of on-site activities that have the potential to result in groundwater contamination is crucial to implementing technically sound infiltration controls. While municipal zoning is a planning tool that can be used to restrict land use activities that may impact groundwater, the review of on-site activities is a higher resolution risk assessment technique. A prudent approach to planning infiltration-based LID BMPs on any site involves delineating catchment areas that contain high-risk site activities and isolating them by applying non-infiltration-based practices to these areas. For example, there may be opportunities to infiltrate generally clean runoff originating on rooftops and landscaped areas.

Some land uses have a greater potential to contaminate groundwater:

- Industrial land uses typically have higher potential to contaminate groundwater resources because of high-risk activities such as hazardous material storage and onsite fueling stations. Activities with a higher risk of contaminated runoff are further identified below.
- Commercial land uses may have high risk site activities such as outdoor storage of products, salt storage areas, and snow storage areas. Certain types of commercial lands such as gas stations, car washes and dry-cleaning facilities may also pose a significant threat.
- Institutional and multi-residential (low, medium and high rise residential) land uses generally pose less of a risk than industrial and commercial sites with risks generally confined to chloride loading from the large parking facilities.
- Typical subdivision-style development with single family detached and townhomes present a smaller risk of contamination to groundwater resources but can contribute to pollutant loading via non-point source pollution such as oils and greases that accumulate on driveways and bacteria from pet waste.

Infiltration-based LID BMPs should not accept runoff from catchment areas that are associated with high risk site activities. These include fueling stations, waste disposal areas, vehicle washing stations, salt storage areas, stockpiling areas and shipping and receiving areas. Instead of using infiltration-based LID BMPs, pollution prevention practices in the form of administrative and engineering controls and stormwater management practices that do not infiltrate stormwater should be applied in these areas.

Catchment areas with potentially contaminating activities require careful assessment of site characteristics, the risks, treatment and other factors, including the possibility of avoiding infiltration-based practices because of the risk to groundwater. LID BMPs that utilize filtration, evapotranspiration (ET) or re-use as the primary processes, however, may be viable. Additionally, catchment areas that are isolated from the respective high risk site activities (e.g. rainwater originating from rooftops, employee parking facilities or directly falling on permeable surfaces) may be suitable for infiltration. While activities are not limited to those listed below, Schedule D Table 2 of the Ontario Regulation 153/04 lists the following potentially contaminating activities under the regulation:

- Acid and Alkali Manufacturing, Processing and Bulk Storage
- Adhesives and Resins Manufacturing, Processing and Bulk Storage
- Airstrips and Hangars Operation
- Antifreeze and De-icing Manufacturing and Bulk Storage
- Asphalt and Bitumen Manufacturing
- Battery Manufacturing, Recycling and Bulk Storage
- Boat Manufacturing
- Chemical Manufacturing, Processing and Bulk Storage
- Coal Gasification
- Commercial Autobody Shops
- Commercial Trucking and Container Terminals
- Concrete, Cement and Lime Manufacturing
- Cosmetics Manufacturing, Processing and Bulk Storage
- Crude Oil Refining, Processing and Bulk Storage
- Discharge of Brine related to oil and gas production
- Drum and Barrel and Tank Reconditioning and Recycling
- Dye Manufacturing, Processing and Bulk Storage
- Electricity Generation, Transformation and Power Stations
- Electronic and Computer Equipment Manufacturing
- Explosives and Ammunition Manufacturing, Production and Bulk Storage
- Explosives and Firing Range
- Fertilizer Manufacturing, Processing and Bulk Storage
- Fire Retardant Manufacturing, Processing and Bulk Storage
- Fire Training
- Flocculants Manufacturing, Processing and Bulk Storage
- Foam and Expanded Foam Manufacturing and Processing
- Garages and Maintenance and Repair of Railcars, Marine Vehicles and Aviation Vehicles

- Gasoline and Associated Products Storage in Fixed Tanks
- Glass Manufacturing
- Importation of Fill Material of Unknown Quality
- Ink Manufacturing, Processing and Bulk Storage
- Iron and Steel Manufacturing and Processing
- Metal Treatment, Coating, Plating and Finishing
- Metal Fabrication
- Mining, Smelting and Refining; Ore Processing; Tailings Storage
- Oil Production
- Operation of Dry-Cleaning Equipment (where chemicals are used)
- Ordnance Use
- Paints Manufacturing, Processing and Bulk Storage
- Pesticides (including Herbicides, Fungicides and Anti-Fouling Agents) Manufacturing, Processing, Bulk Storage and Large-Scale Applications
- Petroleum-derived Gas Refining, Manufacturing, Processing and Bulk Storage
- Pharmaceutical Manufacturing and Processing
- Plastics (including Fibreglass) Manufacturing and Processing
- Port Activities, including Operation and Maintenance of Wharves and Docks
- Pulp, Paper and Paperboard Manufacturing and Processing
- Rail Yards, Tracks and Spurs
- Rubber Manufacturing and Processing
- Salt Manufacturing, Processing and Bulk Storage
- Salvage Yard, including automobile wrecking
- Soap and Detergent Manufacturing, Processing and Bulk Storage
- Solvent Manufacturing, Processing and Bulk Storage
- Storage, maintenance, fuelling and repair of equipment, vehicles, and material used to maintain transportation systems
- Tannery
- Textile Manufacturing and Processing
- Transformer Manufacturing, Processing and Use
- Sewage Treatment and Sewage Holding Facilities
- Vehicles and Associated Parts Manufacturing
- Waste Disposal and Waste Management, including thermal treatment, landfilling and transfer of waste, other than use of biosolids as soil conditioners
- Wood Treating and Preservative Facility and Bulk Storage of Treated and Preserved Wood Products

4.2.2 Shallow and Deep Groundwater Systems

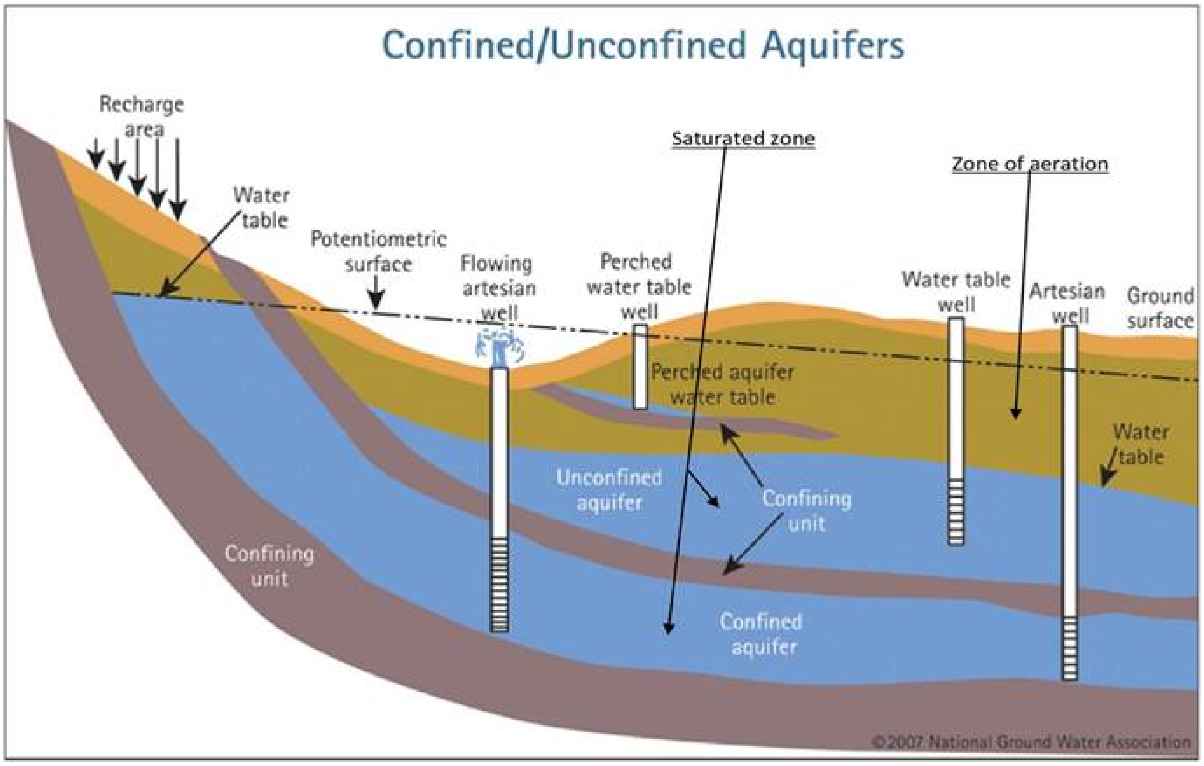
Groundwater flows within the void space between individual soil particles, soil colloids, or the space within fractures in a rock mass, moving from upland recharge areas to low-lying discharge areas. More correctly, groundwater moves from areas of higher potential energy to areas of lower potential energy. The potential energy can be measured in terms of the water level (or head) that would be observed in a well.

Geologic formations are classified as *aquifers* if they can readily transmit significant quantities of water and as *aquitards* if they significantly restrict the movement of water. The definitions can be relative and often vary from region to region. For example, a poorly producing bedrock unit may be the only local source of groundwater for domestic wells and is locally considered an aquifer while that same unit may overlie and restrict water movement to a much better producing unit in another area. Often aquifers are classified by whether they are in the *bedrock* or in *unconsolidated* deposits (overburden). Several of the regional bedrock units, such as the Guelph Formation and the Gasport/Goat Island Formation, are significant regional bedrock aquifers in southern Ontario. The permeable limestone and dolomite aquifers tend to be sandwiched between shale deposits which act as regional aquitards. The overburden deposits in Southern Ontario are mostly the result of glacial deposition. Prolific aquifers are often found in the interlobate moraines (such as the Oak Ridges Moraine, Waterloo Moraine, and Oro Moraine) which are large deposits of sands and gravels exposed at land surface. Outwash deposits, beach deposits, and eskers are also important local aquifers. Often, permeable deposits have been overridden by clay and silt tills deposited during glacial advances or have been buried by glacial lake clay deposits which restrict groundwater movement. These sequences of aquifers and aquitards make up the groundwater system.

In Northern Ontario, the long and complex geologic history, and resulting suite of highly metamorphosed bedrock formations, has resulted in large areas of impermeable bedrock. Northern Ontario, particularly those areas draining to Hudson Bay, James Bay and the upper Ottawa River, is underlain by Precambrian age Canadian Shield below flat lying sedimentary formations of the Paleozoic and Mesozoic ages (Singer and Cheng, 2002). A thin veneer of gravel, sand, silt clay, till and organic is present in many areas. Groundwater recharge primarily takes place in areas where more permeable deposits are present at the surface. Sands and gravels layers, especially where they are thick and extensive, act as important regional aquifers. Groundwater movement in bedrock is primarily dependant on permeability created by fractures.

Aquifers can also be classified as to whether they are *confined* or *unconfined*. An unconfined aquifer is usually shallow, and the unit is exposed at surface where infiltration and percolation of precipitation can readily occur. The top of the groundwater system is marked by the position of the water table where the pore water pressure is equal to atmospheric pressure. Immediately above the water table is the capillary fringe. In this zone, the voids are saturated or almost saturated with water that is held in place by capillary forces. Above this, the soil is not fully-saturated (that is, some of the pore space is occupied by air rather than water). Below the water table, the pores are completely saturated. A confined aquifer is one that is overlain and underlain by low-permeability aquitards. Water levels in a confined aquifer (as measured by wells) can be higher or lower than the water table due to pressurization effects, as shown in Figure 4.3. Groundwater can move slowly from one aquifer to another across the intervening aquitard, from an area of higher potential to one of lower potential.

Figure 4.3 - Confined, Unconfined, and Perched Aquifers



(Source: National Groundwater Association, 2007)

A *perched aquifer* is an unconfined aquifer overlaying a confining unit that, in many cases, is discontinuous. A local perched water table can develop seasonally or over longer periods, but it is vertically separated from the more regional groundwater system. Although perched aquifers generally have little effect on the regional flow system, they can play an important role in maintaining local wetlands and springs.

When implementing infiltration-based LID BMPs, it is important to be able to predict the potential impacts on the groundwater system. This is sometimes difficult because groundwater systems, by their nature, are hidden below the surface of the earth and are hard to comprehend without a good understanding of the underlying geology. Review existing geologic and hydrogeologic studies of the area, including source protection groundwater studies at an early stage of project planning. Supplement this review with an analysis of on-site monitoring data and in-situ infiltration testing. An appropriately-scoped drilling program can yield much information on the soil zone and near-surface geology. A hydrogeologic monitoring program will enable the determination of pre-development rates and direction of groundwater flow.

4.2.3 Groundwater/ Surface Water Interaction and Water Quantity Risk

The lateral movement of groundwater towards surface water features including streams and wetlands and the sustained discharge of groundwater to these features is an important hydrogeologic process that sustains the baseflow of streams during dry periods, especially late summer. Groundwater often provides a significant component of flow to headwater (low-order) streams in Ontario, especially to those that are well connected through groundwater pathways to a significant groundwater recharge area such as the Oak Ridges or Waterloo moraines. Groundwater temperature tends to reflect the average annual air temperature and, therefore, groundwater discharge is a source of cold water in the summer, needed to sustain brook trout and other coldwater fisheries, and relatively warm water in the winter that can keep the margins of streams and lakes ice-free. Changes in the rate of groundwater discharge can therefore affect both quantity and thermal quality of stream flow.

Due to the close relationship between groundwater and surface water, it is important to understand how land development can reduce recharge and thereby affect groundwater interaction with local streams and wetlands. Implementing infiltration-based LID BMPs can help offset water quantity impacts, but care should be taken to ensure that the LID BMPs are placed so as not to divert recharge away from sensitive local groundwater–dependent features. It should also be recognized that high water table conditions are likely to exist seasonally or on a permanent basis in the vicinity of surface water features and that some types of infiltration-based LID BMPs may not function well under these conditions or may function only outside the seasonal effects.

4.2.4 Infiltration and Groundwater Quality

Infiltration-based LID BMPs are typically implemented to mitigate the effects of land development and maintain or restore natural hydrologic conditions. As noted earlier, urban stormwater can contain contaminants, many of which can be reduced by removal processes that occur as infiltrated stormwater percolates through LID BMP filtration media and soil. Groundwater quality issues may arise when LID BMPs are implemented on a large-scale development due to the cumulative effects of recharging water with elevated levels of contaminants. Chlorides from road-salting and other dissolved minerals, for example, are difficult to remove and can directly affect water quality in shallow aquifers. Care should be taken when infiltrating in areas with shallow water table (within a metre of proposed invert during high groundwater conditions) and areas with coarse granular soils as the travel time to the water table will be rapid and there will be less opportunity for filtration and biodegradation. When proposing the implementation of infiltration-based LID BMPs in areas with shallow water table (within a metre of proposed invert during high groundwater conditions), it is recommended that detailed local studies be completed to fully assess the seasonal impacts of the high groundwater conditions in terms of both quality impacts and LID BMP functionality.

Although infiltration-based LID BMPs interact directly with shallow aquifers, their impact on deep groundwater resources should also be considered. Municipal wells for public supply are often drilled into deeper and/or confined aquifers to avoid surface contamination and are therefore less vulnerable to water quality impacts by infiltration-based LID BMPs. As well, where vertical flow is occurring between the shallow and deeper aquifers there is an increased risk of contaminant migration.

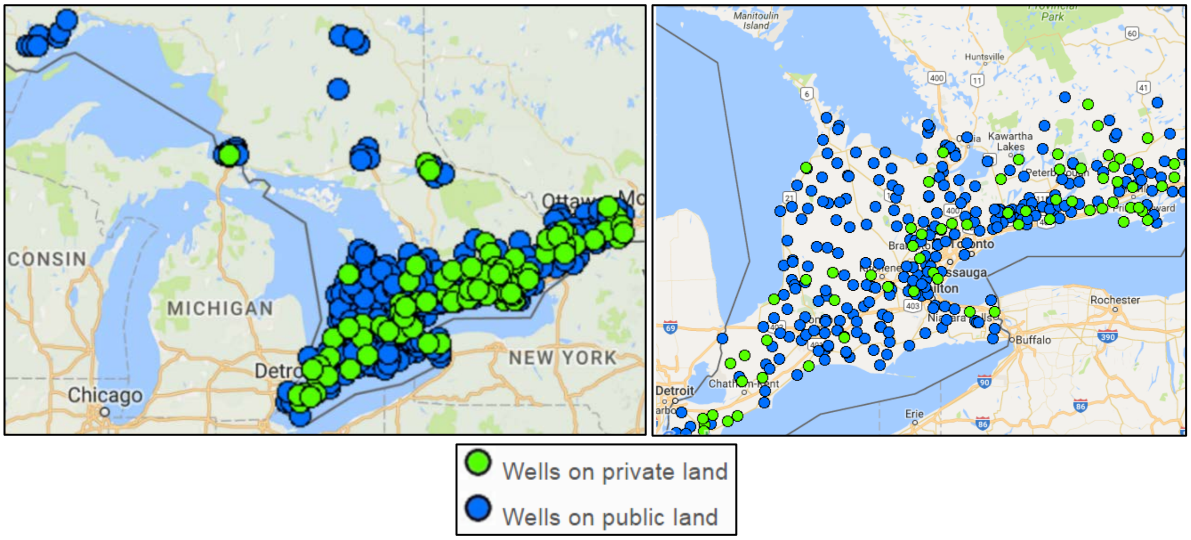
4.2.5 Data Sources and Process for Determining Risks

Groundwater monitoring programs are typically undertaken on a long-term basis to capture seasonal and yearly trends in groundwater levels and water quality. The collection of site-specific groundwater data is preferred to using data from outside of the project area; however, a thorough review of local well records can help scope onsite investigation by identifying potential hydrogeologic constraints. Sources of groundwater data vary depending on locations but may include:

Well Records – The Ontario Government has maintained well records dating back to 1899. Individual well records are available online (see the Resource Directory**)**. This online resource includes a web-based mapping tool that can be used to find local records. Copies of original well records can also be obtained through this resource. Data sets of well records for more than one property can be obtained digitally through this service. The well records contain useful information on the geologic units encountered during drilling, the water level recorded at the time of drilling, well yield, and very general information of water quality (e.g., fresh versus salty).

Provincial Groundwater Monitoring Network (PGMN) – The PGMN is a collaborative program between the MECP, 36 conservation authorities and some municipalities. The project collects and manages ambient (baseline) groundwater level and quality information from key aquifers located across Ontario. The network includes more than 450 monitoring wells. Data collected and maintained as part of this program includes water levels, precipitation and water chemistry. **Figure 4.4** shows the geographic distribution of the PGMN.

Figure 4.4 - Provincial Groundwater Monitoring Network



Additional sources of groundwater quality data across the province may include records from monitoring wells operated by the MTO, the Geological Service of Canada and municipalities.

Source Protection Plans – Source protection plans have been developed for most municipal drinking water sources in Ontario. These plans include science-based assessment reports developed under the *Clean Water Act, 2006* to identify and map vulnerable areas around municipal wells and intakes in lakes and rivers. The reports also identify certain activities as threats to municipal drinking water sources in the vulnerable areas. In areas where source protection plans have been approved by the Minister of the Environment, Conservation and Parks, these plans can provide valuable information on local hydrologic and hydrogeologic conditions that can serve as the foundation for infiltration policy development. Through extensive scientific analysis, water quality and water quantity Wellhead Protection Areas (WHPA) have been delineated around wells that supply municipal drinking water systems. For surface water sources of municipal drinking water, Intake Protection Zones (IPZs) have been established. You can learn more about source protection in Ontario and the locally developed source protection plans at: www.ontario.ca/page/source-protection.

To assess demands and potential stressors, water budgets were mandated in the *Clean Water Act, 2006* for all watersheds in Ontario's source protection areas (i.e. the area over which a conservation authority has jurisdiction under the *Conservation Authorities Act* or an area established by regulation). A tiered system of analysis was conducted where all watersheds underwent Tier 1 water budgets studies. Areas that were identified as being potentially stressed from a water quantity perspective went on to a Tier 2 and often a Tier 3 level of analysis. The four types of source protection water budget studies are described below:

1. **Conceptual Water Budget:** looks at an entire source protection area as one entity, and calculates the water budget based on average annual values.

2. **Tier 1 Water Budget**: A Tier 1 water budget is undertaken to determine whether water demands cause stress on a subwatershed. Current and future water takings are analysed via spreadsheets and mapping to determine if the subwatershed can meet the demands. The natural recharge rate is calculated during this analysis. A description of a Tier 1 level water budget study for the Central Lake Ontario watersheds can be found in the Resource Directory. When a Tier 1 analysis indicated that a subwatershed might be under stress, a Tier 2 water budget was required if the subwatershed contains a municipal water supply.

3. **Tier 2 Water Budget**: A Tier 2 water budget assesses the level of stress on a subwatershed during current, future planned and drought conditions. The study utilizes more complex hydrologic and groundwater models to analyze the components of the water budget under each scenario. The stress level is classified into one of three categories: low, moderate, or significant. No further water budget analysis is required for subwatersheds that are determined to have a low stress level via a Tier 2 analysis. For those that are determined to have a moderate or significant stress level, there could be problems meeting municipal water demand and, therefore, additional analysis in the form of a Tier 3 water budget was needed. A Tier 2 water budget study for the Grand River watershed can be found in the Resource Directory.

4. **Tier 3 Local Area Water Budget (and Water Quantity Risk Assessment and Threats Identification)**: A Tier 3 water budget shifts the focus of the assessment from the subwatershed level to an area specific to the drinking water supply water sources. The goals of the Tier 3 analysis are to define protection areas, assess the risk to the specific systems and identify water quantity threats. These protection areas are delineated as Water Quantity Wellhead Protection Areas (WHPA-Q) or Water Quantity Intake Protection Zones (IPZ-Q). The assessment is completed using more complex models, in some cases integrated surface water/groundwater models, to assess the sustainability of the system under existing conditions, planned municipal growth and prolonged drought conditions. If the Tier 3 analysis determines that the drinking water system is at risk of being unable to meet current or future conditions, the source of drinking water is assigned a significant risk level. Threats are required to be identified and addressed within source protection plans. A Tier 3 water budget study for the York Region municipal water supplies can be found in the Resource Directory.

Significant Groundwater Recharge Areas: Under the *Clean Water Act, 2006*, significant groundwater recharge areas (SGRAs) are considered vulnerable areas. SGRAs are lands that allow for more water to seep into aquifers than lands around these features. They often have loose or permeable soils such as sand or gravel. Maintaining the recharge capabilities in these areas is crucial to sustaining aquifers.

Groundwater Quality Vulnerability Analysis

A groundwater vulnerability analysis identifies sources of municipal drinking water that are susceptible to contamination. Source protection plans can identify three groundwater features that are susceptible to groundwater contamination. These are:

1. Wellhead Protection Areas (WHPAs),
2. Issue Contributing Areas (ICAs) and
3. Highly Vulnerable Aquifers (HVAs).

One of the main goals of a groundwater vulnerability analysis is to map these areas. Design of infiltration-based LID BMPs should take into consideration the location of high vulnerability areas identified in these studies.

Wellhead Protection Area: The area around a well where land use activities have the greatest potential to affect groundwater quality is known as the Wellhead Protection Area (WHPA). The size and shape of this areas is determined by the direction and speed that groundwater travels. Travel times are dependent on several factors including pumping rates, soil types, aquifer type, and landscape characteristics. Vulnerability scores ranging from two through ten have been determined for all areas within WHPAs. The higher the number, the more vulnerable the groundwater source is to threats in the area. Factors that contribute to the vulnerability scores include aquifer depth, soil types, geology, and travel times.

Issue Contributing Areas: An Issue Contributing Area (ICA) is an area within a WHPA where the existing or trending concentrations of a contaminant result in the deterioration of the quality of water for use as a source of drinking water. ICAs are delineated for specific contaminant "Issues". Examples of issues include Chloride, Sodium, Nitrate and Trichloroethylene. Within an ICA, all drinking water threat activities related to the specific issue are considered significant drinking water threats, regardless of the vulnerability scoring.

Highly Vulnerable Aquifers: Aquifers are classified as highly vulnerable when they are more susceptible to contamination. These generally have shorter travel times from the surrounding landscape.

Surface Water Quality Vulnerability Analysis

A surface water vulnerability analysis identifies surface water sources of municipal drinking water that are susceptible to contamination. Source protection plans can identify an intake protection zone (IPZ) that is susceptible to contamination due to infiltration that would impact baseflows and groundwater discharges to surface water features.

Intake Protection Zone - An area around an intake where land use activities have the greatest potential to affect surface water quality is known as the intake protection zone (IPZ). The size and shape of this area is determined by the direction and speed that water travels within the surface water feature (lakes, channels and rivers). Vulnerability scores have been determined for all areas within IPZs. The higher the number, the more vulnerable the surface water source is to threats in the area. Factors that contribute to the vulnerability scores include soil types, geology, slopes, landscape characteristics, etc.

4.2.6 Infiltration Guidelines

Maintaining natural infiltration (rates and geographic distribution) is important for ensuring the long-term viability of groundwater sources and associated ecological habitats. In an SGRA, a relatively large volume of water makes its way from the ground's surface down to the aquifer. In areas where groundwater recharge has been shown to support ecologically significant features such as coldwater streams and wetlands, Ecologically Significant Groundwater Recharge Areas (ESGRAs) may have been delineated. ESGRAs are defined as areas of land that are responsible for supporting groundwater discharge that, in turn, helps sustain sensitive features like coldwater streams, a wetland, or an area of natural or scientific interest (ANSI). A linkage must be present between the recharge area and the discharge to the ecologically significant feature. The identification of an ESGRA is not necessarily related to the volume of recharge that may be occurring and it is not a certainty that ESGRAs will coincide with SGRAs, as they may not represent areas of high volumes of recharge.

It is important to protect this recharge capacity because it has an effect on both the quality and the quantity of water. Therefore, the matching of pre-development recharge rates has historically been recommended especially in SGRAs and ESGRAs. To ensure local groundwater resources are not contaminated, risk assessment and mitigation should play a significant role during the planning stages of site and subdivision development or re-development. To ensure stormwater runoff does not contaminate groundwater sources of municipal drinking water, the following infiltration guidelines apply to the application of infiltration-based LID BMPs practices:

1. For all sites, regardless of proximity to WHPAs, IPZs and HVAs, infiltration-based LID BMPs should not accept runoff from contributing catchment areas that contain high risk site activities (Section 4.2.1).

2. For all sites, regardless of proximity to WHPAs, IPZs and HVAs, infiltration-based LID BMPs are generally encouraged for runoff originating from landscaped areas (front, side or rear yards) and rooftops.

3. For all sites within ICAs, runoff from land uses that have the potential to contribute to the specific contaminant issue should not be conveyed to infiltration-based LID BMPs.
   - For example, in a chloride ICA, the runoff from paved surfaces (roads, sidewalks and parking surfaces) should not be conveyed to infiltration-based LID BMPs unless the paved surface receives no salt applications, are closed/ not maintained during winter months, or the facility is designed with a bypass at the inlet that can be closed during periods of the year when road de-icing occurs (see Figure 4.5).

4. For all sites within vulnerable areas in source protection areas where stormwater management facilities designed to discharge to groundwater or surface water are identified as significant drinking water threats, runoff from the entire site should not be conveyed to infiltration-based LID BMPs unless the requirements in the source protection plans are implemented in the entire site design, as well as the design can enhance treatment properties for infiltration-based LID BMPs as described in Section 4.2.7. For WHPAs or IPZs where road salt application or snow storage are identified as significant drinking water threats, additional operational measures and design factors for mitigation of sodium and chloride loading as described in Section 4.2.7 should be implemented in the entire site design.

5. For all sites within vulnerable areas in source protection areas where stormwater management facilities designed to discharge to groundwater or surface water are identified as Moderate Drinking Water Threats, runoff from the entire site should consider design factors that can enhance the treatment properties of infiltration-based LID BMPs as described in Section 4.2.7 are implemented in the entire site design.

To determine whether a project site is in a WHPA, IPZ, ICA and/or an HVA, the MECP's Source Protection Information Atlas is an online resource that can be used. The Source Protection Information Atlas can be found at the following web address:
https://www.gisapplication.lrc.gov.on.ca/SourceWaterProtection/Index.html?site=SourceWaterProtection&viewer=SWPViewer&locale=en-US
This online tool has a mapping interface that allows the user to click on a site location to determine source protection information including:

- whether the location is within a Source Protection Area and if so, which Source Protection Area;
- whether the location is within a Wellhead Protection Area and if so, what type of Wellhead Protection Area it is and the associated vulnerability score;

- whether the location is within a Wellhead Protection Area E (WHPA-E, Groundwater Under Direct Influence of Surface Water);
- whether the location is within an Intake Protection Zone and if so, what type of Intake Protection Zone it is and the associated vulnerability score;
- whether the location is within an Issue Contributing Area and if so, what the contaminant is;
- whether the location is within a Significant Groundwater Recharge Area;
- whether the location is within a Highly Vulnerable Aquifer; and
- whether the location is within an Event Based Area.

To determine whether stormwater management facilities designed to discharge to groundwater or surface water are identified as significant drinking water threats on a site, the MECP has developed and continues to update Tables of Drinking Water Threats and Circumstances for chemicals and pathogens. These tables can be downloaded in spreadsheet format at the following web address: https://www.ontario.ca/page/tables-drinking-water-threats or an interactive online tool that allows users to quickly search the Tables of Drinking Water Threats. The Threats Tool was created to easily identify significant, moderate or low threats to municipal drinking water sources by:

- Vulnerable zone (WHPA, IPZ) and vulnerability score
- Threat category (i.e. sewage) and subcategory (i.e. sanitary sewers and related pipes)

The Threats Tool can be found at the following web address: http://swpip.ca/
In addition, the ministry has developed a support document that outlines the steps applicants can follow to assess vulnerable areas, risk activities and source protection plan policies.

Caution and due diligence should be used when implementing infiltration-based LID BMPs in areas where karst features and fractured sedimentary rock are common and where anthropogenic activities have the potential to reduce travel times (e.g. close proximity to abandoned wells, quarries and infrastructure bedding). Due to the uncertainty associated with the direction of flow and storage capacity in these areas, thorough hydrogeologic analysis should be undertaken to ensure changes in the site infiltration regime do not negatively impact local infrastructure, structures or wells.

Unlike municipal wells that have been studied as part of source protection plans, technical studies outlining the wellhead characteristics will not be available for most private water supply wells, communal systems and non-residential wells. As such, caution and due diligence should also be used when infiltration projects are proposed in close proximity to private drinking water wells.

It is also recommended that consultation with local agencies regarding the Source Protection Policies be completed early and often in the development of local stormwater management infiltration facilities.

4.2.7 Designing for Minimal Impact on Groundwater Quality

Several ways that soil can naturally remove stormwater constituents before they reach valuable groundwater resources are described earlier in this section. To provide additional protection against groundwater contamination, appropriate site planning is the most important strategy. Recognizing that runoff quality will vary significantly across a site and providing catchment areas with the appropriate treatment approach is essential.
Effective stormwater management employs a treatment train approach that manages stormwater at the source of runoff, along the conveyance network and at the end-of-pipe. Most infiltration-based LID BMPs are located at the source of runoff or built into the conveyance network. As result of their location, there is minimal opportunity for pre-treatment options that require large storage volumes for sediment settlement. Instead, design modifications to the infiltration-based LID BMP can be made to improve overall treatment efficiency or to target specific contaminants of concern. Table 4.4 identifies design factors that can enhance the treatment properties of infiltration-based LID BMP.

Table 4.3 - Design Factors for Enhancing Removal Rates

Factors that Reduce Removal Rates	Factors that Increase Removal Rates
Filter Beds less than 500 mm in depth	Filter Beds greater than 750 mm in depth
Filter media P-Index values ≥ 30 ppm [1]	Filter media P-Index values < 30 ppm [1]
Oversized underdrain system	Properly sized (or no) underdrain system
No pre-treatment provided	Pre-treatment provided
Single cell	Multiple cell
No Forebay	Forebay
Sparsely landscaped with ground cover only	Densely landscaped with trees, shrubs and ground cover
Filter media comprised predominately of sand	Filter media comprised of mixture of sand, fines and organic matter
Filter surface left uncovered or covered with stone	Filter surface covered with mulch and vegetation

[1] P-Index values refer to phosphorus soil test index values in parts per million (ppm). See www.omafra.gov.on.ca for more information on soil testing and accredited soil laboratories.
Source: Adapted from CVC/TRCA LID Stormwater Management Planning and Design Guide

When designing infiltration-based LID BMPs that use filter media for treatment (e.g. bioretention) it is important to consider the Cation Exchange Capacity (CEC) of the filter media. The CEC represents the number of exchangeable cations per dry weight that a soil can hold and is the primary mechanism for heavy metals removals from infiltrated stormwater. Filter media should have a CEC of greater than 10 meq/100g per the LID Stormwater Planning and Design Guide. In general, the CEC value of media increases with fines (clay) content and organic matter. Organic matter can have a 4 to 50 times higher CEC per given weight than clay because the source of negative charge organic matter differs from that of clay-based materials. Organic matter CEC is known as pH-dependent CEC, meaning that as pH increases (alkaline soils) the CEC will increase and vice versa.

When designing infiltration-based LID BMPs on sites where chloride loading is a concern a different mitigation approach must be taken. This approach focuses primarily on administrative and operational modifications to reduce salt loading. Salt management planning sets out a procedural and policy framework for the implementation of new technologies, practices, and equipment to reduce the use of salt while providing safe site conditions during the winter months.

Operational measures that may reduce chloride loading include:

- Moving snow and road salt storage facilities away from infiltration features;
- Modifying the timing, application type and application rates of de-icing agents;
- Modifying the timing of snow removal;
- Tracking and monitoring salt usage to find opportunities for reduced application; and
- Educating and training winter maintenance contractors on proper salt management.

Design modifications should be considered when implementing infiltration-based LID BMPs in a cold climate such as Ontario are identified in Table 4.5.

Table 4.4 - Design Factors for Cold Climate LID BMPs

Concern	Design Modification
Salt can damage buds, leaves and small twigs. Salt can also mimic drought conditions by impeding the uptake of water from soil with salt laden water.	Plant salt tolerant vegetation such as grasses, other herbaceous material and shrubs to avoid plant die-off. In areas where snow may be stored these should be of the non-woody variety.
Chloride contamination of groundwater is a concern.	Install permeable pavement, also known as pervious or porous pavement, porous concrete or asphalt, paving stones or interlocking pavers that allows stormwater runoff to infiltrate into drainage

Concern	Design Modification
	layers and the underlying soils below as these require less salt. Install a winter bypass at the inlet to prevent water from entering the facility during periods of the year when road de-icing occurs (**Figure 4.5**). The inlet gate can be removed in spring. This design modification prevents salt laden runoff from entering the facility and is recommended in areas where chloride contamination of groundwater is a concern. Install an impermeable liner and underdrain system to prevent infiltration while focusing on filtration capabilities for water quality improvements.
A 1 m separation distance is recommended between the seasonably high groundwater table and the invert of a LID BMP designed for infiltration. When a 1 m separation is not technically feasible, groundwater mounding analysis is recommended to assess the impacts over an appropriate temporal scale. (See Resource Directory)	Increase the distance (depth) between the invert of the facility and the seasonally high groundwater table. This design modification decreases direct interaction between local groundwater and filter media that accumulates chloride. Modelling approaches described in Chapter 5 may be considered to determine performance in areas of seasonally high groundwater.
De-icer application over time in increasing pH in soil-based planning medias resulting in impacts to trees and perennial survival rates.	Increase organic matter through the repeated application and decomposition of the soil cover (mulch) materials such as wood chips or bark mulch or application of layered organics in the form of compost (50 to 75 mm thickness) overlain the soil cover (mulch) materials (50 to 75 mm thickness).
High sediment loads from winter road aggregates (i.e. sand) are expected	Install pre-treatment devices or areas for sediment capture and removal as part of spring maintenance activities.
High snow loads have the potential to block inlets during periods of snow accumulation.	Ensure additional inlets beyond the primary inlet are incorporated into the design. Place secondary and tertiary inlets in areas where routine snow removal will remove excess snow (i.e. place within the ploughed portion of the carriageways).

Figure 4.5 - Inlet gate, installed to prevent chloride loading during winter, is removed in the spring

5.0 LID MODELLING APPROACHES

This section provides guidance on the selection of an appropriate modelling approach to analyze the effects of LID measure implementation on the local surface water and groundwater systems. Models applied to analyze stormwater systems should be able to generate overall site water budgets as well as stormwater runoff volumes, flow rates, and water quality estimates. Models developed to predict stormwater quality should include parameters such as suspended solids, sediment transport, nutrients, including nitrogen and phosphorous, and temperature. This section also provides guidance regarding criteria for selecting a technical approach for predicting and assessing the performance of stormwater management plans on different temporal scales of the analysis (e.g. event or long-term basis). The areal focus of the modelling assessment should be on a site scale but will need to recognize the hydrologic context of the surrounding watershed or sub-watershed.

The model selection methodology is suitable for addressing new developments, redevelopments, linear infrastructure and retrofits. The model selection approach attempts to match the level of model complexity to the principal considerations of the project, including scale of the project, the need for a detailed water budget analysis, water quality and runoff modelling, the physical setting of the site, the likelihood of adverse groundwater/surface water interaction and feedback, and the availability of data needed to develop and/or calibrate the model. The types of models widely available to assess the impacts of urban development on the environment are broken down into four model classes. An overview of these model classes is provided in Section 5.2 and expanded upon with examples in Appendix 5 – Model Selection, Development and Data Availability. Specific site conditions that should be addressed when developing a modelling approach are introduced in Section 5.3. A model selection framework is present in Section 5.4 with examples provided in Appendix 5. Model development tasks and relevant data are listed in Sections 5.5 and 5.6 respectively and expanded on in Appendix 5. Appendix 5 Model Selection, Development and Data Availability includes additional information including the following:

- description of the four (4) basic model classes from which a project proponent could select for detailed analysis of LID BMPs;
- information about the level of modelling effort that can address the nature of the proposed development and/or stormwater management retrofit while considering the context of the local setting;
- overview of the steps required to construct, calibrate, and apply a model; and
- overview of the data required to drive an assessment of the potential effects of LID.

This chapter is not intended to serve as a design manual or a cookbook detailing how to model urban development or LID alternatives; it is meant to provide information to practitioners about modelling approaches that will allow the potential impacts of a development project to be assessed. No particular modelling package or tool is explicitly favoured in this document; rather, the discussion and selection framework are intended to assist the adoption of a modelling strategy that can address both the nature of the physical setting and the type of proposed stormwater management system. Developers, planners, ecologists, biologists, geomorphologists, hydrologists, hydrogeologists, and water resources engineers should all be able to consult this document and reach similar conclusions regarding the modelling approach and level of effort required to analyze a proposed development. Likewise, project proponents, consultants, and regulators should be able to refer to this document and reach similar conclusions regarding the suitability of a modelling methodology. For example, if a development is proposed near sensitive groundwater-dependent streams or wetlands, the indicated modelling approach would include consideration of the impacts to the groundwater and surface water systems.

This section provides examples of model codes that have been previously applied within Ontario. The lists were not intended to be all-encompassing nor do they represent MECP-sanctioned or pre-approved models. Other models are available and new models are constantly being developed and older ones updated. The use of up-to-date technology is encouraged, although it may be necessary for a proponent to introduce and explain the advantages of a new model code that has not been used previously in Ontario.

5.1 Assessing LID Performance with Models

Hydrologic models can be used to assess elements of the water cycle (runoff, recharge, streamflow, evapotranspiration, and groundwater discharge to natural features) at a variety of spatial and temporal scales. The models can be used to assess current conditions and can be used as predictive tools to assess the water balance under future conditions. During the LID design process; there is a need to determine, through the use of quantitative tools such as water budget models, that the methods selected are likely to mitigate the increase in runoff and the loss of natural recharge due to changes related to a proposed land development. In a typical design case, there will be a need to:

- assess the natural hydrologic response of the study area,
- predict the likely increase in runoff and associated decrease in groundwater recharge within the development, and
- demonstrate that the proposed LID BMPs and other design improvements are likely to mitigate the excess runoff and maintain the existing rates of groundwater recharge.

For some large-scale developments, or in areas with sensitive groundwater-dependent environmental features, it may be necessary to represent the groundwater system in more detail and apply groundwater flow models to:

- predict the likely decrease in groundwater levels (heads) due to decreased recharge and possible increased groundwater use within the site,
- predict the decrease in natural groundwater discharge to streams (baseflow) due to decreases in recharge or alteration of the locations and timing of recharge,
- predict decrease in wetland stage due to changes in groundwater discharge,
- predict how recharge from infiltration-based LID BMPs may raise the water table causing interference with the LID performance; and
- demonstrate that the proposed LID BMPs and other design improvements will maintain rates of groundwater discharge towards protecting ecologically significant features.

By providing feedback to the designers, model results can also be used to help optimize the use and design of LID BMPs in a proposed development or site retrofit. LID options can be targeted at areas of maximum ecological benefit or overall effectiveness. Where a number of possible LID BMPs are available, building costs can be minimized while siting can be modified to maximize the effectiveness of LID BMPs.

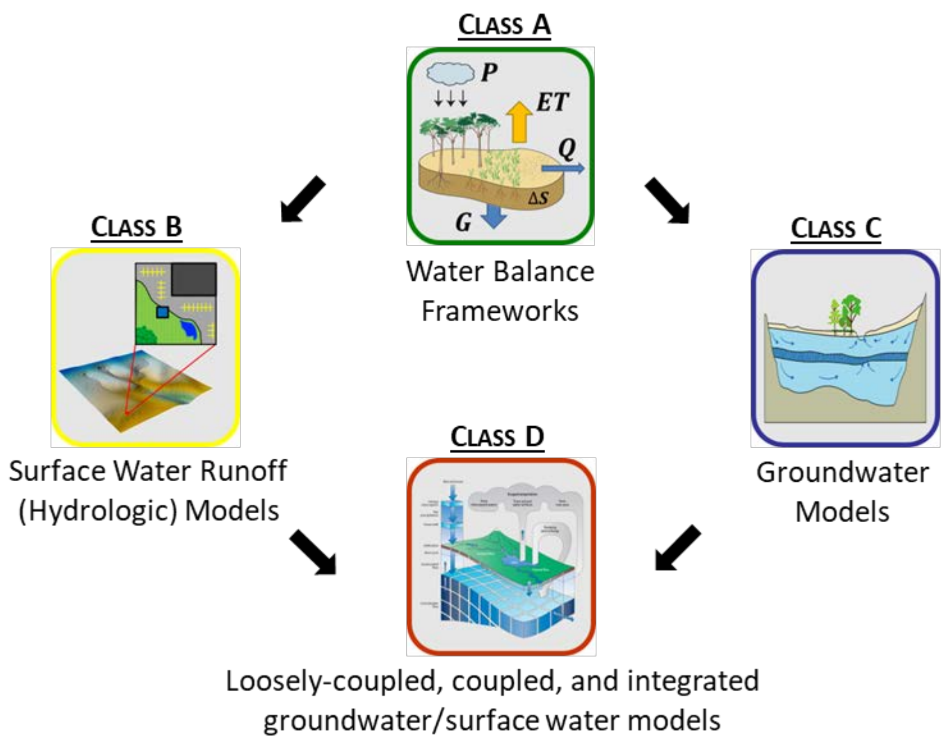
Effective hydrologic design tools can allow natural drainage features to be preserved in the overall site design. This can include quantifying the pre-development runoff volume, runoff quality and the natural conveyance and sediment transport functions of the natural drainage features such that they may be replicated by the site stormwater management system. Where a significant ecological feature is present, the stormwater system can be modified to isolate the feature from potential impacts. Numerical modelling tools can be used to test a variety of design options to confirm that there are no deleterious hydrologic or hydrogeologic impacts to significant ecological features. Where a simple sizing of LID BMPs to meet the volume requirement is not sufficient for assessment of LID performance these numerical tools can be used to demonstrate to stakeholders that negative effects will be mitigated, and that natural hydrologic function will be retained.

5.2 Categorization of Model Types

There are four (4) basic model classes from which a project proponent could select for detailed analysis of LID BMPs. In Appendix 5 – Model Selection, Development and Data Availability each class of model is briefly described, and examples are presented illustrating the level of detail provided for LID assessment. Broadly, each class reflects a family of tools with a similar level of explanatory power. The classification of the model types follows a basic hierarchy shown on Figure 5.1.

Class A represents *simple monthly or annual water budget tools* suitable for small development sites (e.g., 0 to 20 ha in size) or specific LID BMPs. **Class B** captures more sophisticated *hydrologic models and surface runoff models* that can explicitly represent small scale features on an event or continuous daily or hourly time step. **Class C** models and tools incorporate a more rigorous understanding of the *local and regional groundwater* system and can simulate the movement of subsurface flow. **Class D** types attempt to *consider the surface water and groundwater systems in one analysis*, either by coupling surface water (Class B) or groundwater (Class C) models or by applying integrated tools which consider both domains simultaneously. This hybrid class recognizes that in some instances, multiple models or approaches may be required to meet all the requirements of a given project.

Figure 5.1 - Hierarchy of Model Types



It should be noted that there are numerous subclasses by which to characterize the general model types. Rather than going through a comprehensive discussion of all types of models and all model classification schemes, this section focusses on models and methods typically applied in Ontario to analyze surface water and groundwater flows that are directly applicable to stormwater management, cumulative impact assessments to groundwater recharge and streamflow, and LID feature design and analysis.

5.3 Model Selection Factors

The selection of a class of modelling analysis should consider site conditions, project scale, and LID design objectives. Based on these factors, an appropriate model class can be selected from the four general classes of models presented in Section 5.2. This section will present the specific factors to consider as part of the model selection process, particularly in evaluating cases where a more advanced assessment of proposed LID design benefits and risks is warranted. These factors include:

- Scale of Proposed Development
- Pre-Development Site Conditions or Existing Conditions (in the case of stormwater management retrofit)
- Stormwater Management System Design
- Stream Geomorphology and Erosional and Sedimentation Impacts
- Proximity to Surface Water Dependent Natural Features
- Proximity to Groundwater-Dependent Natural Features
- Depth to Water Table
- Soils and Surficial Geology, and bedrock conditions
- Existing Data Considerations.

The following sections provide detailed discussions of these specific factors, providing context for the model selection framework presented in Section 5.4.

5.3.1 Scale of Proposed Development

The size of the proposed design can influence the selection of the appropriate model. A modelling approach should be selected that can demonstrate that a proposed development will have negligible impact to the hydrologic system. For project proposals that have a lower potential for affecting the water balance, Class C or D models may not be appropriate. An exception to this would be subwatershed scale stormwater management retrofits employing a range of LID BMPs in concert with the existing conventional storm sewer systems and end-of-pipe installations. Medium to large-scale developments (for hundreds to thousands of residents), however, are of greater concern, as the cumulative effect of the localized increases in impervious area (roofs, driveways, roads, commercial developments and parking lots) has a greater potential to adversely affect the current water balance in terms of changes in streamflow and groundwater recharge. Accordingly, a higher level of analysis is required to (1) quantitatively assess the cumulative impacts related to the development; (2) aid in the design of LID BMPs and other mitigation measures and (3) demonstrate their effectiveness in offsetting the effects of increased imperviousness and that they do not create unintended consequences such as increased flooding.

5.3.2 Pre-Development Site Conditions

The Runoff Volume Control Target calls for the control of the 90th percentile precipitation event and for the maintenance or restoration of the pre-development water balance (i.e. at the project onset or a natural undisturbed condition). Defining pre-development conditions is a key scoping exercise and is undertaken not only to quantify existing or historical conditions, but also to develop targets for post-development runoff and groundwater recharge rates. It is generally recommended that the determination of pre-development conditions should be made in consultation with the responsible regulatory authority prior to undertaking any modelling activities.

Pre-development site conditions can influence the selection of the appropriate model. Developments in fully naturalized sites would likely have the greatest relative change on the site if significant alteration of natural cover and modifications to the natural topography and drainage are planned. The conversion of natural lands will likely generate greater concern from the conservation authorities and municipalities. In these cases, a higher level of analysis would be required to (1) assess the impacts related to the development; (2) aid in the design of LID BMPs and other mitigation measures, and (3) demonstrate their effectiveness.

Conversion of agricultural lands may require less alteration (such as land clearing and major regrading). Simple measures, such as minor re-grading and tree planting, could be applied to improve infiltration and control runoff compared to pre-existing conditions, although this would depend on the density of the proposed development and the change in imperviousness. The use of models to assess the potential impacts would still be beneficial but may not need to be as rigorous as for the conversion of natural lands. For small-scale urban retrofits where runoff is expected to decrease, a simple Water Balance approach may be sufficient. Conversely, if a large-scale retrofit is planned for an urban area with an existing, complex stormwater system, any increases to offsite runoff would need to be evaluated.

5.3.3 Stormwater Management System Design

The complexity of the proposed stormwater management system can influence the selection of the appropriate model. The number and distribution of the LID BMPs is one consideration, as a large number of widely distributed measures is more likely to affect the overall water balance than a small number of closely spaced measures. Simpler models could be used to assess the effectiveness of the individual measures and to check for interference between them. A site design with widely distributed measures would require a model of greater spatial extent and complexity to assess the cumulative effects and to demonstrate the effectiveness and benefits of LID BMPs. For example, in one proposed development with 19,500 homes (see the Babcock Range Integrated Model Example in Appendix 5), there were hundreds of stormwater ponds and constructed wetlands distributed across the area to capture increased runoff and increase infiltration. Each feature and control structure needed to be designed and the cumulative effect of the system on the water balance was assessed with an integrated surface water / groundwater model.

The complexity of the individual stormwater management features is another consideration. The use of stormwater detention ponds, for example, has been a mandated practice since the mid-1980s. Many easy-to-use surface water runoff models are available that are specifically intended to aid in stormwater management. On the other hand, the design and assessment of infiltration intensive LID BMPs may require a more complex approach. A development with a significant reliance on LID BMPs would benefit from the use of more complex models to optimize the LID measure design. If the proposed stormwater design will rely on existing infrastructure, these systems should be included in the modelling exercise where necessary.

5.3.4 Stream Geomorphology and Erosional Impacts

Changes to runoff volumes, storm flow durations, and flood frequencies can have negative impacts on stream geomorphology downstream of development. Traditional stormwater management best practices of detention and controlled release can help to address erosion impacts based on assumptions of critical erosion thresholds; but erosion and sediment transport processes can be more complex, and this can be particularly true for "glacially conditioned" river catchments in Ontario. As such, erosion assessments in some cases need to evaluate stormwater management erosion control targets based on more advanced scientific approaches to better represent the stream erosion processes and sediment transport patterns within the drainage network.

Proposed developments in areas where the streams are particularly sensitive to geomorphological change will likely generate greater concern from adjacent land owners, conservation authorities, and municipal or county agencies. Models that can address the changes in discharge as well as changes to sediment yield may be required for these studies. Similarly, models that can simulate post-development streamflow can be used to drive a number of geomorphological analyses to assess stream stability, including critical threshold analysis, sediment transport calculations, and stream power mapping as well as for assessing impacts to ecological function.

5.3.5 Proximity to Surface Water Dependant Natural Features

Proximity of the proposed development to sensitive surface water features can influence the selection of the appropriate model. Sensitive surface water features that would have water quantity and/or water quality concerns could include:

- runoff-dependent wetlands that would be sensitive to changes in the drainage pattern or rates of overland flow,
- headwater streams on low permeability bedrock or soils,
- cold water streams where elevated temperature and contaminants in the runoff would be of concern;
- Intake Protection Zones (IPZs) and location of intakes for surface water supplies, and
- streams with erosional or geomorphological concerns (discussed above).

Some wetlands are primarily dependent on overland runoff and interflow to maintain saturation of the soils. These wetlands would be sensitive to changes in the rates of flow due to alteration of topography and drainage patterns within a nearby development. Stream reaches where the bottom sediment is on or underlain by low-permeability bedrock, clays, or fine-grained tills receive little groundwater discharge. Flow into the reach would be primarily as overland runoff and interflow. Flow in headwater streams with these conditions would likely be intermittent and would be very sensitive to changes in the rates of flow due to alteration of topography and drainage patterns within nearby developments. Geology can strongly affect these processes; stream reaches overtop karst outcrops can have significant gains and/or losses of flow to and from the subsurface.

The models could be used to assess the cumulative effects of the development on water quantity and the functioning of the nearby natural feature. Comparative analyses would be done to quantify the mitigation benefit of the LID BMPs. Another concern that could be addressed is the possible impairment of ambient water quality through the transport of high levels of dissolved contaminants from road or lawn runoff. Changes in groundwater and surface water quality could be assessed through the use of combined flow and sediment and/or combined flow and solute transport models.

Proximity: How does one determine what features are within the proximity (or influence) of a proposed development? This would include (1) areas where the development surrounds the feature of interest; and (2) where the development is adjacent to the setbacks/buffers around the feature of interest. Additionally, it would likely include developments close enough that an experienced practitioner would expect some measurable response to be felt within the feature of interest; and could include areas close enough that a reasonable person (e.g., an adjacent landowner or regulator) would expect some alteration and therefore would express concern. Existing minimum setbacks, other regulatory rules, and buffers and study areas determined during the Environmental Planning Process should be incorporated. A clear definition should be created before undertaking a project and study boundaries defined accordingly.

5.3.6 Proximity to Groundwater-Dependant Natural Features

Proximity of the proposed development to sensitive groundwater-dependent natural features can influence the selection of the appropriate model. Sensitive groundwater or surface water features that would have water quantity concerns could include:

- headwater tributaries of streams which are sensitive to small changes in the depth to the water table,
- groundwater-fed wetlands whose hydroperiod would be sensitive to small changes in the depth to the water table,

- environmentally significant groundwater recharge areas (ESGRAs) which are mapped upland areas known to contribute to specific groundwater-dependent ecological features (e.g., wetlands and headwater streams),
- significant groundwater recharge areas (SGRAs) which are mapped upland areas known to contribute high rates of groundwater recharge to aquifers providing municipal or domestic drinking-water supply.

Sensitive groundwater features that would have water quality concerns could include:

- nearby private drinking water supply wells,
- areas mapped as contributing recharge to Highly Vulnerable Aquifers (HVAs),
- Wellhead Protection areas (WHPAs) around municipal supply wells,
- cold water streams where elevated temperature due to reduction in groundwater seepage and/or seepage of groundwater contaminated by road salt and lawn fertilizers would be of concern.

The models could be used to assess the cumulative effects of the development on water quantity and the functioning of the nearby natural feature. Comparative analyses would be done to quantify the mitigation benefits of the LID BMPs. Changes in groundwater and surface water quality could be assessed through the use of combined flow and solute transport models.

5.3.7 Depth to Water Table

The water table in an unconfined aquifer occurs at the depth below ground surface where the pore water pressure is equal to atmospheric pressure. The water table is measurable by the standing water elevation in a shallow well (piezometer) penetrating the top of the unconfined aquifer. The depth to the water table can provide an indication of the vulnerability of natural, groundwater-supported features to changes in the local hydrographic landscape and can influence the function of infiltration-based LID designs. In particular, sites or portions of sites with a shallow water table should be given careful consideration by practitioners and may require the use of more advanced modelling approaches as part of the LID development strategy.

Areas characterized by a shallow depth to water table are often accompanied by streams with high baseflow indices, and groundwater-fed wetlands, owing to the strong interconnectedness between then surface water and groundwater systems. Reductions in recharge to the water table in the environments could have significant effects on both the quantity and quality of water reaching these groundwater-dependent natural features (Bhaskar *et al.*, 2016). The modelling approach selected for these cases should attempt to quantitatively characterize the hydraulic linkages between the groundwater system and these features.

From a practical perspective, the performance of infiltration-based LID BMPs can be limited in areas of seasonally high water table or where seasonal groundwater discharge occurs. In cases where the water table occurs at or near ground surface, the vertical hydraulic gradient between the reservoir and the receiving groundwater system may be small, thereby limiting the rate of discharge from the infiltration-based LID. The use of a model to characterize the behavior of the water table across the site may then be useful for siting infiltration-based LID designs and predicting potential seasonal restrictions on their performance.

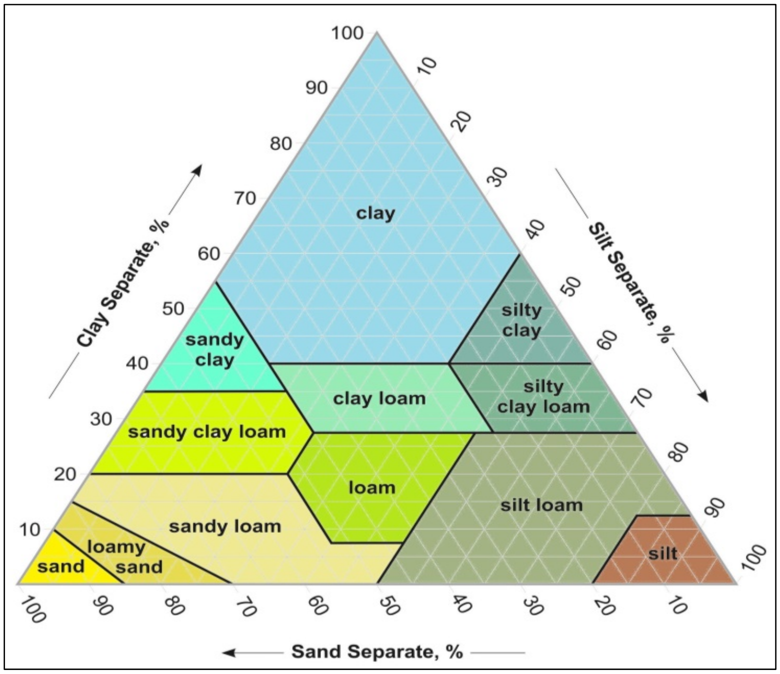
Shallow water table conditions in the subsurface may also necessitate more complex modelling. The water balance in these areas of high water table is particularly complex to analyze as the shallow water table affects evapotranspiration and runoff processes. These changes in the rate of ET and runoff, in turn, affect the rate of groundwater recharge and the position of the water table. Ideally, the level of modelling analysis should capture these interactions in order to evaluate effects on development, effectiveness and performance of LID BMPs. Of the model classes presented in Section 5.2, this non-linear feedback process can best be resolved using the Class D: Integrated Groundwater/ Surface Water Models.

5.3.8 Soils and Surficial Geology

Site conditions related to soils can influence the selection of the appropriate model. The presence of low-permeability soils, such as silts and clays, at surface and/or poor drainage conditions (for, example, where a low-permeability clay till underlies a thin layer of sand) can impair the effectiveness of infiltration-enhancement measures such as permeable pavements, bioswales, and infiltration trenches. Some measures could be made more effective by altering design criteria to increase storage capacity to account for longer residence time than for those located in areas with more permeable soils. Continuous modelling with actual climate data or event-based models using a sequence of storms (e.g., two separate 25 mm storms events within a two-day period) could identify whether the systems will fail to provide the needed retention when exfiltration is limited, and underdrains connected to the sewer system may be required.

Areas with low-permeability surface soils also tend to have shallow water table conditions that limit infiltration rates and drainage rates from retention/detention ponds. Analytical or numerical groundwater models can be used to predict water table response to infiltration and examine how these features perform under a wide-range of climatic series. The hydraulic conductivity values needed for the models may be available from geotechnical investigations (borehole and test pit logs completed by a geotechnical consultant) and those conductivity values may be converted to infiltration rates using tables such as those in CVC/TRCA (2010). Estimates of other key soil zone properties such as wilting point, field capacity, and porosity can be estimated from soil classification (Figure 5.2) and tabulated values (e.g., Saxton and Rawls, 2006).

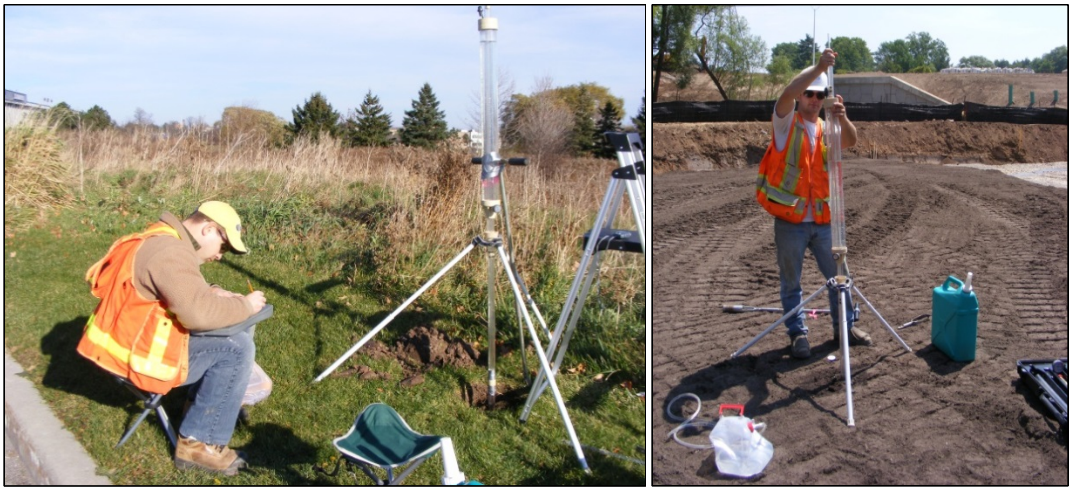
Figure 5.2 - Soil Classification System



In–situ infiltration testing is a preferred method to characterize the hydraulic properties of the existing native material on-site. The more detailed testing is often required in support of approvals, and performance verification of designs. In–situ soil testing can be accomplished using a combination of Guelph permeameter testing (see Figure 5.3), double ring infiltrometer, single ring infiltrometer, a Philip-Dunn infiltrometer, or other methods to determine the in-situ saturated hydraulic conductivity. Once selected the same infiltration measurement method should be used on the site. Site testing of infiltration rates as per the LID Stormwater Planning and Design Guide Version (CVC/TRCA 2010), Appendix C at the likely interface of the proposed infiltration-based facility with the native soils is recommended during detailed design of LID BMPs.

Testing should be performed within the approximate location and invert of proposed LID BMPs. The quantity of test holes and spacing between them should be sufficient to collect enough information for detailed design purposes. In-situ testing should also be informed by the geotechnical reports and borehole logs. In this manner, where stratified soils are encountered, in-situ testing should be completed within the multiple soil layers if they are located within 1.5m of the proposed facility invert. As per the LID Stormwater Planning and Design Guide (CVC/TRCA 2010)), this will permit the appropriate factor of safety to be applied to the calculated design infiltration rate. It is recommended that infiltration parameters within the model utilize the calculated design infiltration rate which has been adjusted with the appropriate factor of safety. The factor of safety accommodates construction-related impacts such as: introduction of fines, compaction and disruption of the soil macrospores, as well as anticipated decreases in long-term performance as the facilities age and are impacted by deposition of sediments.

Figure 5.3 - Infiltration Testing Conducted During IMAX Parking Lot Reconstruction Project – Mississauga (left) and Upper Middle Road Bioretention Project (right)



Infiltration testing is also typically combined with monitoring wells or shallow piezometers, typically consisting of 50 mm diameter well screens installed to depths of 3.0 m and greater (depending on average depth to the water table) and cased within an above-ground, lockable, steel housing. Monitoring wells are installed to determine the pre- and post-construction seasonal high water table and groundwater flow direction. Monitoring wells are needed when observation data from background documentation or previous investigations are not available. The Low Impact Development Stormwater Management Planning and Design Guide Version 1.0 (TRCA/CVC, 2010) includes design criteria regarding groundwater clearance requirements. Infiltration data and water levels collected on site should be considering during model selection to ensure the model approach is appropriate for the conditions found on site.

5.3.9 Existing Data Considerations during Model Selection

The availability of site-specific and regional data sets is an important consideration when undertaking any modelling analysis, to serve as either model inputs or to calibrate and validate the model. As a general rule, the more complex the model, the more data are required to develop and calibrate the model to produce meaningful results. As an example, a groundwater model to assess potential cumulative effects of a proposed development would require borehole data to define subsurface geology, aquifer testing to determine hydraulic properties, permeability test results to define soil properties, climate data to estimate natural groundwater recharge rates, and observations of groundwater levels in wells to calibrate the model. If unavailable for the site, data could be inferred from studies in neighbouring areas. **Section 5.6** discusses the data needs for different model classes and the sources of data available for model development in Ontario.

The practitioner must be aware of the level of modelling analysis required for a given development, as well as the minimum data requirements for successfully implementing the selected model. The application of more complex models in data poor environment is a common technical challenge. This, however, should not be used as an outright justification for pursuing a less rigorous assessment approach, but rather an indication that additional data need to be acquired in order to properly characterize site conditions. Put another way, where site factors indicate the use of a model for which available data are insufficient, the practitioner should first pursue a course of obtaining additional data – not a different modelling solution.

Where obtaining additional data is not practicable, the practitioner may opt to limit the scope of the prescribed model to a more theoretical exercise and support it with secondary analyses using simpler modelling solutions. As an example, consider the case where a large site (greater than 100 homes) is being developed for an area with known groundwater-supplied wetland features. A groundwater flow model is desirable; however, site-specific geologic and hydrogeologic data are sparse. The practitioner may choose to construct a Class C groundwater flow model based on a simplified site conceptualization, along with a Class A water balance model for individual wetland features wherein groundwater fluxes are informed by the Class C model. While this combined solution will generally help to compensate for data paucity, the limitations and assumptions must be clearly presented, along with a discussion of the potentially high degree of uncertainty in the results.

5.3.10 Non-Functional Constraints

Additional model-related considerations should be consciously deliberated during the model selection process such as historical and institutional factors, the feasibility of actually executing the proposed modelling approach, human factors, and model limitations as discussed below.

5.3.10.1 Historical Factors and Knowledge Constraints

No model guide or manual is a replacement for the experience of a seasoned professional. Each practitioner will have to make decisions about model selection and implementation based on his or her own educational background and experience. Historical factors may limit the perceived freedom a practitioner may have to undertake a particular modelling or analysis strategy. Often, a model developed for a particular region is pressed into service on other projects in the area to avoid the effort of new studies. Additionally, some municipalities within Ontario have either stated preferences or mandated requirements regarding the model codes to be employed in their jurisdictions. Historical or institutional factors can include:

- whether the model is recognized and acceptable to the regulatory authority;
- availability of the model and cost of obtaining and installing the code;
- availability of review staff with appropriate modelling expertise; and

- availability of qualified outside experts to review the model.

Innovative, cutting-edge modelling methodologies that produce sound, sustainable development outcomes should always be promoted. Practitioners, proponents, and regulators should be accepting of new solutions and approaches; however, additional effort and documentation may be required when introducing new models and methods.

5.3.10.2 Resources Constraints

Selection of an appropriate modelling approach is an attempt to match the level of model complexity to site considerations. Consideration must also be given to the available resources, this includes the types of models available, precedence for using the model at similar sites, the availability of data needed to develop and calibrate the models, the technical skills required to apply the models appropriately, and technical factors such as those listed below:

- availability of staff with appropriate expertise; or, alternatively, access to training;
- complicated physical settings will require multi-disciplinary teams. For example, a hydrologist should consult a qualified hydrogeologist when undertaking projects in areas with sensitive groundwater supported habitat. Class D modelling efforts will certainly require an interdisciplinary team approach;
- quality of the model's technical documentation, user's manual, and training materials;
- availability of technical assistance from the code developers or users' group;
- access to the source code (i.e., proprietary versus public domain codes);
- availability of a graphical user interface (GUI) or other pre-processing and post-processing tools;
- hardware and software requirements; and
- model execution times (some models can take hours or days to run).

A lack of knowledge or resources is not an acceptable rationale for proposing a reduced level of study detail in highly sensitive or complex areas. Additionally, the user should determine at the outset what hydrologic processes and spatial and temporal scale are required to inform the particular management questions and decisions. The user should then become familiar with the selected model to be sure that the processes and scales for which the model was developed are consistent with these objectives.

5.3.10.3 All Models Have Limitations

A final caveat is that all numerical model codes have their strengths and weaknesses. They were designed by individuals or groups of researchers who may have had specific areas of interest or expertise, and the model codes produced may reflect some of those biases. Some models are better at representing certain aspects of the hydrologic cycle and/or were developed to represent hydrologic processes at specific scales. Further aspects of model selection to consider include:

- multiple models can exist that are suitable for analyzing a given problem;
- model selection comes down to the judgement, skill, and often the preference of the practitioner;
- model construction and application should be performed by qualified and experienced persons;
- models represent calculated estimates. To the extent possible, they should be evaluated by comparing against historical data, field data collected during the course of the site investigation, and longer-term site monitoring data.

5.4 Model Selection Framework

The modelling selection framework can be used to either scope or evaluate a modelling approach. The following discussion is not meant to prescribe the model code to be employed or modelling approach to be undertaken for a given project. It merely provides some insight into the considerations that may inform the model selection process. The modeller should be able to explain his or her approach and how it relates to the specific issues in the project area to various project stakeholders, and justify the approach to planners, biologist, engineers, hydrologists, and hydrogeologists. All members of the project team should have confidence that the approach is reasonable and will effectively assess the possible consequences of the proposed development.

Prior to selecting an appropriate modelling tool for a study area, thought must be given to clearly defining the specific technical objectives of the analysis, either by the proponent or project team. It is important to know the specific questions that the modelling procedure will be required to answer. For example, a model may be needed to examine the performance of a single LID feature in a critical area of the development or the modelling analysis may be needed to assess whether a large-scale development has a cumulative impact on stage in nearby wetlands and streams. In areas with sensitive habitat, stakeholders will likely want assurances that the proposed stormwater management system will mitigate any negative impacts of the planned development. As discussed in detail in below, some general considerations for model selection include:

- the scale and technical complexity of the project ranging from new developments, infill-developments, redevelopments, and retrofits;
- the requirements for regulatory compliance;
- the level of detail required for the analysis (i.e., is the model's intended use for planning purposes, engineering/design, operational performance, or all the above?);
- the spatial and temporal scales of the analysis (i.e., how far from the site do we need to consider possible effects and for how long into the future? Is the goal to model a

single storm event or continuous rainfall? Is the model required to predict large storm events (flood analysis), low-flow conditions, or the full range?)

- the complexity of site conditions;
- the complexity of conditions within the extended study area and the proximity to ecologically sensitive areas;
- the likelihood of significant groundwater/surface water interaction;
- the need for water quality impact analysis; and
- the need to include other stormwater management measures and the existing or planned stormwater sewer system in the modelling.

The technical objectives and often the level of detail evolve over the planning cycle. A simplified analysis may be adequate in the project scoping stage while a detailed analysis may be required at the lot-design level. Similarly, multiple models may be needed to meet the all the objectives of the study. For example, a professional may choose to employ a model to address concerns related to hydrologic and hydraulics and a second model to evaluate the groundwater response. Some modelling approaches are available that can satisfy multiple objectives. Although these are typically more difficult to implement, the combined or integrated solutions can prove more efficient than developing several different stand-alone models.

Two (2) examples of this framework being used are provided in Appendix 5 – Model Selection, Development and Data Availability. The first example uses the framework for a MESP while the second example uses the framework for a subdivision development.

5.4.1 Using the Model Selection Framework

The Model Selection Framework is intended to guide the selection of a defensible modelling strategy. The Framework can be used to either scope a modelling approach based on a proposed site location or to evaluate an existing modelling approach to ensure that major site considerations are factored into the analysis. Each of the categories listed in the *Site Factors* column is discussed in further detail in Section 5.3.

To Scope a Future Modelling Approach

For a practitioner planning to scope a future modelling study, the use of the Model Selection Framework table (Table 5.1) is described in the following steps:

1. Copy the value from the *Indicated Level of Modelling Effort Column* to the adjacent *Proposed Level of Modelling Effort* column.
2. After considering each site factor evaluate the *Proposed Level of Modelling Effort* column, removing those site factors not relevant to the planned study area.
3. Interrogate the suggested level of modelling analysis: What is the maximum proposed level of modelling suggested? Does this class of model or level of effort make sense for

your study area or scale of development? Does a single model type appear when considering the majority of site factors? Does the Framework suggest addressing impacts to sensitive natural features with a dissimilar approach? Does the Framework suggest addressing LID performance with a dissimilar approach? What field data could be collected at the site to enhance the various modelling approaches?

4. Where a practitioner has decided that a simpler level of analysis than the indicated approach, be prepared to *justify* this decision to the regulatory authorities including the MECP.

To Evaluate an Existing or Planned Modelling Approach

For a practitioner or regulator planning to evaluate or review an existing or planned modelling study, the use of the Model Selection Framework table (**Table 5.1**) is described in the following steps:

1. For each site factor, isolate the detailed considerations that apply to the planned study area.
2. Consider the modelling approach employed for each consideration, and in the *Level of Modelling Effort* column indicate the modelling class used in the study.
3. After considering each site factor, compare each *Level of Modelling Effort* vs. *Indicated Level of Modelling Effort* columns.
4. Note the discrepancies in the column. Are the discrepancies significant? Have the linkages to sensitive environmental features been considered? Has the proponent demonstrated that the proposed LID BMPs will function as designed? Are Class B or C analyses warranted where only Class A water balances have been completed? Would a colleague or related water professional reach a similar conclusion?

Disagreement between the Indicated and Proposed Level of Modelling Effort

In case of disagreement between the indicated and proposed level of modelling effort, the practitioner should be prepared to justify their chosen approach. The framework is not meant to compel the practitioner to undertake a level of effort that may be onerous or nonsensical; it instead emphasizes that selected approaches must be defensible. For example, if the project is located on impermeable, fine grained tills, the framework suggests a Type C or D modelling approach to ensure the shallow groundwater system can accept a level of infiltration required by infiltration-based LID BMPs. If field data have been collected (e.g., soil samples, transient shallow groundwater level measurements, and infiltration tests) that demonstrate the site can accept the required level of infiltration, then omitting an approach that expressly considers the groundwater system may be justified. Similarly, if the boundaries of a proposed development are large, but the disturbed footprint or altered area affects only a small zone, a rigorous assessment of the impact to the local hydrologic system may not be necessary.

Undertaking Parallel Modelling Exercises

Based on the site specifics, there may be situations where more than one modelling approach is required to meet the various model selection factors. It is common during many development studies to create multiple models to address the various stormwater design criteria such as flood protection, water quality, erosion control, and water balance requirements. Multiple models, with the appropriate level of complexity for each criterion, can represent a more cost-effective approach than developing a single model capable of addressing all requirements. However, for clarity, multiple models should not be created which address the same factor, hydrologic component, or design criteria.

Table 5.1 - Example Model Selection Rationale Checklist

SITE FACTOR	RATIONALE	SUGGESTED / EXAMPLE CONSIDERATIONS	CONSIDERATIONS FOR THE MODELLING EFFORT	INDICATED LEVEL OF MODELLING EFFORT	(PROPOSED) LEVEL OF MODELLING EFFORT (A/B/C/D)	JUSTIFICATION REQUIRED? (Y/N)
Scale of Proposed Development	*Level of effort required will reflect the physical scale of the proposed development. Larger developments will likely have more significant impacts than a relatively small infill or a retrofit and require more detailed models that consider a larger spatial extent and the impacts on groundwater and surface water.*	Small (0-20 hectares)	Minor impacts to the local hydrologic system expected	A		
		Medium (20-250 hectares)	Should consider the local groundwater and surface water systems	B/C		
		Large (250+ hectares)	Must consider the local to regional scale water balance	D		
Pre-development Site Conditions	*Retrofits, redevelopments, or infill-developments in urbanized areas would have a low potential for measurably affecting the water balance and would generally require a limited level of analysis. Developments in fully naturalized sites would likely have the greatest relative change and would require more analysis. Existing stormwater infrastructure will need to be included in the modelling exercise.*	Full Naturalized	Significant potential for alteration of the hydrologic system	A/B/C/D		
		Agricultural	Moderate to significant potential for alteration of the hydrologic system	B/C		
		Peri-Urban	Moderate to significant potential for alteration of the hydrologic system	B/C		
		Urban	Low potential for negative impacts to the hydrologic system	A		
Stormwater Management System Design	*The number and distribution of the LID BMPs is one consideration. A large number of widely distributed measures is more likely to affect the overall water balance and would need more in-depth analysis. The complexity of the stormwater management features is another consideration. Simple runoff models could be used to analyze standard measures like stormwater detention ponds, for example. The design and assessment of LID BMPs is more complex and requires more sophisticated models. Proposed stormwater sewer system and non-LID stormwater management measures should be included in the modelling.*	None/Evacuation	No stormwater management measures planned (*approach may not be acceptable to regulators or stakeholders*)	A		
		Detention	Traditional stormwater management practices (*approach may not be acceptable to regulators or stakeholders*)	A/B		
		Focussed, localized infiltration and storage	Management plan considered some LID BMPs, mostly large scale, isolated components	B/C		
		Widespread, distributed infiltration and storage	Complex management plan, with many, distributed LID BMPs	B/C/D		
Stream Geomorphology and Erosional Impacts	*Changing the volumes and recurrence of stormwater flows can lead to increased erosion and changes in the geomorphology of reaches within and downstream of the development. Proposed developments in areas where streams are particularly sensitive to geomorphological change will likely generate greater concern from adjacent land owners, conservation authorities, and municipal or county agencies.*	Low likelihood of downstream impacts to channel stability	Sediment transport yields and stream channel stability is unlikely to be affected by planned alterations	A		
		High likelihood of downstream impacts to channel stability	Changes to the runoff or land cover characteristics of the site have a high potential to either destabilize local stream systems or increase sediment yields	B/D		
Proximity to Surface water Dependant Natural Features	*Sensitive surface water features, such as runoff-dependent wetlands, headwater streams on low permeability materials, and some cold water streams, would require more in-depth analysis as they are sensitive to changes in the water balance resulting from the cumulative effects of development.*	Wetlands	Potential for offsite impacts through alteration of the site runoff characteristics (*unless feature is demonstrated to be disconnected from the surface water system*)	A/B/D		
		Sensitive downstream habitat	Potential for offsite impacts through alteration of the site runoff characteristics	B/C/D		
Proximity to Groundwater-Dependant Natural Features	*Sensitive surface water features, such as groundwater-dependent wetlands, headwater streams that are groundwater fed, and cold water streams, would require more in-depth analysis as they are sensitive to changes in the water balance resulting from the cumulative effects of development. Features in areas designated as wellhead protection areas,*	Wetlands	Potential for offsite impacts through alteration of the local groundwater flow system (*unless feature is demonstrated to be disconnected from the groundwater system*)	B/C/D		
		Coldwater Streams	Potential for offsite impact to natural features through alteration of the local groundwater flow system	B/C/D		
		Streams with measured baseflow contribution (BFI > 0.5)		C/D		

SITE FACTOR	RATIONALE	SUGGESTED / EXAMPLE CONSIDERATIONS	CONSIDERATIONS FOR THE MODELLING EFFORT	INDICATED LEVEL OF MODELLING EFFORT	(PROPOSED) LEVEL OF MODELLING EFFORT (A/B/C/D)	JUSTIFICATION REQUIRED? (Y/N)
	highly vulnerable aquifers, high-volume recharge areas, and ecologically-significant recharge area would also require more in-depth analysis	Ecologically Significant Groundwater Recharge Areas (ESGRAs)		C/D		
		Significant Groundwater Recharge Areas (SGRAs)/High Volume Recharge Areas (HVRAs)	Potential for impacts to the regional groundwater flow system	B/C/D		
		Wellhead Protection Areas (WHPAs) & Vulnerable Aquifers (HVAs)	Potential for impacts to municipal/regional water supply sources	B/C/D		
Depth to Water Table	*Analyzing the pre- and post-development water balance is areas with shallow depth to the water table requires complex models to simulate the non-linear feedback between processes controlling Dunnian runoff, ET, and groundwater recharge.*	Shallow (Seasonal depth to water table < 4m)	Suggests high vulnerability to local changes in drainage and recharge, correct functioning of LID BMPs must be evaluated	B/C/D		
		Deep (Seasonal depth to water table > 4m)	Suggests low vulnerability to local changes in recharge, potentially high capacity to accept additional infiltration/recharge	A/B		
Soils and Surficial Geology	*Areas with poor drainage and/or low-permeability soils, such as silts and clays, at surface clay can impair the effectiveness of infiltration-based LID BMPs. Analytical or numerical groundwater models would be needed to predict water table response to infiltration and examine how these features perform and to assess the need for underdrains. (* indicates the need for detailed field investigations)*	Thick (>5-8m), highly permeable soils (gravel to medium sand) at surface	High capacity to accept additional infiltration/recharge	A/B		
		Thin (<5m), highly permeable soils at surface underlain with lower permeable soils	Moderate capacity to accept additional infiltration/recharge, may require further investigation	B/C/D		
		Moderately permeable (fine sands to sandy silts) soils at surface	Low capacity to accept additional infiltration/recharge	B*/C/D		
		Fine grained (silt, clays, silt/clay tills, and organics) at surface	Very low capacity to accept additional infiltration/recharge	B*/C/D		

5.5 Model Development and Application

Selecting an appropriate model (or models) which can address the various hydrological conditions at a proposed site is only the first step. The modelling exercise should be scoped; the model constructed, verified, calibrated and validated; and the final design must be evaluated and documented. It is acknowledged that calibration is not always feasible because of monitoring data limitations. Where appropriate monitoring data is available or can be collected, calibration should also be done. Appendix 5 – Model Selection, Development and Data Availability discusses the following modelling tasks:

- Detailed Model Selection
- Data Collection
- Establishing Modeling Objectives
- Model Construction
- Model Verification
- Model Calibration
- Model Validation
- Application to Assessment of Stormwater Design
- Reporting and Documentation

Further reading has also been provided in Appendix 5 to provide a basic overview of a very complex and challenging topic.

5.6 Model Data Availability

Data requirements for water budget analysis vary with the complexity of the model and the number of hydrologic processes represented. The simplest water budget models require information on climate (average annual or monthly precipitation and potential evapotranspiration (PET) values) and soils (e.g., average moisture storage capacity).

More complex hydrologic models require complete climate data time series and detailed information and mapping of soil types and properties, land use and cover, vegetative cover, topography, and stream course information. Data sources for specific model types are discussed in Appendix 5 – Model Selection, Development and Data Availability. Data categories discussed are:

- Climate Data
- Design Storms and Intensity-Duration-Frequency Curves
- Streamflow and Water Elevation Data
- Topographic Data
- Stream Network, Lake, Pond and Wetland Mapping Products

- Soils and Surficial Geology Data
- Land Coverage Data
- Groundwater Model Data Requirements

A summary table outlining data inputs, intervals and sources is provided in Appendix 5.

6.0 CLIMATE CHANGE

Climate Change tools, guides, protocols and processes are available to Ontario stormwater practitioners to conduct assessments of future climate change, account for uncertainties in the predictions, and develop adaptive strategies that would be resilient to a wide range of climate change outcomes.

This chapter:

- Defines Climate Change, Adaptation, Mitigation and highlights the importance of Climate Change Co-Benefits
- Discusses the need for Climate Change Impact Assessments
- Provides understanding of the various Modelling Approaches for Climate Change
- Includes Climate Change Adaptation Protocols and Tools; and
- Outlines a Four (4) Step Climate Change Adaptation Process for use in Stormwater Management

Along with land use changes resulting from population growth and aging infrastructure, climate change is an additional factor that must be considered by stormwater managers and water resource practitioners in Ontario.

Stormwater management is directly related to climate. Changes in precipitation patterns and seasonal temperatures can reduce the ability of our engineered stormwater systems to effectively provide an acceptable level of service. These changes may also affect the ability of our natural systems such as streams, rivers, wetlands and lakes to support important ecological functions. As stormwater professionals, adaptation and mitigation should be priorities when planning and designing stormwater management systems.

The effects of climate change have already been observed in Ontario and studies predict that annual temperatures will continue to increase with generally warmer and wetter winters and hotter, drier summers. The frequency and intensity of extreme rainfall events may also increase. While a great deal of uncertainty exists with respect to climate change impacts on water resources and stormwater management systems, as a means of providing greater resiliency and adaptation to climate change, GI and LID BMPs which act to decrease imperviousness, increase infiltration, and retain rainfall event volume on site are to be encouraged.

It must also be recognized that stormwater management facilities designed and constructed assuming that the statistical properties of past water and climate history remain unchanged over time may not perform as expected under future climatic conditions. This assumption, commonly referred to by scientific and engineering literature as “stationarity” is often interpreted to mean that the past is a good predictor of the future (World Bank, 2014). In a future climate, the assumption of stationarity is inherently flawed.

6.1 Definitions of Climate Change

> Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use (IPCC).

Climate Change

The climate of a region is defined by its typical or long-term average weather. For example, the climate of Ontario is defined by its cold winters, moderately hot summers, and wet springs and falls. More specifically, regional climate can be quantified by the long-term average temperatures (highs and lows), amounts of precipitation (rain and snow), wind speed, humidity, and other similar factors measured at stations located within or adjacent to the region and averaged over a long period of record. Earth's climate represents the average of all the world's regional climates.

Climate change is defined as any significant change in long-term weather patterns. It can apply to any major variation in temperature, wind patterns or precipitation that occurs over time. Weather patterns are highly variable and therefore climate can appear to be changing depending on the time scale selected for averaging.

Climate change, however, may refer to a consistent, observable trend in the long-term average values. For example:

1. an average increase of 0.05°C per year in the annual average temperature over the last 100 years would be an indicator of climate change.

Climate change could also be reflected in a long-term changes in the frequency or severity of extreme weather events. For example:

2. if a 100-millimetre rainfall event of a given duration had a 5% annual probability of occurrence based on data from 1915 to 1965 but had a 10% annual probability of

occurrence based on data from 1966 to 2015; this would also be considered an indicator of climate change.

The period of record for determining long-term trends and global climate change should be as long as possible; some researchers have used ice-core and tree-ring data to extend specific historic observations back hundreds or even thousands of years.

The following terms are relevant for the purpose of the guidance manual.

Climate Change Mitigation - The use of measures or actions to avoid or reduce greenhouse gas emissions, to avoid or reduce impacts on carbon sinks, or to protect, enhance, or create carbon sinks.

Climate Change Adaptation - The process of adjustment in the built and natural environments in response to actual or expected climate change and its impacts. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate change and its impacts.
In natural resources management, adaptation seeks to address the vulnerability of species or natural systems and processes by reducing threats, enhancing resilience, engaging people, and improving knowledge.

A **Climate Change Co-Benefit** results from technologies or approaches that achieve some level of both climate change mitigation and climate change adaptation.

Climate Change Resilience is the capacity of a system to maintain function despite stresses applied by climate change factors. Climate change resilience can be built into existing systems through adaptation, reconfiguration and learning from the resiliency of natural systems.

6.2 Global Climate Change

The Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) concluded that:

> "Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen." (IPCC, 2014).

The globally averaged combined land and ocean surface temperature data as calculated by a linear trend show a warming of 0.85 (0.65 to 1.06) °C over the period 1880 to 2012, for which multiple independently produced datasets exist (IPCC, 2014). Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. The period from 1983 to 2012 was likely the warmest 30-year period of the last 1400 years in the Northern Hemisphere, where such assessment is possible (medium confidence) (IPCC, 2014). This warming trend has had an impact on the hydrologic cycle. In many regions, changing precipitation or melting snow and ice are altering hydrological systems, affecting water resources in terms of quantity and quality (medium confidence) (IPCC, 2014). Averaged over the mid-latitude land areas of the Northern Hemisphere, precipitation has increased since 1901 (medium confidence before and high confidence after 1951) (IPCC, 2014). Moving forward, it is very likely that heat waves will occur more often and last longer, and that extreme precipitation events will become more intense and frequent in many regions (IPCC, 2014). Some observed changes to global climate relevant to water resources as identified in the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) are:

1. An overall increase in precipitation in mid-latitude areas of the northern hemisphere (high-confidence since 1951)
2. An increase in in the amount of water vapour in the air
3. A decreasing number of snowfall events where increased winter temperatures have been observed
4. A significant reduction of snow cover in the northern hemisphere, with most of the reduction occurring in the 1980s
5. A reduction of snow cover extent in the Northern Hemisphere (especially during June)
6. A decline of the northern hemisphere snow season by 5.3 days per decade since the 1972/1973 winter
7. An increase in the number, frequency and intensity of heavy precipitation events in several regions including central North America
8. An increase in the length and frequency of warm spells, including heat waves
9. Reductions in the annual duration of lake and river ice cover in the mid and high latitudes of the Northern Hemisphere.
10. Fewer numbers of frost days, cold days, cold nights and more frequent hot days and hot nights.
11. Regional changes to evapotranspiration
12. Altered river flow in regions where winter precipitation falls as snow; more winter precipitation falling as rain
13. An increase in annual runoff in high latitudes

6.3 Climate Change in Ontario

Climate change is a global issue that is predicted to have a wide variety of impacts across Canada. In Ontario, the effects of climate change are felt at local, regional and provincial scales.

The latest high-resolution regional climate projections are based on a large ensemble of both global and regional climate models (GCMs and RCMs) using combined downscaling techniques (Deng et al 2017) for all emission scenarios. These projections indicate that, under the business as usual emission scenario (RCP8.5 of AR5), by 2050s, total annual precipitation in Ontario could increase by about 9% (3% ~ 15%), while its average annual temperature could increase by 3.3°C (2.1°C ~ 5°C) above that in 1990s (York University, 2018). Changes in extreme warm temperatures are expected to be greater than changes in the annual mean temperature (Kharin and Zwiers, 2005). The number of days exceeding 30°C is projected to more than double by the 2050s in Southern Ontario (Hengeveld and Whitewood, 2005) and heat waves and drought may become more frequent and longer lasting. Observed changes in Ontario climate is summarized in Table 6.1.

Table 6.1 – Examples of Observed Changes in Ontario Climate

- Mean annual daily temperatures in Ontario have increased by 0.5°C to 1.5°C over a 61-year period (1950–2010) (Vincent et al., 2012).
- Total annual precipitation increased 5%-35% since 1900, (Zhang et al., 2000) and the number of days with precipitation (rain and snow) increased (Vincent and Mekis, 2006).
- Increased night-time temperatures in the summer has been linked to more intense convective activity and rainfall contributing to greater annual precipitation (Dessens, 1995).
- The frequency of intense daily rain events increased from 0.9% (1910 to 1970) to 7.2% (1970 to 1999) for very heavy events and from 1.5% to 14.1% for extreme events (Soil and Water Conservation Society, 2003).
- An increase in lake-effect snow has been recorded since 1915 (Burnett et al., 2003).
- The number of warm days and night-time winter temperatures increased between 1951 and 2003 (Bruce et al., 2006a).
- Water vapour in the Great Lakes Basin and Southern Ontario has increased more than 3% from 1973 to 1995, contributing to higher intensity rainfall events (Ross and Elliott, 2001).
- The number of strong cyclones increased significantly across the Great Lakes over the period 1900 to 1990 (Angel and Isard, 1998).
- The maximum intensity for 1-day, 60-minute and 30-minute duration rainfall events increased on average by 3%-5% per decade from 1970 to 1998 (Adamowski et al., 2003).
- Precipitation as snow in the spring and fall has decreased significantly in the Great Lakes-St. Lawrence basin between 1895 and 1995, although total annual

precipitation has increased, (Mekis and Hogg, 1999).

- Increasing rainfall across Canada over a 60-year period (1950 to 2009) with largest increases coming in spring (Mekis and Vincent, 2011)
- Significant winter snowfall increases (by 10%–30%) are located in the southern portion of the province near the Great Lakes snow-belt areas (Mekis and Vincent, 2011)

6.4 Climate Impacts in Ontario

While, Table 6.1 provides an overview of the observed changes in the broader Ontario Climate, the effects can be felt tangibly at more local levels. Latest projections indicate that, under the business as usual emission scenario (RCP8.5 of AR5), by 2050s, the average annual temperature in Ontario could increase by 3.3 (2.1 ~ 5) ° C above that in 1990s (York University, 2018). The Expert Panel on Climate Change Adaptation (2009) identified that:

> "*more moisture in a warmer atmosphere is expected to cause an increase in extreme weather events — rain, snow, drought, heat waves, wind and ice storms, [and] weather is also likely to be more variable and less predictable year-to-year*".

In the last decade, Ontarians have seen many intense precipitation events cause damage to their communities. An example of this is the July 2013 storm that dropped 125 mm of rain in just a few hours over parts of southern Ontario causing flooding and leading to damages estimated to be $1 Billion in the Greater Toronto Area alone (IBC, 2019). This was the most expensive natural disaster in Ontarian history.

Additional impacts of climate change that are expected to be felt in Ontario include:

- More variable and extreme local weather events such as heavy rains and prolonged droughts;
- Stressed and vulnerable ecosystems, wildlife and their habitats;
- Additional private and public costs associated with industries such as tourism and agriculture;
- Public health risks from an increase in hotter weather, more flooding, and insect-borne diseases; and
- Increased damage to public infrastructure. (Planning for Climate Change InfoSheet, MMAH)

Impacts that are directly related to stormwater management are discussed below.

Impacts on Public and Private Infrastructure

Existing stormwater infrastructure including storm sewers and stormwater management facilities have been designed with the assumptions that precipitation will remain unchanged in the future, specifically the historically observed patterns relating to annual distribution, intensity, duration and frequency. As discussed previously, this assumption, commonly referred to by scientific and engineering literature as "stationarity" is often interpreted to mean that the past is a good predictor of the future (World Bank, 2014). In a future climate, the assumption of stationarity is inherently flawed. As short-duration rainfall events caused by convective heating become more frequent and increasingly intense, storm sewers and combined sewers will be more prone to surcharging causing urban flooding and damage to property. Stormwater management facilities may be overwhelmed and over-top at a higher frequency. More extreme temperature fluctuations during the winter may also put infrastructure in some communities at risk of failure as a result of a more severe freeze-thaw cycle during the winter.

Impacts on Water Resources

Changes in seasonal temperatures and precipitation patterns in Ontario has the potential to upset the hydrologic processes that support the diverse ecosystems in Ontario's streams, rivers, wetlands and lakes. Climate change will affect both the abundance of water and water quality. Higher average temperatures will increase evaporation throughout the year and reduce the duration of ice cover on lakes province-wide. The resulting increased water temperatures may support excess algae growth and invasive species threatening both aquatic habitat and commercial fisheries. In stratified lakes, the average dates of spring and autumn turnover may also be affected be changing climate requiring aquatic species to adapt to a shifting temperature regime.

Watershed Scale Impacts

Because stormwater management must be considered in a watershed context to promote natural hydrologic process and maintain clean usable waterways, climate change impacts on hydrological and ecological cycles at the watershed scale must be considered. Urban trees, which provide runoff volume reduction through interception and contribute to reduced runoff temperature, are susceptible to climate change. Changes in moisture and temperature will have an impact on the urban trees and on the composition of Ontario's forests.

The richness and composition of species across all habitats in Ontario is threatened by climate change. Changes to the availability of water, the abundance of food, competition for resources, disease, symbiotic and predatory relationships are expected because of climate change. In some cases, species will respond by expanding or moving their ranges resulting in significant changes to the composition of species in areas of Ontario. For many species, however; migration is not possible, and populations will be significantly reduced. Lake trout for example rely on deep, cold lakes for habitat. With increased temperatures and decreased dissolved oxygen content, these fish will lose habitat to warm water species that are better adapted to these conditions.

6.5 Roles in Addressing Climate Change

While policies on climate change mitigation and climate change adaptation are being developed at the Federal, Provincial, and Municipal levels it should be noted that the implementation of these policies, especially with respect to water resource management, will likely be borne by local municipalities, agencies and individual practitioners.

Municipal governments own more infrastructure than any other government in Ontario; control land use and transportation; implement building standards and facilitate community organizations. Conservation authorities have a long history of working in partnership with municipalities, provincial ministries, and many other stakeholders to manage Ontario's water resources. This includes roles in watershed management, protecting the public from flood hazards and mitigating the impacts of drought. Municipalities and conservation authorities need to be aware of and respond to potential climate change impacts to reduce economic costs and potential environmental, social and health risks. Actions that can mitigate the impacts of climate change range widely but include:

1) **Actions that reduce greenhouse gas emissions**
    - Example policies and activities that can reduce greenhouse gas emissions include programs for tree planting, green building and energy efficiency incentives, water conservation and carpooling.

2) **Actions that prepare for changes that are occurring, or are likely to occur, in the near future**
    - Examples of policies that can help prepare for increased frequency and intensity of storms can include prohibiting buildings and structures within areas that are prone to flooding, development of stormwater management plans that address intense precipitation events under a future climate and design of infrastructure (e.g., culverts and stream crossings) for higher flows.

The Ontario Ministry of Municipal Affairs and Housing notes that Site Plan Controls (Subsection 41(4) of the *Planning Act*) can be used to help address climate change mitigation and adaptation at the site-development level by requiring GI and LID BMPs such as natural and artificial permeable surfaces that promote infiltration and reduce stormwater runoff (e.g., grassy swales and rain gardens to promote infiltration; roadside curb cuts to direct runoff to grassy swales and rain gardens; permeable pavement and green roofs to reduce runoff; rock pits, catch basins, and detention ponds to reduce peak storm flows). LID BMPs have an important role in in mitigating effects of climate change.

There are many non-technical publications available on climate change and climate change adaptation in Ontario. These include (See the Resource Directory):

- Region of Peel Climate Change Master Plan (2020);
- Climate Change Adaptation Strategy for the Lake Simcoe Region Conservation Authority (2020).

Because of the increased responsibility and potential liabilities, the municipalities and conservation authorities are likely to require additional analyses and assurances from the proponents of developments that their stormwater management systems have been designed with consideration of future climate conditions, that the facilities will function as intended under future conditions, that sensitive ecological features will continue to function, and that the facilities and adaptation measures contribute to the overall climate change resilience of the surrounding area.

6.5.1 Actions to Reduce Climate Change Liability

Regardless of the size, budget, or resources available, stormwater practitioners in Ontario must "turn their minds" to future climate scenarios for stormwater related standards, processes and infrastructure, especially when information suggests that there may be increased risk to persons or property. Steps that stormwater practitioners can take to help minimize the legal risk associated with the impact of climate change on stormwater management infrastructure are (Zizzo and Allan, 2014):

1) Have a process for collecting new information and ensuring it is passed on to the appropriate parties within the organization (and to relevant professional service providers). Information may include but is not limited to updated maintenance procedures, new technologies, results from modelling, and reported incidences of flooding.

2) When working with consultants and other professional service providers, make sure they are provided with, and are considering the best available information.

3) Do not ignore information that suggests there may be a risk to people or property, since doing so is unlikely to be considered a valid policy decision and likely does not meet the standard of care.

4) Ensure active, valid decisions are being made and documented with respect to stormwater management systems and processes. Stormwater decisions should be documented, even if a decision is that changes are too costly given the risk and current resources. Make sure stormwater decisions specifically consider the issue at hand and that the organization has made a conscious decision to act or not to act based on appropriate social, political and economic factors.

5) Set a clear standard of care by coordinating with similarly situated organizations. Ensure information is shared and similar standard of practice is being applied within these organizations.

6) Work with other stormwater management actors (neighbour municipalities, conservation authorities and the Province) to develop best practices and industry standards.

7) Enforce policy decision such as bylaws that have been made to mitigate the effects of extreme climate events.

Municipalities
Further to the above general guidance, specific roles of municipalities in protecting against injury caused by climate impacts such as flooding and other extreme weather events include:

1) Applying a consistent and standardized management policy with respect to wastewater, combined sewer and stormwater management;

2) Considering how planning decisions impact water management systems, even at smaller scales; and

3) Effectively considering infrastructure improvement and upgrades and having a clear prioritization to these works.

Conservation Authorities
Conservation authorities work with municipal and provincial partners to ensure that stormwater management is implemented responsibly from a watershed and feature based perspective, they play an integral role in coordinating regulatory requirements (natural hazard management) and a technical support role in water management and climate change adaptation. Conservation authorities also provide essential warning of imminent or actual flood conditions as a key service. Specific roles of conservation authorities in protecting against injury caused by climate impacts such as flooding and other extreme weather events include:

- Maintain floodplain mapping;
- Implement projects that mitigate erosion risk;

- Enforce development regulations in light of climate change risks; and
- Where applicable, control the flow of surface waters to prevent flooding and to reduce the adverse effects thereof.

While roles and responsibilities differ slightly, it is pointed out that climate change and flooding "should not be seen as the sole responsibility of any particular person or entity. All orders of government, community members and professional service providers, among others, should take appropriate adaptation actions where they can, and may have legal obligations to do so in certain cases" (Zizzo and Allan, 2014).

6.6 Assessing Climate Change Impacts on Development Planning and Design

As stormwater practitioners shift towards a planning and design strategy that takes into consideration the potential impacts of a changing climate it is essential to focus on GI and LID that both increases the resiliency of urban infrastructure to extreme weather and through the application of selected practices may also absorb carbon dioxide (a key greenhouse gas contributing to climate change).

6.6.1 Need for Analysis

Keys to Assessing Climate Change

- Where municipalities have outlined a science-based approach to Climate Change Planning and Design, it should be applied to stormwater management if applicable.
- Seeking the best available science for decision-making while recognizing that there is uncertainty in climate change projections and the associated impacts;
- Incorporating climate change adaptation into existing policies and programs wherever possible;
- Being flexible when developing action plans to accommodate ongoing improvement in our understanding of climate impacts and potential risks;
- Prioritizing actions that have co-benefits between mitigation and adaptation; and
- Contributing to sustainable development by taking into account the effect of decisions on current and future generations.

Consideration of climate change impacts on a development project is part of an environmental assessment (EA) to ensure that the project will not pose a risk to the public or the environment. Two aspects need to be considered:

1. The impact of the project on the environment, for example, through increased greenhouse gas emissions or impacts on valued environmental components; and
2. The impact of the environment on the project, for example, possible changes to a project to accommodate the environment under future climate conditions.

The first aspect, touched on briefly earlier, is beyond the scope of this chapter but is a valid pursuit beyond stormwater management.

The second, when applied to land development projects, recognizes that stormwater management facilities constructed today will be expected to perform under climatic conditions that may be significantly different than the recent past. Accordingly, this chapter focusses on methods for assessing whether adaptation measures for stormwater management will perform as needed under future climate and whether these measures will provide more resilience to future climate change.

Section 6.8 outlines a **Four (4) Step Climate Change Adaptation Process** for use in Stormwater Management projects in Ontario. It includes options for technical analyses (hydrologic and hydraulic modelling).

Climate Change tools, guides, protocols and processes which are available to Ontario stormwater practitioners to conduct assessments of future climate change, account for uncertainties in the predictions, and develop adaptive strategies that would be resilient to a wide range of climate change outcomes are outlined in Section 6.7 and Section 6.8.

6.6.2 Assessing Climate Change at the Watershed Scale

A primary goal in urban stormwater design is to maintain the existing hydrologic conditions while mitigating property damage/loss of life under extreme conditions. A clear understanding of the hydrologic setting of the development within the context of the surrounding watershed is needed for good urban stormwater design. This includes understanding how water moves through the watershed, the overall water budget of the study area under current conditions, where and how water is stored in the system, the location of ecologically-sensitive natural areas and how they are affected by changes in runoff and recharge, as well as how the watershed responds to extreme events (both flood and drought). Understanding how the system behaves under natural (or current /pre-development) conditions) is critical to being able to predict how the system might be altered through development, as well as where and how adaptation measures can be effectively applied to minimize these changes.

When considering climate change, it is important to assess impacts within a watershed context and determine how the system will respond to future climate. Climate change will likely continue to affect the frequency, timing, and intensity of extreme precipitation events, yielding larger volumes of runoff and streamflow and increased potential for flooding and erosion. Climate change will also likely shift the overall behaviour of the watershed including snow accumulation, timing of the spring freshet, streamflow patterns, evapotranspiration rates, groundwater recharge, wetland hydroperiod, and drought frequency and intensity. These, in turn, can affect geomorphic processes, vegetation patterns and wetland/stream ecology.

Hydrologic models (discussed further in detail in Chapter 5) can be developed and applied to evaluate the effects of climate change on the groundwater and surface water system at a watershed or subwatershed scale. Issues that could be addressed include the degree to which less frequent but more intense rainfall events increase runoff and decrease groundwater recharge in the watersheds. Other factors, such as increased ET (due to higher temperature and increased solar radiation) or the increased drought frequency and severity could also be evaluated in terms of the net change to streamflow and groundwater recharge. Decreased streamflow and groundwater recharge may, in turn, lead to a decrease in the water available to support aquatic habitat in wetlands and streams. Increased runoff could lead to an acceleration of stream bank erosion and increase in sediment transport. The effectiveness of adaptation measures, such as LID, can be evaluated using these same tools.

6.6.3 Assessing Climate Change Impacts at the Site Servicing Scale

As has been discussed throughout this section, the most probable impact of climate change on Ontario's stormwater management systems is an increase in intensity and frequency of significant precipitation events. Many municipalities have started assessing how existing stormwater infrastructure will respond to predicted climate change impacts by running computer simulations that take into consideration updated peak rainfall estimates (from revised IDF curves) or percentage-based increases to rainfall depth. Existing hydrologic and hydraulic models can be used to determine high risk areas within the stormwater, sanitary sewer and combined sewer systems. Areas that are prone to failure as a result of climate change impacts are typically the same as those at risk of failure from extreme weather events and uncontrolled impervious area increases.

On a smaller scale, individual sites can be assessed for climate change risk by the analyzing stormwater systems (municipal or private) for components that are at risk of failure or malfunction because of predicted changes to precipitation patterns.

In many cases, a malfunction may be as simple as an increase in the frequency of major stormwater management system responses beyond the predicted or design frequency. Mechanisms of failure or malfunction may include pipe surcharging, nuisance flooding due to standing water, frequent overtopping of storage facilities and/or activation of major system overland flow routes and system bypasses at a higher frequency or at greater depth than expected. These events typically occur at site-specific thresholds such as flow rates or water levels. On sites with an existing stormwater management plan, a useful exercise may be working from these thresholds and determining how much resiliency was built into existing systems at the time of design. For example, pipes may have some additional capacity beyond the design return period based on the size of the installed pipe.

In other cases, a malfunction may result in exceeding or not-fully achieving minimum environmental protection objectives, targets or criteria such as exceeding acute and or chronic in-stream temperatures in cold water fisheries, impacts to the hydroperiod of sensitive wetland features or erosion to watercourse and shorelines. At the site-level, potential interactions with private servicing such as wells and septic systems should be assessed from a climate change perspective to ensure health related risks are mitigated.

6.7 Climate Change Adaptation Protocols and Tools

There are a number of tools available to identify the means of increasing the resilience of stormwater management services to current climate variability or future climate impacts. These tools take the form of documents, computer programs, or websites that operationalize a set of principles or practices. These tools can be classified by function into three major types:

1. Protocols and process guidance tools;
2. Data and information tools; and
3. Knowledge sharing tools.

Two notable examples of available tools which apply a science-based, documented, repeatable process to incorporate climate change considerations into stormwater management planning are:

1. **PIEVC** - Engineers Canada created the Public Infrastructure Engineering Vulnerability Committee (PIEVC) protocol (see the Resource Directory) to assess the vulnerabilities of infrastructure to extreme weather events and future changes in climate. The protocol is a risk screening tool specifically designed to address future climate uncertainty that can:
   - Evaluate infrastructure risks to public and private services that can have negative economic, environmental or societal impacts;
   - Support decision-making for capital investments in the acquisition of infrastructure;
   - Help establish life-cycle operations, maintenance and reinvestment plans (asset management);
   - Inform policy-makers and supports sustainable and resilient objectives at the project, system, region or country level.

2. **BARC** - The International Council for Local Environmental Initiatives (ICLEI) Building Adaptive and Resilient Communities (BARC) tool has been designed to assist local governments with climate change adaptation planning. Methodology provides a structured approach to adaptation planning which moves participating local governments through a series of progressive steps. While each milestone builds off the

findings of the one before, the methodology as a whole creates an opportunity to re-evaluate and review findings and decisions. See the Resource Directory.

There are also many other guides (see the Resource Directory) available which take various approaches to adaptation planning. For instance, there are guides specific to:

- Risk and infrastructure (i.e., A Risk-Based Guide for Local Governments in British Columbia);
- Climate change and health (i.e., Human Health in a Changing Climate);
- Profession specific (i.e., Canadian Institute of Planners);
- Climate Change Risk Assessment Guide (2014);
- ISO 31000 Risk Management;
- Considering climate change in the environmental assessment process (MECP);
- City of Toronto Climate Change Risk Assessment Tool.

The above tools and guides allow practitioners, water resource managers and municipalities to assess proposed stormwater management plans and/or facility designs, to improve resiliency in stormwater management infrastructure, and improve emergency preparedness. Considering the wide range and variety of tools and guides available, choosing the most appropriate approach requires identification of the user's specific adaptation needs and concerns at the onset. Evaluating inappropriate climate change indicators may lead to inappropriate adaptation actions, which could potentially increase system's vulnerability to climate change or unnecessarily increase cost. It is important to note that the tools are not limited to stormwater management and can also be used for other water infrastructure such as drinking water and wastewater treatment plants, etc.

Municipalities are encouraged to develop guidelines and best practices to apply land use planning policies and tools for achieving climate adaptation objectives. For example, policy instruments such as municipal official plans can help establish direction, objectives and overall goals for climate change; and regulatory instruments such as zoning requirements, development permits and defined hazard zones strengthen and define the land-use direction for climate change response. These instruments can be promoted by the use of financial incentives such as charges or fees and grants to enhance the implementation of policies and regulations. (Adapted from Research and Information Gathering on Climate Change Mitigation and Adaptation. McVey, I., et al. 2016)

6.8 Four (4) Step Climate Change Adaptation Processes for Stormwater Management

If a more detailed assessment hasn't already been prepared, the following describes a four (4) step qualitative vulnerability assessment process that stormwater practitioners are encouraged to use to incorporate climate change adaptation strategies into stormwater management projects.

Qualitative approaches begin by first identifying system vulnerabilities to a wide range of future climates and then determining the plausibility of the specific climate impacts using the best available and credible climate information.

A traditional 'top-down approach' is when a limited selection of individual Global Climate Model (GCM) projections are used to attempt to quantify and predict potential climate impacts. Qualitative or "Bottom-Up" approaches reverse this assessment process by first identifying system vulnerabilities to a wide range of future climates (beyond those predicted by GCMs) and then determining the plausibility of the specific climate impacts using the best available and credible climate information. (World Bank, 2014).

Through the application of this qualitative vulnerability assessment process, practitioners can establish bounding estimates for consideration during stormwater planning and design or, if a defensible design estimate cannot be established, how at the early stages of infrastructure planning, approaches can be taken to design infrastructure that is resilient to a wide range of possible future climates. The four (4) step process can be applied to all stormwater projects including:

- Development of stormwater management plans for site, subdivision, or condominium development;
- Design of stormwater management infrastructure;
- Development of stormwater management master plans; and
- Subwatershed and Watershed Plans.

The four (4) step process includes:

1. Identifying Climate Change Considerations
2. Evaluating Risk caused by Climate Change Parameters
3. Climate Change Impact Management Planning
4. Monitoring and Adaptive Management

The steps for considering climate change parameters and, when necessary, applying adaptation strategies into stormwater design are described in this section. Building climate change resiliency into a project is not a reactive process and should be undertaken during early project phase. Waiting until planning and design has been completed before considering climate change may result in inefficiencies, unnecessary design alterations, and exposure to unnecessary technical or legal risks.

6.8.1 STEP 1 - Identifying Climate Change Considerations

Potential climate change impacts will differ depending on location, type of project and other site-specific factors. During the first step of this process, it is suggested that the stormwater practitioner complete the following:

Step 1a) Clearly establish the overall project context, specifically the project goals, objectives, criteria and targets as well as scope, scale and limitations. The context should be clearly articulated before starting the assessment and documented when completed. Objectives should at a minimum include protection of:

i. Human life and health;
ii. Public and private property;
iii. Public and private infrastructure;
iv. Drinking water quality and quantity;
v. Environmental feature and function; and
vi. Terrestrial and aquatic habitats.

Step 1b) Define and document:

vii. The environment features and function at the landscape and local scale using a combination of field activities and / or existing studies.
viii. The state and functionality of existing stormwater management control mechanisms or practices. Existing controls may be an asset or aid in mitigating future impacts.

Step 1c) Evaluate each climate change parameter observed or predicted for Ontario (See Sections 6.3 and 6.4) to determine if it is anticipated to cause impacts for any specific project component. The key climate change parameters that have the potential to cause impacts and which should be considered to determine if they are relevant to the specific stormwater management or water resources projects are listed below. Additional parameters may be relevant on a project-specific basis. These parameters should be, at a minimum, considered during the planning and design process for all projects to mitigate negative climate change impacts on the project level, within communities and/ or at the landscape scale.

Key observed and predicted climate change parameters include (see Table 6.1):

- Increased mean atmospheric temperature
- Increased annual precipitation
- Decreased annual snowfall and increases in lake effect snow
- Increased winter rain events (i.e. rain on snow events)
- Changes in rainfall intensity
- Increased frequency and severity of precipitation extremes
- Changes in lake levels and stream flows

- Changes in soil moisture and groundwater recharge
- Increased potential evaporation rate
- Increased receiver water temperatures
- Other - additional project-specific climate change parameters specific to the project

Step 1d) - Once the potential impact of climate change parameters on a project have been identified, the risks associated with failing to meet project goals, objectives and targets must be evaluated. Not all components of a project will be sensitive to climate change and not all potential impacts will mandate adaptation strategies.

To assess significant risks while avoiding excessive analysis, climate change parameters should be evaluated using the following six (6) ***Climate Change Sensitivity Screening Questions:***

1. Is there a potential for a climate change parameter to result in increased risk, hazard or safety issues in regard to human life and health within or around the project site?
2. Is there a potential for a climate change parameter to result in increased risk, damage or impact to public and property within the project site or on adjacent lands?
3. Is there a potential for a climate change parameter to result in the reduction of the level of service for stormwater management to an unacceptable level?
4. Is there potential for a climate change parameter to cause impacts to drinking water quality and quantity on the project site or resulting from the project site?
5. Is there a potential for a climate change parameter to cause a failure to meet design project goals, objectives and targets?
6. Is there potential for a climate change parameter to cause degradation or impacts to environmental features and functions and/ or terrestrial and aquatic habitats within the project site or resulting from the project site?

The practitioner can answer and document the climate change parameter screening process by utilizing the template below and modify as required (Table 6.2).

Table 6.2 - Climate Change Parameter Screening Template

Climate Change Parameters for Stormwater Management	**Apply the six climate change screening questions. (yes/ no)**	**List Anticipated Impact(s)**
Increased Mean Atmospheric Temperature	1. (yes/ no) 2. (yes/ no) 3. (yes/ no) 4. ..... 5. ..... 6.	1. ..... 2. ..... 3. ..... 4. ..... 5. ..... 6. .....
Increased Annual Precipitation		
Decreased Annual Snowfall and Increases in Lake Effect Snow		
Increased Winter Rain Events (i.e. Rain on Snow Events)		
Changes in Rainfall Intensity		
Increased Frequency and Severity of Precipitation Extremes		
Changes in Lake Levels and Stream Flows		
Changes in Soil Moisture and Groundwater Recharge		
Increased Potential Evaporation Rate		
Increased Receiver Water Temperatures		
Other		

If "Yes" to any of the six climate change screening questions for a parameter, proceed to STEP 2

6.8.1.1 STEP 1d) EXAMPLE

Two projects scales are discussed below as examples in Tables 6.3 and 6.4. One example is a stormwater management plan for the development of a site; the second is the development of city-wide stormwater master plan.

Table 6.3 - Predicted Climate Parameters and Possible Impacts on Stormwater Projects

Climate Change Parameters for Stormwater Management	Response to Screening Questions	Example 1: Development of Stormwater Management Plan for a Site List Anticipated Impact(s)
Increased Mean Atmospheric Temperature	No	
Increased Annual Precipitation	Yes	Impact on annual runoff volume and pollutant loading
Decreased Annual Snowfall and Increases in Lake Effect Snow	Yes	Impact on winter and spring operation
Increased Winter Rain Events (i.e. Rain on Snow Events)	Yes	Increased probability of surface ponding and flooding. Impacts to on-site safety for pedestrians and vehicles
Changes in Rainfall Intensity	Yes	Increased risk of failure or malfunction of minor stormwater management system responses beyond the predicted or design frequency.
Increased Frequency and Severity of Precipitation Extremes	Yes	Impact on runoff rates and associated conveyance and storage sizing
Changes in Lake Levels and Stream Flows	Yes	Impact if site adjacent to lake or stream (outlet conditions and receiver requirements)
Changes in Soil Moisture and Groundwater Recharge	No	
Increased Potential Evaporation Rate	No	
Increased Receiver Water Temperatures	No	
Other	n/a	n/a

Table 6.4 - Predicted Climate Parameters and Possible Impacts on Stormwater Projects

Climate Change Parameters for Stormwater Management	Response to Screening Questions	Example 2: Development of City-Wide Stormwater Master Plan List Anticipated Impacts
Increased Mean Atmospheric Temperature	Yes	Potential impact on in-ground stormwater infrastructure (freeze-thaw cycle impacts)
Increased Annual Precipitation	Yes	Impact on local water balance
Decreased Annual Snowfall and Increases in Lake Effect Snow	Yes	Impact on freshet response
Increased Winter Rain Events (i.e. Rain on Snow Events)	Yes	Increased probability of surface ponding on roadways, urban and riverine flooding. Impacts to emergency services during event.
Changes in Rainfall Intensity	Yes	Increased risk of failure or malfunction of minor and major stormwater management system responses beyond the predicted or design frequency. Increased probability of surface ponding on roadways, urban and riverine flooding.
Increased Frequency and Severity of Precipitation Extremes	Yes	Impact on urban flooding and erosion processes
Changes in Lake Levels and Stream Flows	Yes	Impact on aquatic habitat, surface water consumption and assimilative capacity
Changes in Soil Moisture and Groundwater Recharge	Yes	Impact on groundwater consumption and baseflow
Increased Potential Evaporation Rate	Yes	Impact on local water balance
Increased Receiver Water Temperatures	Yes	Impacts to environmental features and functions and/ or terrestrial and aquatic habitats
Other	n/a	n/a

6.8.2 STEP 2 - Evaluating Risk caused by Climate Change Parameters

Once the sensitivity to climate change parameters to which the project is vulnerable have been identified (Step 1), questions as to the likelihood of those parameters arising can be addressed in a more efficient and targeted manner.

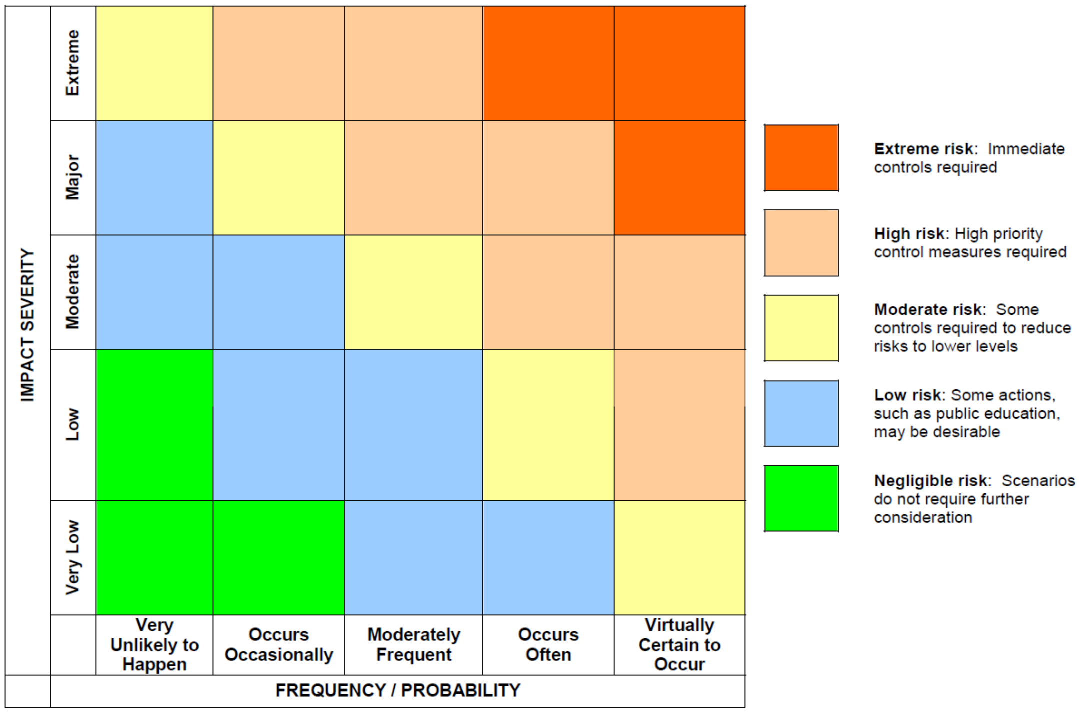
Climate change is a field that is characterized by uncertainty. There is uncertainty associated with climate projections and the impacts of these projections, especially on a local scale. Uncertainty is a common issue facing engineers and risk management offers a reliable approach for prioritizing complex risk issues and for selecting preferred risk reduction strategies. To use a risk assessment framework in a climate change context, the following climate change risks must be established:

a) Probability (certain to very unlikely to occur); and
b) Impact severity (severe to negligible impacts).

The **Climate Change Risk Evaluation Matrix** (Figure 6.1) from Climate Change Risk Evaluation Matrix (Bruce et al., 2006b) adapted from *Adapting to Climate Change: A Risk-based Guide for Ontario Municipalities* (Bruce et al., 2006b), demonstrates how risk can be evaluated. Impact severity is shown increasing along the y-axis, while probability or frequency is shown along the x-axis.

Using this approach, addressing risks can be prioritized with extreme risks requiring immediate adaptation strategies and negligible risks requiring no action. This can be used to assess any climate change impact on a stormwater management project.

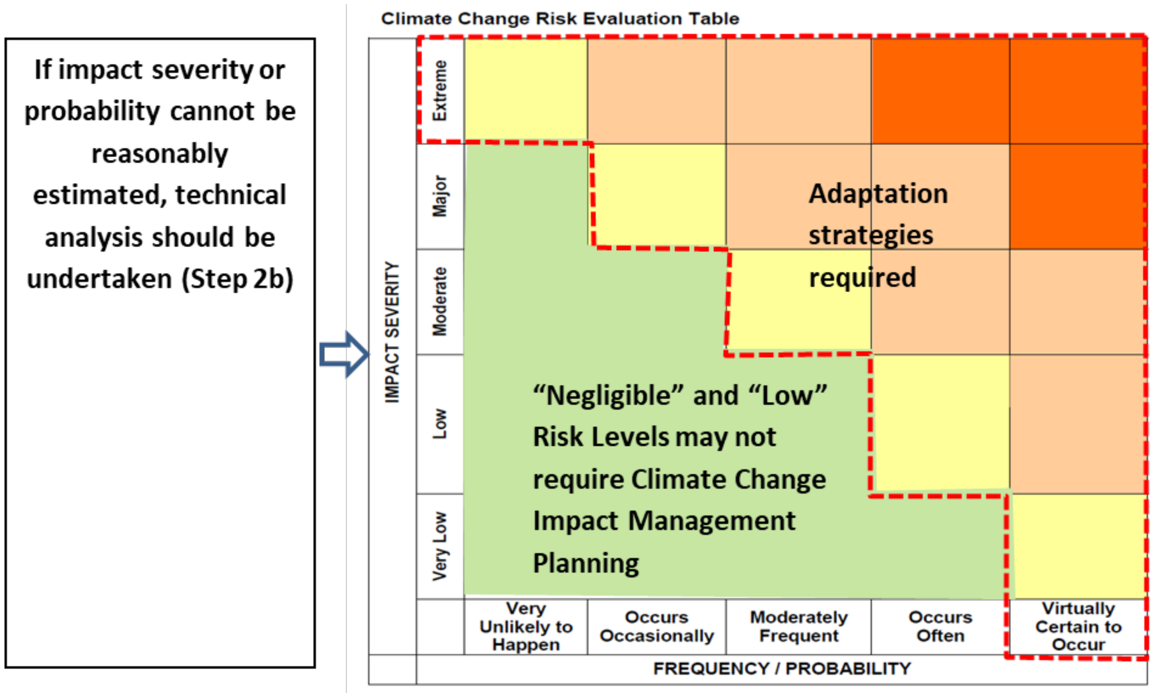
Figure 6.1 - Climate Change Risk Evaluation Matrix



(Source : Bruce et al., 2006b)

Step 2a) – For each parameter and impact identified in Step 1d), assess the probability and impact severity to determine if the threshold level of risk is exceeded. For parameter and impact identified in Step 1d) that meet a threshold level of probability and impact severity, adaptation strategies must be evaluated to avoid an unacceptable level of risk (Figure 6.2).

Figure 6.2 - Application of the Risk Evaluation Matrix



(Source: Bruce et al., 2006b)

Step 2b) - At this step, if the impact severity or probability cannot be reasonably estimated, **technical analysis** should be undertaken (see Section 6.9.2.1). Technical analysis for stormwater management and water resources projects would typically include hydrologic and/ or hydraulic analyses, including associated potential impacts to the form and function of terrestrial and aquatic ecosystems.

For watershed, subwatershed, or city-wide studies, climate change impacts may be wide-ranging and require multi-disciplinary analysis. For smaller site-level projects, it may not be immediately clear if climate change is expected to cause problems for the stormwater management systems. At a minimum, all projects requiring technical analysis should assess the impacts of expected increased frequency and severity of precipitation extremes by including a modelling scenario that reflects predicted climate change.

6.8.2.1 Technical Assessments

It should be noted that technical analysis can not only provide more accuracy with respect to impact severity it can also provide a quantitative indicator of probability. In many cases, a probability can be assigned to the climate change risk via the technical analysis. For example, hydrologic and hydraulic modelling may indicate that inflow volumes calculated using predicted IDF Curves under climate change encroaches within the freeboard that was designed using the existing IDF curve but does not exceed the designed storage volume of a facility during the 1:100-year rainfall event. In this case, the technical analysis can show that the probability of occurrence of failure in light of climate change is very low, the expected level of service will be maintained, and that the risk associated with not increasing the storage volume may be deemed acceptable.

Technical assessment of climate change risks should use the most up-to-date information related to climate projections to the local environment. Technical assessments to address climate change concerns may include but are not limited to:

- Updated water balance analysis for a future climate;
- Updated IDF curves for a future climate;
- Site planting / vegetation sensitivity analysis for a future climate;
- Updated floodplain mapping for a future climate; and
- Others

The following provides guidance in regard to various options to be used in the technical analyses:

Hydrologic Modelling for a Future Climate

When conducting hydrologic analyses, as it relates to climate change, the overall objective is to conduct assessments of future climate change scenarios, account for uncertainties in the predictions, and develop adaptive strategies that would be resilient to a wide range of climate change outcomes.

To ensure that a duty and standard of care have been provided and to help minimize the legal risk associated with the impact of climate change on stormwater management infrastructure, the practitioner should select and apply one or more of the following approaches to account for the range of possible climate change outcomes:

1. Data sets downscaled from a wide selection of Global and Regional Climate Models (GCMs and RCMs) results have been assembled by several Ontario agencies and made available to the public and can be used in hydrologic modelling activities (see Appendix 6). This includes:

    a) Ministry of Northern Development, Mines, Natural Resources and Forestry has established a website where future climate data sets can be downloaded for use in hydrologic models – See the Resource Directory.

    b) Dynamically downscaled climate projections are available for the Province from the Ontario Climate Data Portal - See the Resource Directory.

2. Where intensity-duration-frequency (IDF) curves (see Section 6.9) for the 1:2, 1:5, 1:10, 1:25, 1:50, 1:100-year return period storm events are applied, the practitioner should select and apply one or more of the following approaches to account for the range of possible climate change outcomes:

   a) Apply the results of Localized Climate Projections for the local municipality or Region (as available) developed from statistical downscaling of global model from a full ensemble of the latest generation of climate models (Coupled Model Intercomparing Project version 5 - CMIP5) or most recent.

   b) Apply one or more of the Predicted IDF Curves under Climate Change:
      i) For a local meteorological station from the IDF CC Tool for deriving rainfall Intensity-Duration-Frequency Curves for future climate scenarios (University Western Ontario and the Canadian Water Institute) - See the Resource Directory.

      ii) Intensity Duration Frequency (IDF) curves have been developed for future climate conditions and are available for the Province from the Ontario Climate Data Portal - See the Resource Directory.

      iii) Ontario Ministry of Transportations' IDF Curve Lookup - See the Resource Directory.

   c) An adjustment to the design flows (i.e. percentage adjustment for IDF curves) as dictated by local agencies and/ or municipal standards. It is noted that is not a preferred approach to selected percentage adjustment for IDF curves which have not been selected following the methods outlined previously. This is discussed further in Section 6.9.1).

Hydraulics Analysis for a Future Climate

When conducting hydraulic modelling for stormwater infrastructure, culvert, watercourse crossing, bridge design, or major system conveyance capacity, the practitioner should select and apply one or more of the approaches outlined as 2a), 2b) or 2c) above.

Appendix 6 presents additional information on the above approaches to representing future climate within the framework of the types of models discussed in Chapter 5. The models can predict the impact of climate change on a wide-variety of environmental parameters including local water balance; runoff volumes and streamflow groundwater recharge; seasonal or long-term water quantity; and water quality trends. As well, a full case-study example detailing the Climate Change Sensitivity of the Lake Simcoe Basin is provided in Appendix 6.

6.8.2.2 STEP 2 Example No. 1: The impact of increased air temperature on an urban watercourse

Stormwater management ponds are not designed to mitigate thermal pollution and the lack of shading features at many of these facilities contributes to thermal pollution in riverine systems. As has been discussed earlier in this chapter, average temperatures in Ontario have been increasing over the last 60 years and climate change models agree that temperatures are likely to continue to increase through 2050. Increased air temperatures will cause earlier spring melts and a prolonged seasonal period of warm water in stormwater management facilities especially during the long and dry summer months.

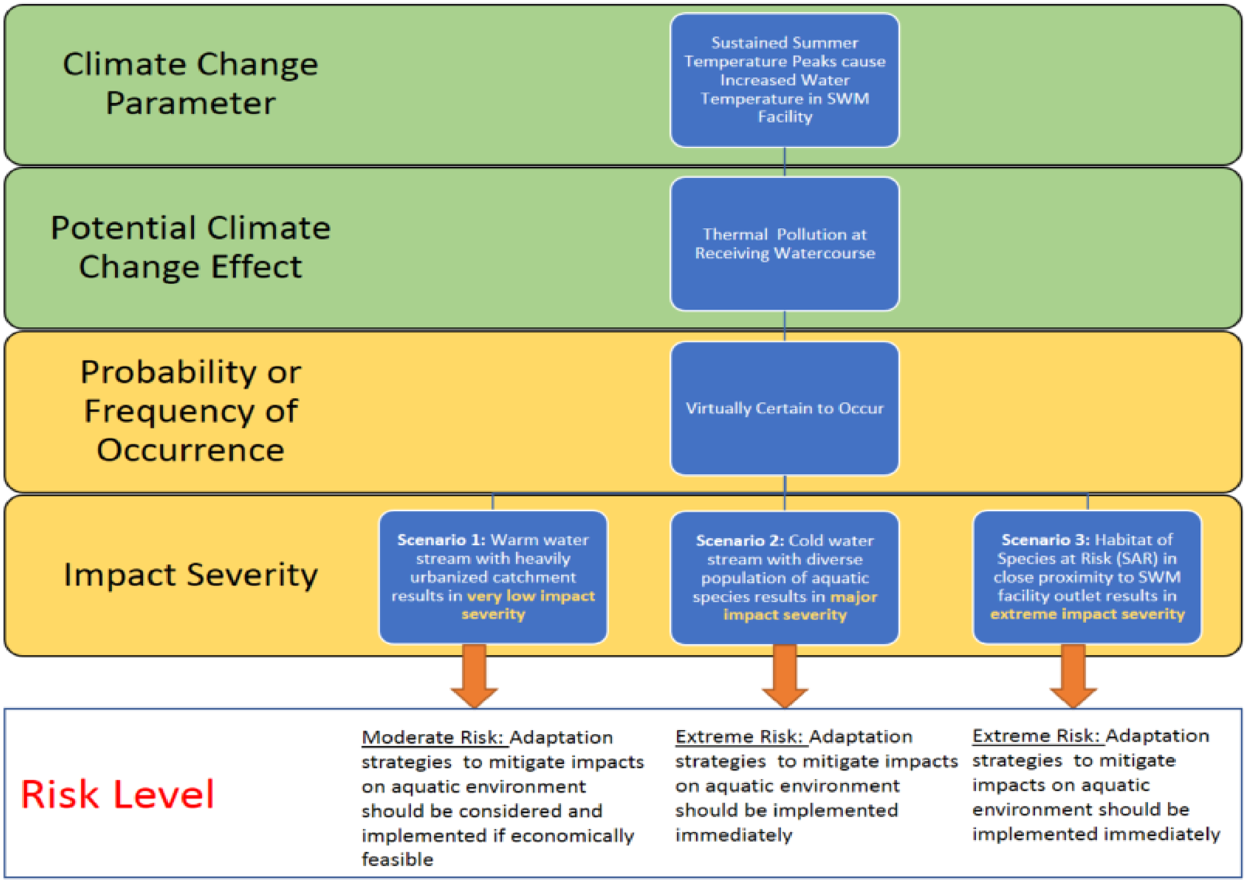
Figure 6.3 illustrates a risk assessment process for evaluating temperature increases in a stormwater management facility. This example focuses on thermal pollution at the receiving stream, but site-specific examples may focus on other temperature-related concerns such as algae growth or the impact on mosquito breeding. Based on historical climate trends and model projections, increased air temperatures are likely to occur and the correlation between air temperature and water temperature in the stormwater management facility is strong. For this example, three (3) scenarios are used to demonstrate how site-specific factors can influence impact severity of the climate change risk.

- In Scenario 1, the stormwater pond discharges into a stream that is characterized by warm water and a heavily urbanized catchment. The warmer water will have little impact on existing environmental conditions, so the impact severity has been classified as low, resulting in a moderate overall risk level.

- In Scenario 2, the stormwater pond discharges into a stream that is characterized by a coldwater regime and has a diverse range of aquatic life. The warm stormwater effluent has the potential to harm cold water fish habitat reducing fish diversity downstream of the stormwater management pond and thus an impact severity rating of major has been classified for the climate change risk.

- In Scenario 3, the stormwater management pond discharges to a stream reach that is in close proximity to habitat of a Species at Risk (SAR), for example a Redside dace. The resulting impact severity for this scenario has been classified as extreme.

Figure 6.3 - Example 1: Stormwater Management Facility Temperature Increase Impacts on an Urban Watercourse



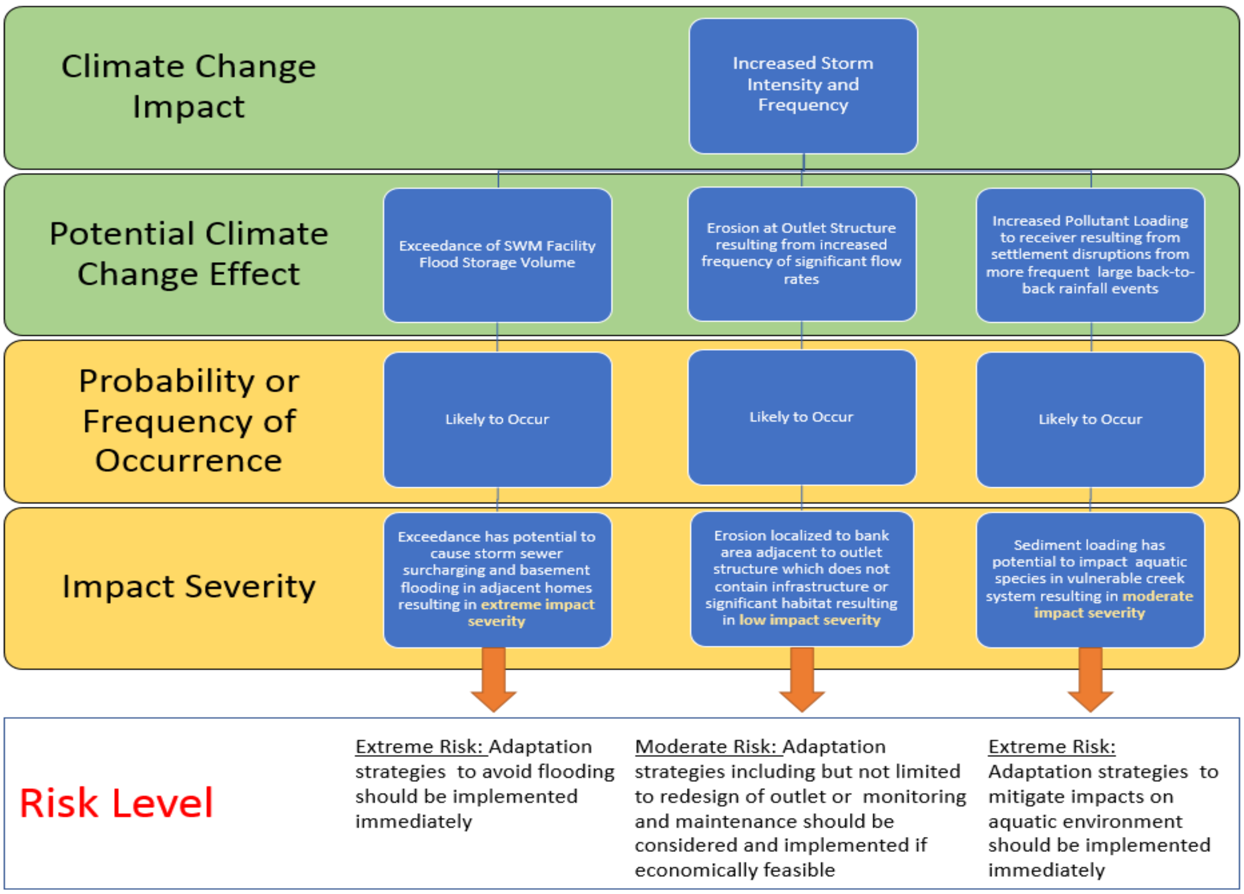
Although the ponds in Scenarios 1, 2 and 3 were identical and the same potential climate change effect and associated probability were assumed, the associated risk levels were weighed by site-specific conditions of the receiving watercourse. Using the matrix shown in Figure 6.1, the resulting climate change risk of Scenario 1 is moderate, where as Scenario 2 and 3 are extreme. Adaptation strategies to mitigate thermal pollution on the environment should be considered for Scenario 1, but climate change risks that are considered high or extreme (Scenario 2 and 3) should be given priority.

6.8.2.3 STEP 2 Example No. 2: The impact of storm intensity and frequency on an urban stormwater management facility

A change in the intensity and/or frequency of rainfall events can have both acute and long-term effects on stormwater management facilities. Rainfall events that produce a larger volume of water than the design flow can result in many complications. If a sufficient outlet or emergency overflow is not provided, large volumes of water can cause surcharging of the storm sewer systems, resulting in flooding in upstream urban areas. More frequent intense rainfall events can also cause erosion at points of flow concentration such as inlet and outlet structures. From a water quality perspective, stormwater management facilities function by allowing sediment to settle during inter-event periods. Consecutive storms that lack a sufficient inter-event period can cause stormwater management facilities to discharge sediment-laden water.

Figure 6.4 illustrates a risk assessment process for evaluating three (3) different potential climate change effects related to increased storm intensity and severity.

Figure 6.4 - Example2: Increased Intensity and Frequency of Rainfall Events Risk



In all cases, the probability of increased intensity and frequency was given a probability of occurrence classification of likely. For this high-level risk assessment, impact severity might not be known with great accuracy. For example, technical analysis (modelling) may be necessary to identify the extent of hydraulic effects such as storm sewer surcharging. At this stage, conservative assumptions (worst case) can be made and refined via technical analysis. In this example, due to the risk of flooding properties adjacent to the stormwater management facility, an extreme impact severity was assigned to the climate change impact. For the impact of erosion at the outlet structure, a low impact severity was assigned due to the localized nature of the impact. If initial analysis determined that bank failure of the facility, damage to critical infrastructure or harm to significant habitat was possible as a result of the erosion risk, the impact severity would be increased to major or extreme.

Using the matrix shown in Figure 6.1 the risk classification for the exceedance of stormwater management facility flood storage volume is extreme. As a result of this classification, adaptation strategies to avoid flooding should be implemented immediately. The low impact severity score associated with the erosion risk results in a risk classification of moderate. Adaptation strategies including, but not limited to, a redesign of the outlet or a monitoring and preventative maintenance plan should be considered and implemented, if economically feasible. The climate change risk of increased sediment loading resulting from rainfall events with short inter-event periods has been evaluated as an extreme risk for this facility largely due to aquatic species vulnerability in the receiving watercourse. Based on this classification, adaptation strategies to mitigate impacts on aquatic environment should be implemented immediately.

6.8.3 STEP 3 - Climate Change Impact Management Planning & Design Adaptation

The risks such as failing to meet project goals, objectives, performance criteria and targets identified through Steps 1 and 2, including via technical analysis, are mitigated through climate change impact management planning and design adaptation.

The application of adaptation measures to reduce the project's vulnerability to changes in specific climate parameters is critical to long-term viability as well as reducing environmental impact and protecting public health and property. Climate change impact management planning typically involves applying adaptation measures to reduce the project's vulnerability to changes in climate parameters and/ or modifying the design to account for expected climate change impacts. Incorporating LID BMPs into a project is an excellent way to reduce some risks associated with climate change. Another example of climate change impact management planning is increasing the storage capacity of a stormwater management facility based on expected changes to intensity and frequency of extreme precipitation events or incorporating LID into urban environments. Additional strategies are discussed in Section 6.8.3.1.

6.8.3.1 Adaptation Options

Because of the uncertainties over the impacts of climate change on the water environment, where possible measures that can cope with a range of future climate conditions should be chosen. The following options of measures should be prioritized (in decreasing order of priority) (adapted from UN, 2009):

Option 1: Win-win options – cost-effective adaptation measures that minimise climate risks or exploit potential opportunities but also have other social, environmental or economic benefits. In this context, win-win options are often associated with those measures or activities that address climate impacts, but which also contribute to climate change mitigation or meet other social and environmental objectives. For example:

- Tree planting in urban settings shade impervious areas and intercept rainfall providing environmental, aesthetic, and social benefits;
- Use smart growth and sustainable growth strategies that decrease road building and include transportation choices other than automobiles;
- Protect wetlands through “no net loss” concept and re-establish wetlands where feasible to hold runoff and recharge groundwater.

Option 2: No-regrets Options – cost-effective adaptation measures that are worthwhile (i.e. they bring net socio-economic benefits) whatever the extent of future climate change. These types of measure include those which are justified (cost-effective) under current climate conditions (including those addressing its variability and extremes) and are also consistent with addressing risks associated with projected climate changes. For example:

- Promoting good practice in street cleaning to limit pollutant loading to end-of-pipe facilities and receiving water bodies;
- Promote landscaping with native vegetation to further reduce runoff and the need for irrigation;
- Minimize impervious surfaces such as parking lots, roads, and rooftops;
- Encourage riparian buffers along streams, rivers, and waterways and maintain flood plains;
- Increasing forecasting and warning capabilities;
- Modifying inspection and maintenance programs.

Option 3: Low-regrets (or limited-regrets) Options – adaptation measures where the associated costs are relatively low and where the benefits, although mainly met under projected future climate, may be relatively large. For example:

- Constructing drainage systems with a higher capacity than needed to accommodate current climatic conditions can have limited additional (incremental) costs, but can help to cope with increased run-off as a result of expected climate change impacts;
- Removing or diverting flows from undersized storm sewers to mitigate the damages associated with more frequent intense storm events;
- Increasing the flood storage volume of existing ponds in flood prone areas and/or increasing the sizing of future ponds to avoid an increased frequency of urban flooding;
- Utilizing LID or GI to reduce runoff volumes during all rainfall events (see Section 6.8.3.2);
- Replacing storm sewers with higher capacity systems.

Options 4: Flexible adaptation Options – measures which are designed with the capacity to be modified at a future date as climate changes. For example:

- Influencing the design of a stormwater management facility so that its capacity can be increased at a future date;
- Dynamic control systems for facilities which respond to real-time climate data;
- Reducing seasonal storage levels in dams.

Climate change impact management planning is project specific and adaptation strategies implemented during this step will be dependent on time, cost, complexity, jurisdictional regulations, and risk assumption. Both short-term and long-term consequences of adaptation strategies should be considered. General considerations for climate change during the adaptation process are identified in Table 6.5.

Table 6.5 - Consideration for Climate Change During the Adaptation Process

General Considerations	Explanation
Capitalize on local knowledge and data	A good knowledge of existing local conditions, including collection and analysis of historical and predicted data used to develop IDF information, has high value in designing infrastructure under projected climate change scenarios (i.e., understanding how systems have responded to past extreme conditions will be useful in understanding how systems are likely to respond to future extreme conditions as they become more frequent).
Carefully consider the anticipated service life of infrastructure	Anticipated service life of new and existing infrastructure becomes an increasingly important consideration under projected climate change scenarios. Common practice was to assume that historical data were a good indicator of future climate, meaning that required design capacities for most drainage and stormwater infrastructure would not change over time. Due to projected climate change, this assumption is no longer valid, implying that required design capacities may change over time. It's also useful to consider operation, maintenance, inspections and monitoring to ensure the infrastructure performs as designed or potentially is more or less resilient than design.
Do not count on beneficial aspects of climate change	Projected climate change is anticipated to adversely affect most infrastructure. However, in some instances and some particular locations, there may be beneficial aspects, theoretically allowing a reduction in required design capacity under a future climate as

General Considerations	Explanation
	compared with design using historical information. In these cases, and because of the inherent uncertainty in projections for climate change, it would generally be recommended to neglect these beneficial aspects in selecting an ultimate capacity for infrastructure design, except in unusual circumstances.
Consider an adaptation design increment when investing in larger, long-lived infrastructure	In general, installing infrastructure with increased capacity normally results in a relatively small additional incremental cost (e.g., the cost of increasing pipe size to the next commercially available diameter) at the time of initial construction. In many cases, this may be a reasonable approach to provide allowances for projected climate change.
Allow for flexible designs that can accommodate future infrastructure upgrades where possible	There may be cases where it is not necessary to construct all anticipated capacity required due to projected climate change at the outset (e.g., a detention facility that might need to be expanded in the future due to the effects of climate change). In these circumstances, it may be reasonable to make appropriate considerations (e.g., acquire necessary lands) for this possible future expansion, but complete the additional construction work only when necessary.
Arrange for possible expansion of major flow path	Most infrastructure commonly designed using IDF information considers establishing a major flow path for use during extreme conditions. In many areas, it may be reasonable to expect the major flow path to be used more frequently, or require expansion, due to projected climate change. A reasonable approach in some cases may be to make the necessary arrangements for anticipated future expansion.

6.8.3.2 LID Adaptation Options

Planning and implementation of stormwater green infrastructure and LID can contribute to the adaptation of the built infrastructure and the environment to climate change. Planning for and achieving the objectives for stormwater management discussed in Section 1.3 under the current or any future climate conditions is a way of increasing the resiliency of our communities, the built infrastructure and the environment to climate change.

Stormwater green infrastructure and LID manage the rain where it falls and snow melts to help maintain the ecosystem function and value of water (e.g., vegetation, habitat for fish or wildlife) while rapid conveyance of runoff can potentially increase the cumulative impact on downstream communities and ecosystems, which could be exacerbated due to climate change. LID practices use vegetation, media and sunlight along with mechanisms such as water infiltration, evaporation, transpiration and rainwater harvesting and reuse. Where LID is implemented on property lots or on the road rights-of-way, these aspects and mechanisms of LID help to maintain or restore the natural water cycle and reduce runoff volume and thereby contribute to flooding control and erosion control. Reducing the runoff volume also reduces contaminant loading into waterways indirectly or directly via municipal storm sewers, thus increasing protection of the environment. LID filtration practices can reduce contaminant levels in runoff as well as allowing some water volume to be retained in the ground. While conventional end-of-pipe control facilities are generally less effective in helping to maintain the ecosystem function and value of water, some are designed with volume detention such that stormwater is temporarily stored with controlled release of stormwater to waterways that can reduce the risk of flood and erosion.

Several scientific studies have highlighted the climate change resiliency of urban stormwater infrastructure when designed with source-based stormwater controls. A selection of studies is summarized below.

A study titled "*Assessment of low impact development for managing stormwater within changing precipitation due to climate change*" by the researchers at the USEPA and the University of Wisconsin-Madison evaluated the effectiveness of LID BMPs, specifically at compact development sites with decreased impervious cover, for reducing stormwater impacts on surface water under changing precipitation patterns. The study identified that the stormwater response of the site was most sensitive to changes in the impervious cover followed by changes in the precipitation volume and rainfall event intensity. The study concludes that even a modest reduction in impervious cover by incorporating LID BMPs into urban design has the potential to significantly reduce increases in stormwater runoff volume and pollutant loads associated with increases in precipitation intensity and volume (C. Pyke et al., 2011).

Another study, titled "LID implementation to mitigate climate change impacts on runoff" analysed potential LID BMPs, specifically rainwater harvesting and bioretention, to control and decrease stormwater runoff in urban areas subject to potential future climate change impacts on wet weather flow. This study used the EPA SWMM code to model an urban catchment in New York City with and without LID BMPs. Increased rainfall associated with climate change produced additional runoff volume and higher peak flows from the catchment. The scenario with LID BMPs was found to provide adaptation benefits to stormwater volume and peak flow (Z. Zahmatkesh et al., 2014).

As well, see Section 1.8.3 for the analysis of the impacts of climate change and the adaptation benefits of LID on their stormwater management system (storm sewers and facilities) as part of the City of Kitchener's Integrated Stormwater Management Master Plan (Aquafor Beech, 2016).

6.8.4 Step 4 – Monitoring and Adaptive Management

Many of the methods used to manage water resources in the past, directly or indirectly, commit an organization to future decision pathways and restricts making other, alternative decisions. The monitoring and adaptive management step is in place to incorporate lessons learned, determine the timing or triggers for the review or update to the completed climate change assessments and define reporting and communication plans.

The implementation of a monitoring and adaptive management plan provides information that can be used to reduce risk and allow for adaptation to predicted future changes. This step involves collecting and evaluating data on key climate parameters over the lifetime of a project and modifying the project or introducing new adaptation measures in response to updated information. An example would be updating the timing of the seasonal drawdown and filling of a water control structure in light of changing rainfall and snowmelt patterns.

Vulnerabilities can be mitigated during this phase by incorporating remedial measures, new operations procedures and or management processes. Monitoring of climate change impacts is an important aspect of this phase and should be incorporated into standard stormwater management monitoring programs. Maintaining access to local precipitation records is important as is long-term monitoring programs that track responses in storm sewers, stormwater management facilities and along natural stormwater receivers. Where hydrologic models are available, these should be updated and calibrated against any significant rainfall event, especially those that exceed previous calibration boundaries.

Infrastructure performance or environmental triggers signal the need to revisit the completed climate change assessment to incorporate new climate data or predictions, technology or management approaches. Triggers may be temporal, based on the data set available or assumptions made in the technical analysis. It is not intended that the established approach be static, but rather evolve with policy and supporting science.

See Chapter 9 for potential monitoring approaches and procedures.

6.9 Rainfall Intensity Duration Frequency Methods

One method of modifying a project design to accommodate future climate change is through the use of modified intensity-duration-frequency (IDF) curves. IDF statistics are used in many water management applications, including drainage design, stormwater and watershed planning, flooding and erosion risk management, and infrastructure operations. In Ontario, regulatory authorities such as the Ministry of Transportation, Ministry of Environment, Conservation and Parks, municipalities, and conservation authorities mandate the use IDF statistics as one of the major criteria in the design of stormwater management systems

(Coulibaly *et al.*, 2016). The IDF statistics are based on historical rainfall records, which are updated by Environment and Climate Change Canada.

Up-to-Date IDF Curves and IDF Curves for Future Climate Conditions
Keeping IDF Curves up-to-date ensures that the most recent rainfall events are included in probabilistic hydrologic calculations. IDF curves for future climate conditions go further by using downscaled GCMs to simulate predicted future rainfall patterns.

IDF curves are used by stormwater practitioners to design stormwater infrastructure. They are localized risk-evaluation tools based on historical rainfall records across the province. Even though IDFs are regularly updated, the increased frequency and severity of rainfall events resulting from climate change presents a risk to much of Ontario's stormwater infrastructure. It is important to note that not all precipitation events "are created equal" when discussing IDF relationships. Municipal engineers may be concerned with short duration events that cause flooding very quickly in urban settings with high impervious cover and short times of concentration. These short-term events (typically 3 hours or less) are often the product of thunderstorms that may be associated with convective heating or fast-moving storm fronts. These systems are the ones responsible for most urban stormwater failures including the surcharging of sewers.

On a watershed basis, water resource engineers are also concerned with longer duration precipitation events. These events are often the product of vast weather systems such as hurricanes or tropical depressions that have lost energy before reaching Ontario, but still have the potential to drop vast volumes of rainfall. Rain on snow events that also have the potential to generate excessive runoff and generate riverine flooding.

Increasing the spatial coverage of the rainfall monitoring network across Ontario and updating IDFs as new data are collected are key actions to move towards climate change resilient stormwater infrastructure.

If the primary concern related to a development is the behaviour of the system under a more intense storm event, a modified IDF curve approach can be used. IDF curves have been developed for future climate conditions and are available for the Province from the Ontario Climate Data Portal (see the Resource Directory) or the Ontario Ministry of Transportation's IDF Curve Lookup (see the Resource Directory). These curves offer a means to estimate flows and generate future runoff events that is well understood by most urban hydrologists and engineers. The modified design storm intensities can be used to determine optimal sizes of the stormwater management facilities and the required infrastructure.

It is important to note that the results of global climate models should be considered with great care and proper analysis is to be undertaken of any future rainfall predictions (e.g. IDF curves) to ensure that the values used in hydrologic analysis truly represent, as much as possible, future rainfall predictions. Although the approach is simple to implement, there is uncertainty regarding the accuracy of these future IDF curves. As noted by (Coulibaly, et al, 2016), there is a lack of consensus on the most appropriate methods for developing the curves due to the wide array of distribution functions, future climate model datasets, downscaling methods, and future scenarios that could be used in creating future IDF statistics. With the large range of possible approaches available, there is the potential for significant variability among future IDF statistics for a given area. This variability and the current lack of consensus on the most adequate methods ultimately translates into uncertainty associated with the development of IDF statistics and on how climate change is projected to affect local rainfall regimes. Therefore, it is recommended, as with the use of GCMs, that practitioners account for uncertainties in the predictions, and develop adaptation strategies through the application of multiple sources of climate predictions to reduce the variability.

Example: Many Ontario municipalities have conducted climate change and/or IDF analysis studies to provide direction for municipal infrastructure planners in light of climate change risks. Of note is the City of Niagara Falls which conducted an IDF curve update and climate change analysis as part of their 2015 Master Drainage Plan Update Study. Updated IDFs for four of the five climate stations within the City were found to generate rainfall volumes and intensities that were slightly lower than those generated by the previous IDF curves (Hatch Mott MacDonald, 2015). Additional analysis conducted for Niagara Falls found that the "average annual rainfall volumes for the past 15 years (2000 to 2014) were actually 5.5% lower than the long term average, and significantly lower (by 12.6%) than the average annual rainfalls in the 1970's, 80's and 90's; and the frequency of the larger rainfall events (> 25 mm) that cause most of the stormwater management and combined sewer overflows problems were all significantly lower than the long term average (by 15%-25%)" (Hatch Mott MacDonald, 2015). Even with these findings, it was recommended that the City use the more conservative (higher intensity) IDFs and apply a 5% increase to provide a safety factor in the design of future stormwater infrastructure (and upgrades) to account for possible future climate change impacts.

These finding are supported by a provincial-scale study titled Potential Impacts of Climate Change on Stormwater Management (Hulley et al., 2008) studied potential impacts of climate change on stormwater management practices in southern Ontario based on findings of the United Nations Intergovernmental Panel on Climate Change. This study found that the frequency of relatively intense rainfall may increase as a result of increased ratio of precipitation to number of wet days, little change in the number of drought days and an expected increase in annual precipitation. The study did however note that the level of model uncertainty associated with the 2007 IPCC results, and the resolution of the numerical tools, is not adequate to support detailed predictions regarding IDF curves. It also noted that general trends, such as the expected increase in more intense precipitation events, are generally supported by the IPCC summary reports.

It should be pointed out that there is risk associated with applying IDF increases on conveyance infrastructure without properly assessing the impact on downstream infrastructure and natural systems. This is further discussed in the subsequent section.

6.9.1 Unplanned Negative Outcomes

As stormwater practitioners in Ontario adapt stormwater infrastructure to observed and predicted climate change risks, it is important that the environmental, social and economic risks associated with our solutions are fully analyzed. One area of concern is applying capacity increases to conveyance infrastructure without properly assessing the downstream impacts.

For example, to provide an expected level of service during the 1:5-year event, a municipality may decide to increase storm sewer pipe sizes in light of expected climate change. If the catchment area where increased pipe sizing is implemented is uncontrolled (i.e. discharge to a watercourse such as a creek or river), the increased flow may cause localized erosion at the outfall and the cumulative impact of several retrofits may cause erosion and flooding downstream. Sensitive environmental features such as fish spawning grounds and wetlands may also be affected by the changes in flow regime and sediment transport. As such, it is important to consult with managers of natural watercourses (i.e. local conservation authorities or Ministry of Northern Development, Mines, Natural Resources and Forestry) when considering modifying standard pipe sizing across a large catchment or subwatershed area that is uncontrolled.

For catchments that drain to stormwater management facilities, while the risk is generally lower, there still remains a risk associated with increasing pipe sizes. Where significant changes to the conveyance network are considered, hydrologic modelling should be updated to ensure the stormwater management facility can meet design objectives under increased flows.

Capital costs are also considered when implementing climate change adaptation strategies. Within our existing stormwater management framework, aging infrastructure and a lack of upgrade capacity has prevented many municipalities from meeting a city-wide level-of-service for stormwater conveyance capacity, stormwater quantity control and stormwater quality treatment. In many instances, solutions are feasible but prove to be too much of a financial burden especially when applied to large geographical areas over a short period of time. Climate change impacts threaten to exacerbate this problem. It is up to municipalities to assess the impact of observed and predicted climate change on existing infrastructure and prioritize upgrades in a prudent and economically feasible manner. This would entail prioritizing high-risk areas, providing long-term capital works schedules, developing rigorous inspection programs and providing continuous monitoring.

7.0 EROSION AND SEDIMENT CONTROL DURING CONSTRUCTION

Sediment accumulation in infiltration-based LID BMPs can result in malfunction and failure of the facilities (Figure 7.1). Fine sediment such as silt and clay that accumulates on top of these facilities creates a less-permeable barrier that can lead to ponding of water and stormwater bypasses of the infiltration system. As a result, it is essential that the construction of LID BMPs is staged properly with other site construction activities and provided with appropriate Erosion and Sediment Control (ESC) practices.

Figure 7.1 - Clay sediment accumulated on top of the mulch layer of a bioretention facility resulting from improper erosion and sediment controls

7.1 Current Guidelines

ESC practices have evolved significantly over the past decade. The most current approach to ESC involves a hierarchical strategy whereby erosion mitigation is the primary focus followed by the control of sediment. This approach recognizes that previous efforts which focused on sediment control fail to deal with the root cause of the problem - the erosion. This hierarchical approach is supported by national certification boards including the Certified Inspector of Sediment and Erosion Control program (CISEC) which recommends a stepped ESC approach of:

Step 1 – Eliminate or Reduce erosion
Step 2 – Control sediment releases

In this two (2) step process, the development of an appropriate erosion and sediment control plan for a project site mitigates to the greatest extent possible the erosion of soils during construction, reduces the reliance on sediment controls to reduce releases and protects the LID

BMP and the receiving watercourse from sediment releases. In this regard, it is important to note the following:

- Sediment control does not control erosion, but erosion control does minimize sediment; and
- Sediment control practices do not remove all suspended sediment found in runoff water.

ESC guidelines differ between municipalities. In the Golden Horseshoe, nine (9) conservation authorities comprising the Greater Golden Horseshoe Area Conservation Authorities prepared ESC guidelines in 2006 for common usage in an effort to coordinate the response of various municipalities and agencies involved in land development, construction and water management. These guidelines detail the requirements of for developing an effective ESC plan within areas under the jurisdiction of the Greater Golden Horseshoe Area Conservation Authorities. In 2019, the Toronto and Region Conservation Authority released an updated Erosion and Sediment Control Guideline for Urban Construction (TRCA, 2019). Some municipalities within the province mandate that only individuals with CISEC certification prepare ESC plans. To qualify for admission into the CISEC certification program, applicant must meet the following minimum criteria:

- 2+ years of construction site field experience involving erosion and sediment
- Through understanding of erosion and sedimentation process and how they impact the environment
- Complete understanding of key federal, provincial and local regulations
- Ability to read and interpret ESC plans

7.2 Basic Principles of Erosion and Sediment Control

There are basic principles that guide the development of any ESC plan. These principles are:

- Construction staging is a fundamental component of any ESC plan and is of particular relevance in the implementation of the LID BMPs.
- Stage construction such that the LID BMPs are built after the site has been substantially stabilized and direct silt laden runoff away from LID BMPs to protect the infiltration medium from being clogged.
- Use a multi-barrier approach which begins with erosion controls, followed by sediment controls and avoids reliance on a single control point for sediment.
- Retain existing vegetation to the greatest extent possible for as long as possible during construction.
- Minimize the land disturbance areas within the project site.

- Minimize the period of time from disturbance of project areas to coverage with erosion controls.
- Reduce runoff velocities and detain runoff to promote settling of suspended solids.
- Divert runoff from areas that are prone to erosion.
- Minimize the slope length and gradient of disturbed areas.
- Maintain overland sheet flow and avoid concentrated flows.
- Store and stockpile soils away from all watercourses, drainage features and the top-of-slopes.
- Ensure any end-of-pipe stormwater management facilities are fully functional and vegetated prior to development area grading.
- Manage the tracking of sediment into and through the construction site by traffic and heavy equipment.

It is also important to note that construction sites are dynamic and to properly protect LID BMPs, infrastructure and the local environment, ESC plans must also be dynamic. Successful ESC plans require application of the Adaptive Management Approach (AMA) whereby the ESC plan is continually updated as a result of site inspections.

For an effective AMA, site conditions should be inspected frequently so management strategies can respond to changing conditions. The frequency will depend on site specific conditions but at minimum inspection should occur:

i. On a weekly basis
ii. After every rainfall event
iii. After significant snowfall event
iv. Daily during extended rain or snowmelt periods
v. During inactive construction periods where the site is left unattended for 30-days or longer, a monthly inspection should be conducted.

All inspections should be documented in a report or memo noting the condition of existing ESC practices, recommendations and including relevant pictures.

Timing is also essential for successful ESC plan. Depending on the area of the province, municipal policy may dictate how long a recently graded site can be maintained before topsoil and seed must be applied. The shorter this timespan the smaller the window for significant erosion. If seasonal conditions prevent effective seeding, alternative erosion control methods as outlined in Table 7.1 should be used.

7.3 Erosion and Sediment Controls Practices

Table 7.1 identifies ESC practices that can be used to prevent unwanted sediment discharges to important areas including LID BMPs. These are identified as either erosion controls or sediment controls. As stated in Section 7.1, erosion controls are the primary focus but a multi-barrier approach that uses both is necessary on all LID construction sites.

Table 7.1 - Summary of Erosion Control Practices and Sediment Control Practices

Erosion Control BMPs	Sediment Control BMPs

Diversion Structures
• Slope drains
• Diversion berms
• Conveyance channels
 	
Erosion Control Methods
• Soil Roughening
• Seeding or turf establishment – sprayed, drilled or spread
• Turf Reinforced Mats (TRMs)
  o For drainage channels/ conveyance
• Soil binders - tackifier or polymers
• Rolled Erosion Control Products (RECP)
  o For hillsides
• Mulch application (wet or dry)
  o Dry mulches such as straw, hay, compost, RECPs or Rock
  o Wet mulches such as shredded wood, corn stalk fiber with or without tackifier or polymers
	Perimeter Controls
	• Silt fence barrier
	• Fiber log/ roll
	• Compost socks
	• Compost berms
	
	Check Structures
	• Straw bale barrier- check dam
	• Rock check dam
	• Geosynthetic check structure
	
	Inlet barriers
	• Rock bags
	• Curb inlet "sump barriers'
	• Curb opening to vegetated areas
	• Area bale/ rock barrier
	• Inlet inserts
	
	Stabilized Construction Access controls
	• Vehicle tracking pad/ mud mat
	• Entrance Grates or ridge systems
	• Tire washing
	• Traffic routes and signage for site traffic and heavy machinery
	• Signage to delineate LID BMPs and allowable storage and stockpiling areas

7.4 Erosion and Sediment Control Report

The development of an Erosion and Sediment Control Report (ESC Report) is a critical element of a successful LID project. An ESC Report should be a "living" document that is reviewed at all stages of construction as well as after storm events. The ESC plan outlined in the report should be amended when inspections indicate ineffective practices or changes to the plan affect the discharge of pollutants. A LID Construction Guide was developed by CVC in 2012. The guide recognizes the importance of appropriate ESC to successful implementation of LID BMP projects and discusses appropriate approaches for site preparation, mass grading, utility installation, working near building infrastructure and pavement and finish grading. The ESC Guide should be looked to for further guidance in developing an ESC report.

Per the LID Construction Guide (CVC) – see the Resource Directory – an ESC Report should:

1. Discuss potential sources of sediment and other pollutants on site during the construction process.
2. Identify communication and/or training methods for all workers onsite to be aware of the LID BMPs, their proposed locations and how site activities may unintentionally impact these features.
3. Identify areas of the site where flows concentrate.
4. Identify who will be responsible to oversee the implementation and maintenance of the practice.
5. Identify temporary sediment basins and how they will be managed.
6. Identify the permanent stormwater management system and how it will be managed.
7. Identify erosion protection practices such as construction phasing and minimization of land disturbances, vegetative buffers, temporary seeding, sod stabilization, horizontal slope grading, preservation of trees and other natural vegetation, and temporary and permanent vegetation establishment.
8. Identify sediment control practices such as installation and maintenance of perimeter controls, practices to control vehicle tracking, control of temporary soil stockpiles, and protection of storm drain inlets.
9. Identify dewatering and basin draining practices to prevent erosion & scour of discharged water.
10. Identify inspection and maintenance practices to ensure that inspections occur weekly or after individual rainfall events, are routinely recorded, that repairs and maintenance and replacement of ineffective practices are completed in a timely manner - see ESC Guide for further guidance.
11. Identify pollution prevention management measures to address proper storage, collection and disposal of solid waste, oil, paint, gasoline and other hazardous materials, and fueling and maintenance areas.
12. Identify designated wash out areas for ready mix trucks and concrete forming tools.

13. Include a strategy for retaining records and who is responsible for them.

7.5 Enhanced ESC for Infiltration Controls and LID BMPs

Protecting LID BMPs with a well-designed ESC plan is essential. During LID BMP construction, the construction supervisor should always take an active approach to ESC and be ready to modify the plan as necessary to react to changing site conditions. Since LID design components are sensitive to sediment contamination, supervisors should ensure the proper installation of ESC practices, dust control and general site clean-up as necessary.

Examples of construction best practices that should be considered when developing an ESC plan for LID BMPs include:

- Excavating the final grade (invert) of the infiltration bed immediately prior to backfilling with specified aggregate and media to avoid premature facility clogging.
- Storing all construction materials downgradient of LID BMPs (where possible). Construction materials stored up-gradient of excavated site are to be enclosed by appropriate sediment control fencing. Where these are left exposed for 30 days or greater, temporary cover should be applied to stabilize the area.
- Storing all materials used for construction of infiltration-based LID BMPs separate from other material.
- Directing the concentration of runoff including overland flow routes and roof drainage away from LID facilities during construction.
- Installing barriers in front of curb cuts to prevent sediment from washing into facilities where curbs are part of the design.
- Installing a sacrificial piece of filter cloth on top of the filter fabric-wrapped clear stone filled trench to collect dust and debris during construction. This is removed before biomedia is installed.

For a detailed discussion of ESC approaches for LID BMPs, refer to the LID Construction Guide (CVC) – see the Resource Directory.

8.0 OPERATION AND MAINTENANCE

Like all stormwater management controls, LID or conventional stormwater management approaches, proper operations supported by maintenance are essential to ensure the on-going stormwater management performance as designed or intended over the life span of the BMP. Site maintenance conducted per the recommendations of a well-designed maintenance plan can also extend the functional life of facilities. These operations and maintenance activities, their frequency and timelines should be outlined in an operation and maintenance manual or plan. For the purposes of this manual the term "Operations Manual" will be used to indicate operating and maintenance procedures for routine operation of the works.

The functional and treatment performance of all stormwater LID BMPs will be sustained over time only if they are adequately inspected and maintained. A proactive, routine inspection and maintenance program will:

- Identify maintenance issues before they significantly affect the function of the LID BMP;
- Help to optimize the use of program resources and reduce operation and maintenance (O&M) costs by providing the feedback needed to determine when structural repairs to the facility are needed and to adjust the frequency of routine inspection and maintenance tasks where it is warranted to increase efficiency; and
- Help to improve LID BMP design guidance and develop appropriate municipal standards.

The level of maintenance and associated risk of failure is influenced by several factors. These factors include, but are not limited to, location of the practice, habitat sensitivity, and the impact on the level of service if there is a failure of the system. A practice that is integral to the performance of the overall stormwater system or preserves the hydrologic function of a sensitive habitat may require additional focus and level of effort. Similarly, facilities that transcend stormwater management, such as those with broader community and social objectives like neighborhood beautification, public education, crime prevention, air quality, and climate change; or represent a significant feature that has been adopted by local residents, may require additional operation and maintenance resources and funding, regardless of its designed function. In this way, O&M resources can be allocated based on the relative risk of failure and the importance in the community based on the design goals and objectives.

The following sections of this chapter highlight:

- The differences between traditional stormwater management practices and LID BMPs:
- The process for optimizing O&M activities and costs during the design process;
- The process for limiting O&M liabilities resulting from construction;

- Resources which provide additional information about various operations, maintenance and inspections for various LID BMPs;
- The various O&M considerations and approaches for municipally owned systems
- Examples of municipal tools and approaches for mitigating O&M risks for LID BMPs on private property.

8.1 Considerations for Operation and Maintenance

Best designs for LID stormwater management systems that have considered community needs and local conditions are effective only to the extent that they are properly built, operated and maintained as per design.

Maintenance activities for LID facilities or system can be pre-planned or triggered by inspection or monitoring results. A preventative maintenance approach that identifies who would do what maintenance and the maintenance frequency is advisable. As well, inspections or monitoring thresholds that trigger maintenance action(s) could be identified early on, perhaps during the LID design stage, to work in conjunction with the preventative approach.

An inspection can include making observations, taking measurements or taking samples for laboratory analysis. The use of technology may allow remote inspections and monitoring, such as the use of auto samplers, sewer flowrate sensors/monitors, telemetry equipment or camera drones. The frequency of routine inspection and maintenance, including housekeeping, may vary from daily, monthly to annual, depending on the action and the reason for it. For example, grass cutting could be bi-weekly, and litter and sediment removal could be scheduled on seasonal basis. Some inspections could be event based, such as after a severe rain storm event. While some activities, such as media replacement, could be needed every 10-15 years.

Records of inspections, monitoring and maintenance should be kept along with date, location, name of the person and other pertinent information. A regular review and assessment of the inspection, monitoring and maintenance activities, such as through an annual reporting process, could confirm the proper functioning of the LID as well as to identify potential future problems and any needed upcoming maintenance or rebuild activities. For municipalities, it could also allow coordination of activities across departments for sharing resources and reducing costs.

It is recommended that an O&M program be developed as part of the stormwater management system design and be recorded within the design documentation which:

- Is cost effective and efficient;

- Is integrated into standard O&M activities and actions (e.g., roadway sweeping, catch basin cleaning, pipe flushing, vegetation maintenance, litter removal, sediment removal)
- Leverages existing staff training, machinery and equipment;
- Includes a basic or standard list of O&M activities for each specific practice, or group of practices, to streamline standard operating procedures;
- Has the ability to be customized where needed based on risk, community importance or other;
- Is adaptive based on a feedback system which informs subsequent plans and activities; and
- Achieves outcomes associated with the key objectives for stormwater management discussed under Section 1.3.

8.2 Importance of Factoring Operation and Maintenance During Design

To ensure LID facilities and all BMPs perform as intended, represent a valued investment of capital dollars and are financially sustainable over their design life, it is important to design with consideration of on-going operation and maintenance needs.

- **Standard Products:** Use of standard products, such as curbs, inlet, overflows, and catch basins instead of specialized or one-off products, where appropriate. While this may not always be possible, the additional effort to scan and select appropriate standard products can reduce O&M costs and specialized equipment.

- **Warranty Period:** Including a requirement for the contactor to complete an extended warranty period such as 2-years can be an effective means to ensure that when later assumed, O&M activities are minimized.

- **Pre-treatment:** Pre-treatment devices are designed to provide a buffer area or collection system where sedimentation occurs before it can reach the LID BMP. The inclusion of pre-treatment devices can help to reduce O&M costs and increase life expectancy of the facility. Pre-treatment devices which have easy access to the accumulated sediment are most appropriate for the workforce tasked with undertaking the removals. Consider equipment which balance the frequency of maintenance with the protection of the facility.

- **Sediment Removal:** Sediment removal techniques may involve hand tools, high-pressure washers, and vacuum trucks. The frequency of sediment removal will vary depending on pre-treatment practices and catchment conditions, including the particle size distribution of the soil. For example, the presence of clay or silt soils may increase the frequency of maintenance. Knowing the particle size distribution of your soil will aid in the design of LID facility and help to optimize on-going maintenance.

- **4-Season Design:** Designing LID facilities with spring, summer, winter and fall conditions in mind may help to reduce O&M costs. Anticipation of vegetation deposition in the fall (leading to blocked inlets or temporary clogging of narrow jointed permeable pavements), and winter maintenance activities (e.g., ploughing, sanding, salting) are encouraged during design. A key optimization strategy can include behavioral change in regard to operation activities (e.g., sanding and salting), but also consideration of where snow is stockpiled during winter months and provisions for additional inlets or overflows for use during winter.

- **Vegetation Selection:** Selecting vegetation which is appropriate for the climate zone, local conditions as well as operational conditions can reduce operational and maintenance effort. Selection of salt and drought tolerant species, as well as species which can tolerate periodic inundation will help to ensure plant survivability. Use of block plantings or limited plant palettes (while ensuring to avoid monocultures which are highly susceptible to disease and or climate induced mortality) can also increase O&M efficiency. The specification of higher planting densities may reduce opportunistic weed growth and reduce plant replacements. More detail is provided in the following section.

8.2.1 Selecting Vegetation for Operations and Maintenance

Many LID facilities (e.g., bioswales, bioretention areas, and green roofs) make use of vegetation including turf and native or ornamental plantings that have climate change co-benefits including provision of habitat and aesthetics. Maintenance requirements for vegetation in LID practices are not much different from most other turf, landscaped, or natural areas and do not typically require new or specialized equipment (EPA, 2007). The degree to which vegetation is included, the type of plants, the number of species and their relative costs are all at the discretion of the designer and can be refined for each individual project during the design process. The consideration of long-term O&M during the design stage is a critical step that can be used to limit operational and maintenance burdens. Common practices in vegetation selection are listed below in order of higher to lower operations and maintenance activities:

- Annuals.
- Ornamental perennial plants and grasses (high species diversity – greater number of species).
- Ornamental perennial plants and grasses (lower species diversity - limited number of species).
- Trees and shrubs only.

- Naturalized plantings (not ornamental). Can include native plants.
- Turf and / or sod.
- Rock mulches

Vegetated LID BMPs may require a more landscape-based maintenance program as compared to maintenance of more conventional stormwater management facilities (e.g., outlet inspections, pond dredging, vacuum trucks to empty OGS systems). Municipalities generally have the required staff and equipment within different departments (such as the Parks Department, Urban Forestry, and Operations) including staff with training and expertise in arboriculture, horticultural, and / or landscape architecture.

Private industrial, commercial, institutional, or multi-residential properties that have implemented LID BMPs may rely on trained service professionals from the landscape industry for site maintenance that have an appropriate level of training and experience.

The landscape is a living system that evolves in response to the environment and natural successional processes. Consequently, the inspection and maintenance program should be implemented with an understanding of the long-term evolution of the landscape and with a view to the desired state of the landscape in the future. The following are the objectives that should be considered when developing a landscape maintenance program for LID:

- Acknowledge seasonal influences on vegetation and recognize the increased maintenance requirements typical of spring (and potentially in the fall);
- Promote the succession of naturally occurring species and associations;
- Support the process of natural succession;
- Manage for the control of non-native invasive or undesirable species;
- Manage to ensure public safety with respect to preservation of sightlines, removal of hazards and control of noxious species; and
- Ensure that the primary stormwater management function of the facility is achieved.

There are often co-benefits of utilizing vegetation-based stormwater management facilities. They include green space for the people as well as habitat for animals, fish, insects, and other organisms. While the needs, views and any requirements of local community and agencies should be considered, the primary function of managing and controlling stormwater must be maintained through maintenance activities.

8.3 Optimizing Operations and Maintenance During Construction

LID BMPs may not provide the intended level of treatment if they are not installed properly or protected from damage during construction. Experiences with early applications have shown that failures are often due to:

- LID practices not being constructed as designed or with specified materials;
- Lack of erosion and sediment controls (ESCs) during construction; and/or
- Lack of rigorous inspection prior to assumption.

A 2009 survey of stormwater BMPs in the James River watershed (Virginia) by the Center for Watershed Protection found approximately half (47%) of the 72 BMPs deviated in one or more ways from the original design, or were receiving inadequate maintenance (CWP, 2009). Similar results have been revealed from surveys of stormwater detention ponds in Ontario (Drake et al., 2008; LSRCA, 2011), highlighting the need for thorough inspections of BMPs prior to assumption and a proactive approach to stormwater infrastructure operation and maintenance. (TRCA/ STEP, 2016).

Therefore, it is important to conduct timely inspections during construction and detailed inspection and testing prior to assumption to ensure that LID BMPs are:

- Built according to approved plans and specifications;
- Installed at an appropriate time during overall site construction stages and with protective measures to minimize risk of siltation or damage; and
- Fully operational and not in need of maintenance or repair at the time of assumption by the municipality, property owner or manager.

8.4 Operations Manual

An operations manual that supports and complements the LID design should be developed by the proponent. As part of this process, the key objectives for stormwater management discussed under Section 1.3 should be reviewed. The operations manual should include, but is not limited to, the following:

- procedures for routine operation of the stormwater management facility or system;
- inspection programs, including the inspection frequency for structures, apertures and functional design elements (e.g., minimum of once annually), and the inspection or test methods;
- effluent sampling protocol (if applicable);
- repair and maintenance programs, including the frequency of repair and maintenance for the LID, stormwater management facility or system;

- sediment removal frequency, technique and equipment;
- sediment testing protocols and method of disposal or reuse (if applicable);
- method for the re-stabilization of all disturbed areas;
- design life expectancy stormwater management facility or system;
- replacement/ refurbishment recommendations/ plans at the conclusion of BMPs life cycle;
- procedures for the inspection and calibration of monitoring equipment (if applicable);
- contingency plan and procedures for dealing with equipment breakdowns, and any other abnormal situations, including notification of the local Ministry office; and,
- procedures for receiving, responding and recording public complaints, including recording any follow up actions taken.

The operations manual should be kept current through annual review or other regular review frequency.

In 2016, the Toronto and Region Conservation Authority (TRCA) under the Sustainable Technologies Evaluation Program (STEP) released the Low Impact Development Stormwater Management Practice Inspection and Maintenance Guide (See Resource Directory).

This document provides information to municipalities and industrial/commercial/institutional (IC&I) property managers that are considering LID as part of their stormwater management programs. The document is divided into two (2) parts:

- **Part 1** of the document provides guidance on designing an effective LID BMP inspection and maintenance program, based on experiences and advice from leading jurisdictions in the United States, adapted to an Ontario context. A summary is provided in Section 8.5.

- **Part 2** of the document provides guidance on standard cold climate protocols for inspection, testing and maintenance of seven types of LID BMPs:
  - Bioretention and Dry Swales,
  - Enhanced Swales,
  - Vegetated Filter Strips and Soil Amendment Areas,
  - Permeable Pavements,
  - Underground Infiltration Systems,
  - Green Roofs, and
  - Rainwater Cisterns.

  Part 2 includes an overview of each LID BMP, an inspection and testing framework, lists the critical timing of construction inspections which can influence long-term operation and maintenance, provides template inspection field data forms, lists routine maintenance activities, rehabilitation and repair activities as well as life cycle costs of the frequency of inspection and maintenance tasks.

The costs associated with the operation and maintenance of the various stormwater management plan elements may vary with the type and size of the element. Sources such as the TRCA/CVC LID Planning and Design Guide and the TRCA/ STEP Assessment of Life Cycle Costs for Low Impact Development Stormwater Management Practices (2013, or most recent) may provide information when reviewing operation and maintenance and life-cycle costs. It is also important to recognize that stormwater management facilities or systems provide an essential service to safeguard people and the ecosystem which is often not recognized in many cost accounting approaches.

8.5 Operations & Maintenance for LID

Unlike conventional stormwater management systems that centralize treatment facilities in few locations on publicly owned land (e.g., detention ponds) a LID design approach involves smaller scale practices distributed throughout the drainage area, potentially on both public and private land. Implementing a LID approach can involve an increase in number and types of BMPs to be tracked, inspected and maintained. The current operation and maintenance methodology, frequency, software, mapping and procedures will likely need to be adapted to account for a new type of infrastructure.

Table 8.1 provides a high-level summary of the various general categories of O&M activities for both conventional stormwater management practices and LID BMPs. The summary demonstrates where O&M activities differ and where they are similar. Facility refurbishment should be included in life cycle cost assessments.

Table 8.1 - O&M Activities: Conventional Stormwater Management Versus Low Impact Development

Operation or Maintenance Activity	**Conventional Stormwater Management Practices** (e.g., storm sewers, wet ponds, dry ponds, wetland, OGS, end-of-pipe infiltration facility)	**LID BMPs** (e.g., bioretention, bioswales, soakaway pits, cisterns, permeable pavements, etc.)
Education	■ Normally Required	■ Normally Required
Inspection	■ Normally Required	■ Normally Required
Inlet, outlet, catch basin cleaning	■ Normally Required	■ Normally Required
Grass Cutting *	■ Normally Required	■ Normally Required
Weed Control	■ Normally Required	■ Normally Required
Removal of Accumulated Sediments	■ Normally Required	■ Normally Required
Trash Removal	■ Normally Required	■ Normally Required
Pipe / Subdrain Flushing	■ Normally Required	□ May be Required
Pruning/ removal of old plant growth *	□ May be Required	■ Normally Required
Mulch Replacements *	□ May be Required	■ Normally Required
Soil Replacements *	□ May be Required	■ Normally Required
Vegetation Replanting *	□ May be Required	□ May be Required
Removal of Accumulated Sediments from control structures, etc.	□ May be Required	□ May be Required
Outlet Valve Adjustment	□ May be Required	□ May be Required
Core Aeration or Basin Floor Tiling	□ May be Required	□ May be Required
Irrigation *	□ May be Required	□ May be Required

* indicates operation or maintenance activity only required for vegetative LID BMPs
(Adapted from: MOE, 2003 and TRCA/STEP, 2016)

8.6 Operations and Maintenance for Municipal and Private Systems

Whether the context is a municipality, or another organization involved in the management of properties where stormwater LID BMPs are present, some important scoping decisions need to be made at the onset of developing an inspection and maintenance program. Table 8.2 adapted from the Low Impact Development Stormwater Management Practice Inspection and Maintenance Guide (TRCA, STEP, 2016) summarizes key questions which highlight the preliminary work and key decisions that need to be made to establish the scope of a LID BMP inspection and maintenance program. It should be noted that in general, the owners of industrial, commercial and institutional properties have responsibility and control for activities on their respective properties including the management of runoff on and from their properties.

Table 8.2 - Key O&M Program Scope Setting Questions

Key Questions	Description/ Summary
1. How Many BMPs are to be Included in the Program?	A critical first step in setting the program scope is conducting an inventory of all existing and anticipated future BMPs within the organization's jurisdiction. The inventory should include information on both the physical and regulatory condition of each BMP. Managers must also decide what elements of the overall drainage infrastructure system should be included in the program.
2. Who is Responsible?	Assigning or determining responsibility for inspection and maintenance tasks is an important question and one that may have multiple answers depending on the location and function of the BMP.
3. What is the Status of Legal Tools for Inspection and Maintenance?	In general, municipalities may wish to consider seeking the legal authority to require inspection and maintenance of BMPs located on private property, or it is likely that these duties could be neglected.
4. What "Level of Service" is desired for the BMP or Program?	The desired level of service for an individual BMP or an entire inspection and maintenance program encompasses the frequency and type of inspection and maintenance activities that will be undertaken. For example, will maintenance be performed in response to complaints or emergencies or will it be based on preset schedules and findings from routine inspections?
5. Who is Responsible for Routine Maintenance Versus Structural Repairs?	Types of maintenance activities range from routine maintenance tasks like removal of accumulated trash, debris, and small amounts of sediment, weeding and trimming vegetation to more costly and complex structural repairs and rehabilitation of clogged or damaged components.

Key Questions	Description/ Summary
6. How will Maintenance Requirements be Tracked, Verified and Enforced?	For municipalities, enabling policies and program tracking and evaluation systems are key components of an effective stormwater BMP inspection and maintenance program. Before a development proposal is approved, each BMP in the stormwater management plan that contributes to meeting regulatory requirements should at a minimum, have an inspection and maintenance plan prepared and included in submissions for plan review and approval.

(Source: Adapted from the Low Impact Development Stormwater Management Practice Inspection and Maintenance Guide (Version 1.0))

8.6.1 Approaches to Sharing Responsibilities

Inspection and maintenance of LID BMPs are essential to their on-going performance. TRCA's 2016 Low Impact Development Stormwater Management Practice Inspection and Maintenance Guide (Version 1.0) (see the Resource Directory) provides information for consideration of municipalities regarding inspection and maintenance of stormwater infrastructure, such as, who will be responsible, and for what types of tasks, which can also affect decisions on how the program will be designed. In general, there are three (3) approaches a community can use to implement a stormwater infrastructure inspection and maintenance program (Source: adapted from the Low Impact Development Stormwater Management Practice Inspection and Maintenance Guide (Version 1.0) and CWP, 2008.). As such, the approaches to sharing responsibilities in Chapter 8 are provided as information only.

1. Property owner approach: Property owners are responsible for performing all inspection, maintenance and repair/rehabilitation, and associated record keeping for BMPs on their properties. The municipality provides inspection and maintenance plan templates, property owner outreach education resources and inspects, maintains and repairs BMPs on their land and within infrastructure rights-of-way.

Typical Program Characteristics

- Property owner responsible for all inspection and maintenance tasks
- Property owner responsible for maintaining an inventory of all BMPs they own and record keeping related to inspection, maintenance and repair, including results from periodic inspections to verify performance

Strengths:

- Inspection and maintenance are responsibility of owner of the property where run-off would have originated
- Least costly approach for municipalities

Weaknesses:

- Higher potential for inadequate inspection and maintenance

- Municipality responsible for educating property owners about the BMP and inspection and maintenance needs
- Municipality responsible for legal tools to require/enforce maintenance for regulated BMPs on private property

- Cost borne by private property owners

2. Public approach: Municipality is responsible for performing or tracking inspection, maintenance and repair/rehabilitation of all BMPs that qualify for inclusion in their stormwater infrastructure program, whether located on public or private land.

Typical Program Characteristics

- Municipality responsible for inspection and maintenance tasks for all regulated BMPs and any others that qualify for inclusion in their program
- BMPs required to meet regulatory requirements should only be located on public property, in rights-of-way or easements to allow for municipal access
- Municipality responsible for maintaining an inventory of all BMPs that qualify for inclusion in their program and record keeping related to inspection, maintenance and repair, including results from periodic inspections to verify maintenance and performance

Strengths:

- Part of municipal services to the community – municipality has or can establish capacity
- Municipality has control over maintenance practices and schedules (and costs)
- Continued performance with regular municipal inspection and maintenance

Weaknesses:

- Municipal staff require access to private property
- Municipality absorbs costs from property owners unless there is a cost recovery program
- Most costly approach for municipalities

3. Hybrid approach: A hybrid approach consisting of both public and private entities responsible for various inspection, maintenance and repair tasks.

Typical Program Characteristics

- Municipality inspects and maintains BMPs on public land, and within rights-of-way or easements on private property

Strengths:

- Responsibility and costs are shared with property owners
- Part of municipal services to the community – municipality has or can establish capacity

- Property owner responsible for performing some inspection and maintenance tasks and record keeping
- Municipality responsible for an inventory of all BMPs that qualify for inclusion in their program, and periodic inspections to verify maintenance and performance
- Municipality responsible for educating property owner about the BMP and inspection and maintenance needs
- Municipality responsible for legal tools to require/enforce maintenance of regulated BMPs on private property

- Municipality has control over maintenance practices and schedules (and costs)
- Continued performance with regular inspection and maintenance
- Maximum flexibility
- Useful during transition from property owner to public approaches as programs mature

Weaknesses:

- Municipal staff require access to private property
- Potential for confusion about roles & responsibilities

8.6.2 Private Property – Municipal Tools and Approaches

The establishment of LID BMPs on private industrial, commercial, institutional, and residential property may raise operational issues for some Ontario municipalities. While this concern is valid, many Ontario and neighboring U.S. municipalities have developed solutions to mitigate the risks of inadequate inspections and maintenance (e.g., facility failure), including the ability of the municipality to take over maintenance responsibilities.

Table 8.3 provides a summary of the various municipal tools and approaches being employed related to O&M of LID BMPs on private property. Each of the municipal tools can and / or are being applied through municipal by-laws, subdivision agreements, site plan approvals or other such legal mechanism as described below. In many cases, multiple mechanisms and / or approaches can be applied to a specific project or group of projects. The mechanisms and approaches listed within Table 8.3 may be modified and / or adapted based on the local context and existing legal framework.

Table 8.3 - Summary of Municipal Tools and Approaches Relating to O&M Activities of LID BMPs on Private Property

Mechanism	Outcome	Applied Through
O&M Financial Responsibility All costs for constructing and maintaining the stormwater management Facility/LID or structure are the responsibility of the owner.	• Designates responsibility and costs.	• Approvals (subdivision agreement, site plan or other) • By-law
Easements - Legal Right to Enter and Inspect An easement is placed over the private facility/LID including an easement for access from the nearest vehicular entrance off the municipal right-of-way and extending to the facility and shall be dedicated to the municipality. This easement (if required) grants the municipality with the right-to enter and inspect the facility. The easement includes access to any controls structure(s). If easements over parts of the property are not feasible, then the LID should be constructed over the area that can acquire an easement. The easement must be shown on the property survey and recorded in the title.	• Ensures the municipality retains the legal ability to enter and inspect.	• Approvals (subdivision agreement, site plan or other) • By-law
Minimization of Post Construction O&M - Inspection Prior to Occupancy The proponent's consulting engineer supervises and certifies the installation prior to occupancy of the affected lot, block or building to the satisfaction of the municipality.	• Minimizes O&M activities related to improper construction or installation. • Incentivizes proper construction practices.	• Approvals (subdivision agreement, site plan or other) • By-law

Mechanism	Outcome	Applied Through
Annual O&M Reporting & Inspection An annual report is to be submitted by the property owner to the municipality verifying that the required maintenance activities as defined within the operations manual (design brief) and /or environmental compliance approval has been completed and the facility(ies) are functional and meet the designed performance target. The municipality reserves the right to inspect all such facility(ies) at its discretion provided 48 hours' notice is given prior to inspection. For private residential LID BMPs located on an easement, the municipality may choose to accept inspection and reporting duties to ensure continued operation.	• Documents O&M activities on private property • Municipality reserves the verify maintenance has occurred	• Approvals (subdivision agreement, site plan or other) • By-law • Stormwater management Utility or Rate Structure if applicable.
Mechanism for Assurance of O&M For commercial properties, annual O&M and associated reporting requirements as specified, is to be received and approved prior to the renewal of 1) Stormwater management change rebates/ credits, 2) Business licenses, 3) Fire Inspection/ Certifications, 4) Public Health Inspections/ Certificates to other.	• Links submission of O&M activities to non-stormwater management related renewals and approvals • Utilizes existing mechanisms to ensure compliance	• Stormwater management Utility or Rate Structure if applicable. • By-law
O&M Non-Performance Should repairs or maintenance to any LID feature be abandoned by the property owner, the municipality can maintain the right to enter and perform the necessary maintenance as described within operations manual contained within the required design brief. Should the municipality be forced to undertake the prescribed maintenance activities, all costs can be recovered through the provisions of the Property Standards By-law or other and collected through property tax.	• Permits the municipality to recover costs for maintenance activities through existing or amended by-laws	• By-law

Mechanism	Outcome	Applied Through
Minimization of Post Construction O&M - Contingency Areas or Practices The proponent is to prepare a detailed engineering design for stormwater management facilities including a required amount of contingency stormwater management facilities as specified and shall place such areas under a City easement. The easement(s) over the contingency facilities may be released, in whole or in part, and may occur concurrently with the issuance of building permit(s) for each identified block, lot or building. Release of contingency blocks may be subject to verification through appropriate monitoring as approved and confirmed by the respective approval authority.	• Minimizes O&M activities related to improper construction or installation. • Incentivizes proper construction practices. • Ensures compliance with stormwater management targets in sensitive environments • Allows for a performance verification mechanism	• Approvals (subdivision agreement, site plan or other)
Minimization of Post Construction O&M – Letter of Credit/ Construction Phasing The proponent can provide a letter of credit based on, for example, 60% of the estimated cost of approved facilities and any contingency facilities to the satisfaction of the respective approval authority. The letter of credit will be reduced to, for example, 15% once 90% of the catchment area is stabilized (meaning buildings are constructed and lots/blocks are sodded or vegetated), and the submission of the first report for post-construction monitoring. The balance of the letter of credit will be reduced after the “post-construction” monitoring program has expired (two years after 90% of the catchment area is stabilized).	• Minimizes O&M activities related to improper construction or installation. • Incentivizes proper construction practices. • Ensures compliance with stormwater management targets in sensitive environments • Allows for a performance verification mechanism	• Approvals (subdivision agreement, site plan or other)

Mechanism	Outcome	Applied Through
Notice of O&M Responsibility - Notification to Buyers The proponent can include a statement in all Offers of Purchase and Sales Agreements that advises of lot level facilities requirements and the requirement to maintain such facilities including the any all maintenance requirements. Offers of Purchase and Sales Agreement with builders obligate the builder to notify purchasers of the exact location, size and intent of lot level facilities.	• Notifies perspective buyers of the presence of the private facilities • Serves to outline maintenance requirements, municipal contacts and / or resources.	• Approvals (subdivision agreement, site plan or other)
Registration of O&M Agreement The proponent can enter willingly and without reservation into a maintenance agreement that is recorded with the property title that identifies the responsible party and the applicable lot(s) and specifies right-of-entry for maintenance and inspections by municipal staff or their contractors.	• Ensures the municipality retains the legal ability to enter and inspect. • Establishes contractual requirements for O&M on the property title.	• Approvals (subdivision agreement, site plan or other)

9.0 MONITORING, PERFORMANCE VERIFICATION, AND ASSUMPTION PROTOCOLS

The overall goal of monitoring is to provide an understanding of the extent that a LID activity, facility or system is achieving outcomes that are consistent with the stormwater management objectives outlined in Section 1.3.

Monitoring includes observing and checking on the progress or function of an activity, facility or a system and its effect on the environment. Monitoring activities can include inspecting, observing, measuring and sampling activities (with samples sent for laboratory analysis). Monitoring often informs decision making about any action that may be needed.

The analysis of the monitoring information assists to understand whether the LID activity, facility or system is functioning as designed or intended and the effect the LID practice is having on the environment as well as people's ability to use, enjoy and benefit from Ontario's lakes, streams and groundwater.

LID and stormwater management monitoring primarily consist of environmental monitoring and performance monitoring. Table 9.1 identifies various categories of stormwater monitoring and the typical components that could be included.

- **Environmental Monitoring** - Monitoring designed to assess how the LID stormwater management activity, facility or system may be impacting the environmental health of a watershed or subwatershed (measured based on a range of environmental indicators), in response to land use or climate change. This includes climate data collection as well as project specific monitoring. An example of this is monitoring used to determine the assimilative capacity of a watershed. Environmental monitoring may be undertaken to better understand the relationship between the performance of stormwater management facilities and their cumulative impact on the sub-watershed and the broader watershed. Environmental monitoring may for example include:
    - stream flow,
    - water quality, sediment quality, biodiversity of the local receiver,
    - assimilative capacity of a watershed, and
    - rainfall, snowfall and other weather station information.

- **Performance Monitoring** - Monitoring to evaluate how a LID stormwater management activity, facility or system performs, in particular, as compared to design or intent. Performance monitoring also allows comparison with other facilities, technologies, and/or development contexts. Where possible, performance monitoring should form the foundation of adaptive monitoring. Performance monitoring may include:

- runoff volume reduction/control which can be compared with an applicable target
    - water quality at an inlet or an outfall to a waterway (e.g., concentration, loading, other parameters)
    - stormwater flow volume and rate, duration, frequency
    - clogging of permeable pavement or rain garden
    - level of sediment build-up
    - debris at inlets and outlets
    - contamination and any spilt materials at docking areas
    - de-icing salt use in the road, parking lot and sidewalks
    - confirming that a designed level-of-service is achieved;
    - confirming design infiltration rates are maintained; and
    - confirming that LID BMP is achieving design groundwater recharge

Monitoring is performed to collect data that can be used to make informed decisions to best manage and improve the environment. Monitoring helps to identify issues, focus actions where needed, project future conditions, and track progress over time. The clients of LID monitoring include owners and operators of LID BMPs (e.g., developers, municipalities, and businesses), conservation authorities, provincial ministries and others. Monitoring for the client's needs is client dependent and can include performance monitoring and environmental monitoring in various combinations:

- *Adaptive monitoring* – This includes monitoring undertaken by the owner and operator to evaluate how stormwater management practices can be adjusted to improve performance and their impact on the environment. For example, practices could be adjusted to improve water quality, meet hydrologic goals, last longer, require less maintenance, or meet new challenges of climate change. An adaptive environmental management approach allows for adjustments to design and site practices in response to monitoring and evaluation. The benefits to this approach include:
    - Promotes flexible decision making;
    - Monitoring supports science-based understanding and decision making by owners and operators;
    - Acknowledges natural variability in contributing to ecological resilience and productivity.

- *Operational monitoring* – This includes any monitoring that is needed by the owner and operator of a LID facility or system to support everyday operations and maintenance activities. The monitoring informs operational planning decisions regarding routine or major actions. While the focus is often performance monitoring, it can include environmental monitoring.

- *Risk Based Monitoring* – Monitoring designed to detect negative outcomes associated with stormwater management facilities. For example, infiltration can contaminate drinking water, greenroofs can increase nutrients in runoff, and altered runoff patterns can affect wetlands and alter hydroperiods and hydrologic regimes. In areas where groundwater contamination is a significant concern, a risk-based approach to monitoring is used to confirm BMP function and adapt to any negative impacts of stormwater infiltration. Section 4.2 of this manual discusses the risk of groundwater contamination associated with the infiltration of stormwater via LID BMPs. While the risk is significantly reduced if high risk site activities are avoided and infiltration guidelines are followed, groundwater quality should be monitored where:
    - The project site includes any high-risk site activity as identified in Section 4.2.1; or
    - The LID BMP is within or partially within an ICA or a WHPA and accepts runoff from a paved surface.

  Groundwater quality monitoring should compare background conditions or historical data to that of the area directly influenced by the infiltration-based LID BMPs. Monitoring periods will vary based on site-specific conditions but should measure any incremental influence on groundwater quality. Should a LID BMP be found to be contributing to groundwater contamination the design and/or site management strategies should be modified immediately to avoid any additional pollutant loading.

- *Assumption monitoring* – This includes monitoring designed to assist the current and future owners of a stormwater management facility to evaluate whether a stormwater management facility has been implemented and/or constructed properly prior to assumption by the new owner.

- *Compliance monitoring* – This includes monitoring that is required by law or a regulatory authority. For example, monitoring may be required under a director's order under the OWRA, EPA or an environmental compliance approval issued under the EPA.

Table 9.1 - Stormwater Monitoring Components and Parameters

Monitoring Component	Parameter
Hydraulics (at facility)	• Capacity • Outlet design flows • Retention
Flow Rates (in sewers)	• Peak flow rates • Base flow
Hydrology (in receiving stream)	• Time series flows (continuous flows) • Spot flows • Flood flows
Hydrogeology	• Infiltration /recharge • Water Balance
Water Quality (LID BMPs)	• Sediment removal • Outlet concentrations • Event mean concentrations • Contaminant loadings
Water Quality (in receiving stream)	• In stream concentrations • Contaminant loadings • Dry and wet events
Erosion & Fluvial Geomorphology (at facility- inlet/outlet – pre/post)	• Retention volume • Flow duration • Outlet Design Flows
Erosion & Fluvial Geomorphology (upstream/ downstream & at ref. site)	• Channel Stability • Erosion indicators • Rapid Geomorphic assessment. • Detailed Geomorphic
Aquatic Habitat & Communities (at facility- inlet/outlet – pre/post)	• Aquatic invertebrate collection
Aquatic Habitat & Communities (upstream/downstream & at ref. site)	• Aquatic invertebrate collection • Habitat parameters • Habitat suitability measures

9.1 Existing Monitoring Resources

LID monitoring in has been conducted in Ontario by academic institutions, municipalities and conservation authorities. Much of their monitoring data and relevant guidance is available as reports or case studies through online resources. Some examples of the documents that can be found in the Resource Directory include:

- A monitoring guidance document published by CVC in 2015 titled “Lessons Learned: CVC Stormwater Management and Low Impact Development Monitoring and Performance Assessment Guide”
- Performance evaluations of several LID BMPs conducted by the Sustainable Technologies Evaluation Program
- LID BMP monitoring plans, technical reports and case studies

On a broader level, several American organizations including the Environmental Protection Agency, the American Public Works Association, the American Society of Civil Engineers, and the U.S. Department of Transportation in collaboration with non-governmental organizations and consulting engineers have created an International Stormwater BMP Database which is available online (see the Resource Directory).

This database allows for a public search of international LID BMP performance data including some Ontario data.

The U.S. Environmental Protection Agency’s document, Data Quality Assessment: Statistical Methods for Practitioners, provides general guidance to organizations on assessing data quality criteria and performance specifications (see the Resource Directory).

And, a 2014 Landscape Architecture Foundation commissioned study involved the coding and analysis of all metrics and methods used in evaluating case studies and used this information to identify a set of widely applicable metrics and methods for each benefit category. This resulted in EVALUATING LANDSCAPE PERFORMANCE A Guidebook for Metrics and Methods Selection 2018 (see the Resource Directory).

9.2 Developing a Monitoring Plan

The development of a monitoring plan is an important step in establishing a successful monitoring program that fulfills all the identified objectives and goals. Monitoring programs and plans are generally site-specific and are developed per the requirements of more detailed studies which consider the broader landscape features and functions such as watershed and subwatershed studies, master stormwater / drainage plans, environmental impact statements and/ or as from specific approvals or assumption requirements. It is important that each monitoring plan be developed in consideration of the stormwater management objectives outlined in Section 1.3 and site-specific goals, objectives and targets as the central focus.

A monitoring plan will vary depending on the scope of the project and required level of detail, however the typical minimum monitoring plans elements may include:

- Background information, including deliverables, monitoring plan schedule.

- Monitoring purpose and objectives: specific targets for water quantity or quality, volume reductions, water balance or species-specific monitoring requirements.
- Background site information and study area discussion: New Development, Redevelopment, Linear Development, Retrofit, etc.
- Monitoring location and infrastructure to be included.
- Work plan: hydrology, water quality and infiltration, etc.
- Site visits and data extraction.
- Data management, communication strategies and reporting.
- Budgeting and costing.

Monitoring parameters, locations and methodologies should all be selected to answer specific questions and provide feedback with respect to how the BMP was selected, planned, designed and approved. In this manner a 'goal' oriented targeted monitoring plan is developed.

9.3 Stormwater Management Monitoring Programs

Although stormwater monitoring program objectives, opportunities and constraints will differ from site to site, a few key water quality and water quantity parameters are the focus of most stormwater monitoring programs. Conventional stormwater monitoring programs have focused on both water quality and water quantity parameters. Several key parameters and data collection methods that may be considered are identified in Table 9.2. Potential stormwater contaminants are also discussed in Section 4.2 for groundwater. Please note that the table is not intended to be comprehensive and site-specific concerns could require additions or deletions.

Table 9.2 - Examples of Stormwater Management Monitoring Parameters and Collection Methods

Data Type	Monitoring Parameters	Collection Methods
Water Quantity	Precipitation Flow rates, long-term flow regime and total volume discharges at hydraulic structures Water levels within facilities and storm sewers Infiltration	Precipitation gauges Loggers at facility inlet and outlet with rating curves Loggers and/or staff gauges Permeameters, infiltrometers, or other methods
Water Quality	Water quality constituent concentrations and properties (instantaneous) at inlet, outlet and receiver including but not limited to: • Total Kjeldahl Nitrogen (TKN) • Nitrate & Nitrite (NO_2 & NO_3) • Total Phosphors (TP) • Dissolved Oxygen (DO) • Chloride (Cl) • Metals (Pb, Ni, Cu, Al, Zn, Fe, Cd, Mn) • Suspended Solids (SS) • Bacteria • Benthic Macroinvertebrates • Fishes • Organic Compounds (Hydrocarbons, Pesticides, etc.) • Turbidity • Temperature • pH • Conductivity • Phenols • PAHs, BTEX and PHCs F1-F4 • Any additional discharge criteria outlined in ECA	1. Water quality probes and grab samples 2. Automated water quality samplers calibrated for flow proportional sampling

9.4 Environmental Monitoring at Watershed, Subwatershed and Catchment Level

When applied across a large geographical scale such as a watershed, subwatershed or urban catchment, source and conveyance controls provide a wide range of environmental benefits. Environmental monitoring may be undertaken to better understand the relationship between the performance of stormwater management facilities and their cumulative impact on the sub-watershed and the broader watershed. To fully understand the positive impact of LID BMPs on a watershed, subwatershed, or urban catchment, a multidisciplinary monitoring plan would be applied as LID BMPs are being implemented across the community and continue for years after LID BMPs have been fully established. This approach to monitoring is especially important when LID BMPs are being implemented within an existing urban area as part of re-development and retrofits.

Multidisciplinary monitoring will be dependent on the location and anticipated impact. Monitoring results that can indicate that LID BMPs are providing hydrologic and water quality benefits include but are not limited to:

- Changes to the urban flow regime including reduced peak flows and reestablishment of pre-development baseflow levels;
- Reductions in suspended solids and pollutant concentrations after storm events compared to pre-LID implementation;
- The maintenance or re-establishment of a groundwater recharge regime; and
- A greater diversity of aquatic invertebrates and fish species.

Receiver based monitoring programs for water quality as part of pollutant impacts studies and assimilative capacity studies are common in Ontario. The MECP regional offices may become involved in these studies and as part of the environmental assessment, development and approval processes. Pre-development monitoring may be required to establish a baseline to gauge the magnitude of post-development changes. Post-development effects may not be manifested immediately (i.e., years may pass before effect become evident).

In situations where municipalities and their partner conservation authorities, MECP offices and other regulatory authorities are monitoring the impact of significant LID implementation across a watershed, subwatershed or catchment areas (e.g. a neighbourhood or project area), the monitoring of individual LID BMPs may not be necessary. Watershed, subwatershed and catchment level programs should be tailored to local environmental receivers and be developed in close cooperation with neighbouring municipalities, local conservation authorities and MECP offices where applicable.

9.5 Assumption Protocols and Verification

Assumption monitoring is designed to assist the current and future owners of a stormwater management facility to evaluate whether it has been implemented and/or constructed properly prior to assumption by the new owner.

For LID BMPs that will be assumed by a municipality, the site developer may be required by the municipality to verify built LID BMP specifications and performance following the post-construction period of LID BMP stabilization and vegetation establishment but prior to property transfer.

An example of five possible levels of assessment (simple to complex) that can be used to verify a variety of infiltration and filtration practice designs and performance is outlined below and is based on the Low Impact Development Construction Guide (CVC, 2012) which in turn is based on research by the University of Minnesota and the Minnesota Pollution Control Agency. The certification takes place as a 3rd step, following:

1) Design and Plan Review; and
2) Construction Inspection & Maintenance (up to assumption by the municipality).

Certification protocols ensure that knowledgeable personnel (e.g. inspector, design engineer, or permitting agency) evaluate whether the LID BMPs have been installed properly before the contractor is released of responsibility.

The certification process is the last opportunity to identify issues due to improper construction and/or unforeseen site condition issues. These issues can then be addressed before the new owner takes ownership and responsibility for operation and maintenance.

Level 1 – Visual Inspection: Visual inspections require the least effort and minimal cost. It is recommended that visual inspection be used as the initial assessment tool for all LID BMPs. Visual inspection involves inspecting LID BMPs for evidence of malfunction or deviation from the design plans. This can be accomplished with a brief site visit, the original plans and a checklist. Visual inspection can be used to quickly and cost-effectively determine if, and potentially why, a LID practice is not operating properly. Simplified techniques focus on these aspects:

- General confirmation of site draw-down time (hours) and inspection of soil properties
- Presence of ponded water on site beyond specified time to drain (typically 24 to 48 hours following a rainfall event)
- Physical design elements such as verification of inlets, grading, inlet and overflow function including blockages, examination of how flows enter and exit the facility.

Visual inspection alone cannot provide quantitative information about the LID performance and should be done in conjunction with qualitative monitoring and testing.

Level 2 – Capacity Testing: A step beyond visual inspection involves the collection of additional data through testing and measurements including:

- Soil characterization sampling and testing via laboratory analysis. This testing ensures that the installed filter media meets the design specification.
- Elevation surveys of all LID BMP components. This confirms that the depths, storage volumes, and drainage areas correspond to the design plan.
- Sedimentation monitoring and vegetation surveys. These tasks help to establish the necessary maintenance schedules for sediment removal from inlets/pre-treatment areas and vegetation care. Due care to observe preferential flow paths that can be prone to plugging.
- Infiltration testing. A Guelph permeameter test, double-ring or single-ring infiltrometer tests as well as others are tools that are used to measure in-situ saturated hydraulic conductivity. A Guelph permeameter test can be used to determine rates at depth, while double-ring or single-ring infiltrometer test can be used to determine rates at the surface.

This level of certification will establish if the practice was built to the design plan, including the soil composition, the storage volume, and drainage area. The infiltration testing will provide an estimation of expected drawdown times depending on the number of permeameter measurement tests spatially distributed throughout the LID BMP. Capacity testing will not provide the same level of accuracy as the real-world monitoring.

Level 3 – Synthetic Runoff Testing: Synthetic runoff testing uses a clean water source such as a fire hydrant or water truck to generate a known volume of runoff. Level 3 is typically used for individual LID BMPs but can be used for multiple facilities based on the scale of the project and testing.

The performance of the LID BMP is then monitored and measured under well-controlled conditions (to prevent erosion and scouring of the landscaped surfaces). For filtration or infiltration rate assessment, the following four conditions must be met for synthetic runoff testing to be feasible:

- There must be a water supply that can provide the required discharge and total volume of runoff needed.
- The BMP must be offline, and/or no precipitation is expected for at least 48 hours.
- Outflow paths other than infiltration are either measurable or can be temporarily plugged.
- The water surface elevation in the stormwater treatment practice can be measured

Once the stormwater treatment practice is filled with synthetic runoff, the change in water level with time can be used to evaluate the infiltration rate. A perforated observation well which extends to the bottom of the practice is necessary to measure subsurface water level drawdown within a bioretention soil or other subsurface storage area.

Level 4 – Continuous Water Level Monitoring: After infiltration testing (level 2) and synthetic runoff testing (level 3) have been considered and either dismissed or performed, low intensity monitoring can be considered to measure LID performance using continuous water level/temperature data loggers. This type of monitoring provides cost-effective monitoring alternative by tracking temperature and groundwater levels over time including evaluation of seasonal and winter infiltration performance, potentially affected by frozen soils. Subsurface water levels and temperatures can be continuously monitored with a water level logger installed in an observation port/well. For a continuous water level assessment, the following conditions must be met:

- A perforated observation well (or piezometer) must be installed which extends from the bottom of the practice to 300 mm above the surface.
- Two water level loggers which are small and relatively inexpensive monitoring equipment need to be installed. One logger is installed in the observation well and the other is installed in a protected open-air space to measure the atmospheric pressure.
- A rain gauge must be in the vicinity, onsite is preferable, but within 1 km is acceptable. The rainfall data and known drainage area are necessary to know for comparison to the water level drawdown data.

The water level data in combination with the rainfall data can then be used to determine how long it took the practice to drain down after the end of an event and what size events resulted in overflows.

Level 5 – Comprehensive Monitoring: Level 5 Monitoring is the most comprehensive and expensive assessment technique and can be used to effectively document water volume reduction and peak flow reduction for most stormwater treatment practices by measuring discharge during natural runoff events.

This level of monitoring is recommended for larger demonstration purposes when a stormwater practice is being implemented for the first time in a specific jurisdiction or development context (e.g. pilot testing of a new technology, challenging soil or geologic contexts, unique or hybrid facility design). It is not intended that this level of monitoring be completed for the first installation of each practice in every jurisdiction, rather to ensure that new and innovative approaches are appropriately evaluated and documented.

Another situation where this level of monitoring might be warranted is if the facility has been designed to meet higher standards due to the sensitivity of the receiving water or the presence of species of concern.

To assess runoff volume and pollutant load reduction, peak flow reduction, or both by monitoring a stormwater treatment practice, the inflow(s) and outflow(s) must be measured or estimated as in determining a water budget. The summation of the inflows can then be compared to the summation of the outflows to determine the runoff volume reduction, peak flow reduction, or both. Level 5 may also include the collection of water quality samples at both inflow and outflow of a LID BMP to demonstrate that the LID BMP is not impacting groundwater (i.e. transferring the pollutants into groundwater), and to measure the pollutant loading changes throughout the proposed LID facility.

Typical urban runoff events are flashy (rapid response) and require continuous flow measurement (or estimation). Pollutant loading changes will require state-of-the-art automated sampling devices to obtain flow-weighted or time-weighted sampling that, coupled with continuous flows, allows estimation of loads and development of Event Mean Concentrations (EMC). Where inflow(s) and outflow(s) are estimated, it is recommended that a verification or assurance process be included such that the estimated flow reflects what is happening in the field. This may include spot measurements, video, photos or field visits during an event.

Besides having considerable additional costs, comprehensive monitoring has more potential for missed or erroneous data as compared to synthetic runoff tests for the following reasons:

- Weather is unpredictable and can produce various runoff volumes of various durations with varying pollutant concentrations at various times.
- In order for a storm event to be monitored correctly and accurately, all the monitoring equipment must be operating correctly and the parameters (water depth, etc.) must be within the quality control limit ranges for the equipment.
- Equipment malfunction due to rodents, electrical interferences, routine wear, storm damage/loss, or vandalism are common.
- State-of-the-art continuous monitoring of stormwater runoff is the most expensive of monitoring techniques as it requires trained technicians, proper installation, frequent inspection, runoff flow-gauging, maintenance and adherence to quality control protocols.

The STEP website, sustainabletechnologies.ca, and the International Stormwater BMP database are publicly available sources of comprehensive LID monitoring data and performance studies.

9.6 Post-Assumption LID Monitoring Programs

Although many of the objectives of conventional stormwater management monitoring will be the same, LID monitoring differs especially in practices that rely on diverting runoff to the natural hydrologic pathways of infiltration and evapotranspiration. Three common types of LID specific monitoring are detailed below.

Infiltration Testing: The ability of infiltration-based LID BMPs such as bioretention facilities and bioswales to reduce runoff rates and mitigate associated pollutant loading is dependent on maintaining infiltration rates. Over the lifecycle of a LID practice, the infiltration rate of bioretention media may be reduced due to clogging at the top of the soil column. A Guelph permeameter test, double-ring or single-ring infiltrometer test as well as others are tools that are used to measure in-situ saturated hydraulic conductivity. A Guelph permeameter test can be used to determine rates at depth, while double-ring or single-ring infiltrometer test can be used to determine rates at the surface. After assumption protocols are met, using this device to test infiltration rates is only necessary if prolonged ponding of water is noted.

Volume Reduction: Reducing rainfall runoff to municipal stormwater systems by promoting infiltration and evapotranspiration is a key component of pollutant load reductions. Pollutant reduction estimates can generally be inferred by measuring the volume reductions over the course of a monitoring period. To determine volume reductions, a water level logger can be installed on an outlet structure or downstream storm sewer with a known stage-discharge relationship. To determine volume reductions, a comparison must be made to the system without the LID BMP. This can be done in several ways:

- Comparisons can be made to a control site. A control site is a similar catchment in close proximity to the LID site that is also equipped with monitoring equipment.
- Comparisons can be made to the site before the LID BMP was constructed (pre-construction). Pre-construction monitoring should cover a sufficient monitoring period to cover a wide-variety of storm durations and intensities.
- Influent and effluent volumes can be compared. This method is preferred because catchment and rainfall variables can be eliminated. This method of comparison is however difficult to facilitate because inflow to LID BMPs is rarely concentrated. It is difficult to accurately gauge flow rates and volumes from sheet flow, curb inlets and direct infiltration (permeable pavement).

Water Quality: The monitoring of stormwater quality constituent concentrations in LID can provide information on effluent concentrations, but neglects loading reductions accomplished via volume reduction. For all infiltration-based LID BMPs, water quality monitoring programs should be conducted concurrently with volume reduction monitoring. Similar to conventional stormwater monitoring programs, representative EMCs are more valuable than grab samples as they represent an average sample across a runoff event as opposed to an instantaneous runoff time during the event.

Water quality monitoring ideally compares influent and effluent quality immediately upstream and downstream of LID treatment features. It may be difficult to collect influent samples from LID BMP where water enters the facility via sheet flow or direct infiltration (permeable pavement). In these cases, a control catchment or historical water quality data from the catchment can be used. Effluent quality monitoring can also be difficult as outlet structures are not always built into the design (e.g. bioretention facilities built in highly permeable soils). Monitoring ports that extend below filter media may need to be built into the design to allow for water quality monitoring. For LID designs that include overflow grates that direct water ponding on the surface of the filter bed to an underdrain or outlet, analysis should be conducted to identify bypasses of the filter media treatment.

9.7 Compliance Monitoring

It is the responsibility of the proponent and owner of a stormwater management facility or system to demonstrate that it will or is performing as designed or intended. The monitoring of stormwater management infrastructure and environmental receivers has provided insight into the effectiveness of stormwater management facilities and BMPs.

With respect to environmental approvals for the treatment and disposal of sewage (including stormwater) by industrial, municipal, and private systems, compliance monitoring may be included as a condition of an environmental compliance approval in order to evaluate whether a stormwater management facility or BMP meets design and environmental performance criteria. The designer is advised to consult with authorities regarding site-specific requirements when applying for an environmental compliance approval.

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APPENDIX 1 – GLOSSARY OF TERMS

Atmospheric Deposition - Atmospheric deposition refers to the phenomenon that deposits pollutants in gases and particulates from the atmosphere on to the earths' surface including fresh water systems.

Biofilter – a stormwater management practice that consists of mulch layer, engineered filter media and vegetation root zone and provides sedimentation and filtration of urban runoff. A biofilter typically features an underdrain and may or may not have an impermeable liner that prevents infiltration of runoff into the underlying native soil.

Bioretention – a stormwater management practice that consists of a shallow excavated surface depression containing a prepared soil mix, mulch, and planted with specially selected vegetation and provides filtration and infiltration for stormwater. The system is engineered to temporarily store runoff in the depression and gradually filters it through the mulch, engineered soil mix, and root zone. They remove pollutants from runoff through filtration in the soil and uptake by plant roots and can help to reduce runoff volume through evapotranspiration and infiltration.

Depression storage – a stormwater management technique that consists of shallow depressed area(s) in 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 draining from the maximum water level and to the minimum level (dry-weather or antecedent level).

Dry Swale – linear bioretention cells that consist of engineered filter media soil mixture and vegetation and designed to convey, treat and attenuate stormwater runoff. It slows the runoff water to allow sedimentation, filtration through the root zone, evapotranspiration, and infiltration into the underlying native soil.

Evapotranspiration is the combination of evaporation of water and transpiration of water from vegetation. 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. For the purpose of this manual, harvested rainwater which is used for irrigation and lost to the atmosphere will be considered as volume retention rather than as evapotranspiration. 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).

Enhanced Grass Swale – vegetated open channels designed to convey, treat and attenuate stormwater runoff, also referred to as enhanced vegetated swales. Enhanced grass swales are not capable of providing the same water balance and water quality benefits as dry swales, as they lack the engineered soil media and storage capacity.

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

Filtration refers to the interception and removal fine particulate material and pollutants from runoff as it passes through an engineered filter media, synthetic filter cells and/or cartridges. Filtered runoff may be collected and returned to the conveyance system or allowed to partially infiltrate.

Grass swales - vegetated, open channels designed to convey, treat and attenuate runoff. Design variations range from simple grass channels, which are designed primarily for conveyance to more complex treatment and volume reduction designs like enhanced grass swales, and dry swales or bioswales.

Green infrastructure (GI) means 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. Depending on its use and context, green infrastructure for stormwater management can also refer to just the human-made (engineered) elements, which is then essentially the same as LID or low impact development.

Green roof – a thin layer of vegetation and growing medium installed on top of a conventional flat or sloped roof, also referred to as living roofs or rooftop gardens.

Infiltration – the entry of water into the site soils or material.

Intensification – development of a property, site or area at a higher density than currently exist through new development, redevelopment (see Redevelopment definition) and revitalization, and includes:

- redevelopment, including the redevelopment of brownfield sites;
- the development of vacant or underutilized lots within previously developed areas;
- infill development - new development on formerly vacant land;

- the conversion or expansion of existing industrial, commercial and institutional buildings for residential use; and,

- the conversion or expansion of an existing residential building or buildings to create new residential units or accommodation, including accessory apartments, second dwelling units and rooming houses.

Impervious Area or Surface – hardened surfaces which do not significantly absorb rainwater and/or are not specifically designed to permit the entry of water.

Linear Development – the construction or reconstruction of roads, rail lines and transit infrastructure that are constructed or reconstructed separate from a new development or re-development project or common plan of development or sale. (Also refer to Section 3.2.2 for additional information)

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 and 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. It has the same meaning as green infrastructure for stormwater management when it is a human-made (engineered) green infrastrcuture.

New Development – means the creation of a new lot, a change in land use, or the construction of buildings and structures commonly requiring approval under the *Planning Act*.

Percolation – the movement of water through soil or media.

Permeable pavement – is an alternative pavement practice to traditional impervious asphalt or concrete pavement, which prevents the generation of runoff by allowing precipitation falling on the surface to infiltrate through the surface course into an underlying stone reservoir and, where suitable conditions exist, into the native soil.

Pollutant load – the total mass of a pollutant entering a waterbody over a defined time period.

Pre-development – is defined as follows for the various development conditions:

- For New Development (i.e. Greenfield Development and or agricultural conversion to urban) - the pre-development impervious condition shall correspond to the current conditions present in the field at the project onset or to an undisturbed forested condition.

- For Redevelopment (existing urban areas) – the pre-development impervious condition shall correspond to the current conditions present in the field at the project onset, or the least urbanized condition (i.e. lowest total impervious percentage for the site) prior to the project onset.

- For Linear Development and retrofits - the pre-development impervious condition for the right-of-way shall correspond to the current conditions present in at the project onset.

Rainwater harvesting – is the practice of intercepting, conveying and storing rainwater for future use. The captured rainwater is typically used for outdoor or non-potable water uses such as irrigation and pressure washing, or in the building to flush toilets or urinals or other uses that do not require potable water.

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

Redevelopment – the creation or alteration of buildings, land uses or lots on land where development has previously occurred, including redevelopment of brownfield and greyfield sites, infill development and intensification. It may also involve the partial or full demolition of a building and/or structure and the assembly of lands for development.

- Brownfields means 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

- Greyfields are previously developed sites that are not contaminated.

Re-use – includes storing stormwater runoff and then using it as a source of water for outdoor or indoor 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 and 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.

Retrofit – construction and/or reconstruction of a municipal stormwater infrastructure within an existing urban area, as new or replacement stormwater infrastructure. (See Section 3.2.3 for additional information)

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

Sewage works - any works for the collection, transmission, treatment and disposal of sewage or any part of such works, but does not include plumbing to which the Building Code Act, 1992 applies

Soil amendment – the practice of adding organic material, such as mulch or compost to soil to improve fertility, and tilling of the native soils to reverse compaction and restore its water retaining capacity.

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

Stormwater management facility – a sewage works for the management of stormwater.

Transpiration – the release of water vapour from plants and animals back to the atmosphere.

Vegetated filter strip – gently sloping, densely vegetated areas that treat runoff as sheet flow from adjacent impervious areas. They function by slowing runoff velocity and filtering out suspended sediment and associated pollutants, and by providing some infiltration into underlying soils. Also known as buffer strips and grassed filter strips.

Water balance – the accounting of inflow and outflow of water in a system according to the components of the hydrologic cycle.

Water budget – the mathematical expression of the water balance.

Water table – the water table in an unconfined aquifer occurs at the depth below ground surface where the pore water pressure is equal to atmospheric pressure.

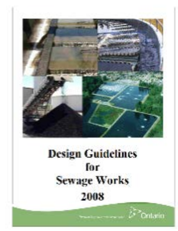
Watershed – An area of land that drains into a river or a lake. The boundary of a watershed is based on the elevation (natural contours) of a landscape.

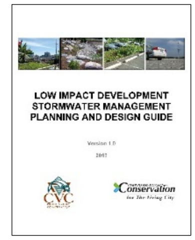
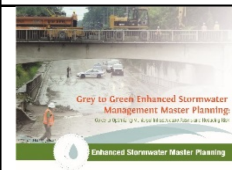
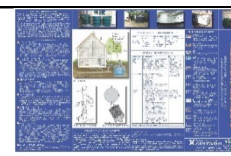
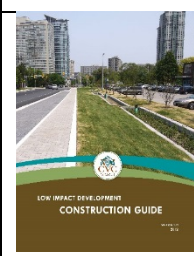
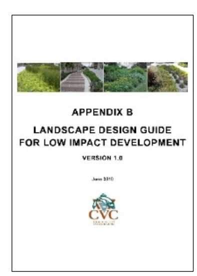
APPENDIX 2 – LIST OF ABBREVIATIONS AND ACRONYMS

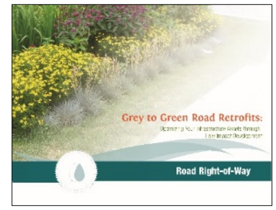
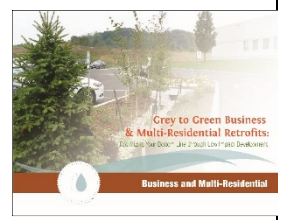
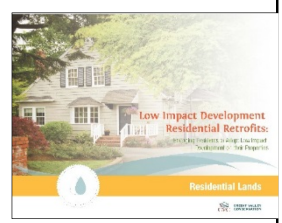
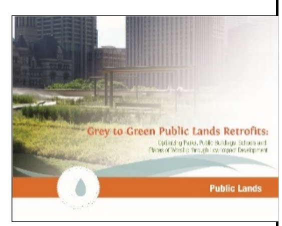
AET	Actual evapotranspiration
BMP	Best management practice
CA	Conservation authority
CEC	Cation Exchange Capacity
cm	Centimetre
CCCMA	Canadian Centre for Climate Modelling and Analysis
C of A	Certificate of Approval
CWP	Center for Watershed Protection
CVC	Credit Valley Conservation
CSO	Combined sewer overflow
ECA	Environmental compliance approval
EIS	Environmental impact statement
EPA	Environmental Protection Act
EPA	Environmental Protection Agency, U.S. EPA or USEPA
ESGRA	Ecologically Significant Groundwater Recharge Area
GI	Green Infrastructure
GCM	Global Climate Model
GDE	Groundwater Dependant Ecosystems
GHG	Greenhouse gas
hr	Hour
HRU	hydrologic response units
HVA	Highly Vulnerable Aquifers
HSG	Hydrologic soil group
ICA	Issue Contributing Area
IDF	Intensity-duration-frequency
IPZ	Intake Protection Zones
L	Litre
LSPP	Lake Simcoe Protection Plan
LID	Low impact development
m	Metre
mm	Millimetre
MEP	Maximum extent possible
MIT	Minimum interevent time
MECP	Ontario Ministry of the Environment, Conservation and Parks
MTO	Ontario Ministry of Transportation
N	Nitrogen
O&M	Operation and maintenance
OMAFRA	Ontario Ministry of Agriculture, Food, and Rural Affairs
MMAH	Ontario Ministry of Municipal Affairs and Housing

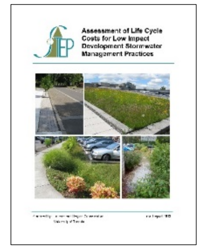
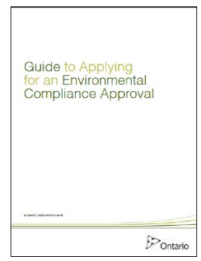
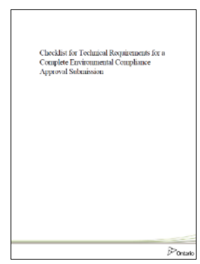
MNDMNRF	Ontario Ministry of Northern Development, Mines, Natural Resources and Forestry
OPSS	Ontario Provincial Standard Specification
OWRA	Ontario Water Resources Act
RFS	Rainfall Frequency Spectrum
ROW	Right-of-way
P	Phosphorus
PAH	Polycyclic aromatic hydrocarbons
PET	Potential rates of evapotranspiration
PICP	permeable interlocking concrete pavers
PPS	Provincial Policy Statement
PWGMN	Provincial Groundwater Monitoring Network
PWQO	Provincial Water Quality Objective
RCM	Regional Climate Model
s	Second
SGRA	Significant Groundwater Recharge
SS	Suspended solids
STEP	Sustainable Technologies Evaluation Program
TP	Total phosphorus
TRCA	Toronto and Region Conservation Authority
U.S. EPA	United States Environmental Protection Agency
USEPA	United States Environmental Protection Agency
WHPA	Wellhead Protection Areas
WWIS	Water well information system
yr	Year

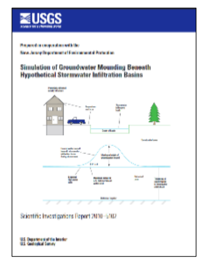
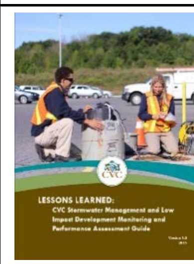
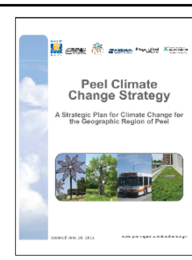
APPENDIX 3 – RESOURCE DIRECTORY

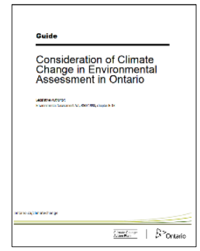
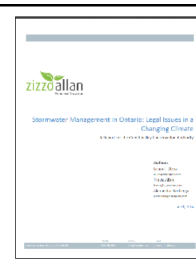
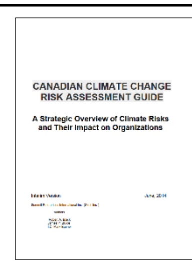
Provincial Manual	Stormwater Management Planning and Design Manual (MOE, 2003) https://www.ontario.ca/document/stormwater-management-planning-and-design-manual-0	
Provincial Manual	Design Guidance for Sewage Works (MOE, 2008) https://www.ontario.ca/document/design-guidelines-sewage-works-0	
Groundwater Data & Studies	Well Records ontario.ca/page/well-records Description of a Tier 1 level water budget - Central Lake Ontario http://www.ctcswp.ca/wp-content/uploads/2016/03/CLOCA-Tier1-SPC-Presentation.pdf. Example Tier 2 water budget study for the Grand River watershed https://www.grandriver.ca/en/our-watershed/resources/Documents/Water_Supplies_Tier2.pdf. Example Tier 3 water budget - York Region http://www.ctcswp.ca/wp-content/uploads/2014/08/RPT_20131114_Earthfx_York_Tier3 WBLocAreaRiskAssFNL.pdf.	

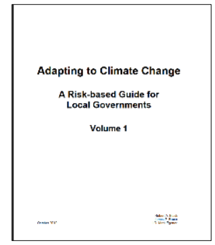
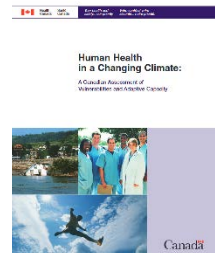
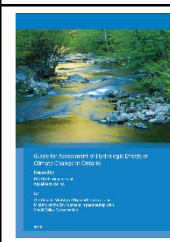
Planning and Design Guide	Low Impact Development Stormwater Management Planning and Design Guide (TRCA/CVC, 2010, Version 1.0) http://sustainabletechnologies.ca/wp/wp-content/uploads/2013/01/LID-SWM-Guide-v1.0_2010_1_no-appendices.pdf	
Planning and Design Guide	https://wiki.sustainabletechnologies.ca/wiki/Main_Page	
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) http://www.sustainabletechnologies.ca/wp/wp-content/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	
Environmental Compliance Approval Submission Checklist	Checklist for Technical Requirements for Complete Environmental Compliance Approval Submission https://www.ontario.ca/document/checklist-technical-requirements-complete-environmental-compliance-approval-submission	
Standard	CSA Group: https://www.csagroup.org/ CSA W200 – Design of Bioretention Systems CSA W201 – Construction of Bioretention Systems CSA W202 – Erosion and Sediment Control, Inspection and Monitoring CSA W204 – Flood resilient design of new residential communities CSA W205 – Erosion and sedimentation management for northern community infrastructure CSA B184 Series – Polymeric Subsurface Stormwater Management Structures	

	CSA/ICC B805 – Rainwater Harvesting Systems CSA PLUS W4013 – Development, Interpretation and use of Rainfall Intensity-Duration-Frequency (IDF) Information: Guideline for Canadian Water Resources Practitioners	
Standard	CSA Group: https://www.csagroup.org/ Under Development at time of printing: Erosion and Sediment Control, Installation and Maintenance	
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	
Monitoring Guide	CVC Stormwater Management and Low Impact Development Monitoring and Performance Assessment Guide (2015, V1.0) http://www.creditvalleyca.ca/wp-content/uploads/2016/06/Monitoring_Guide_Final.pdf	
Climate Change	Region of Peel Climate Change Strategy (2011) https://www.peelregion.ca/planning/climatechange/reports/pdf/climate-chan-strat-rep.pdf	

Climate Change and Environmental Assessment Guide	Considering climate change in the environmental assessment process (updated 2019) https://www.ontario.ca/page/considering-climate-change-environmental-assessment-process	
Climate Change Tool	PIEVC Engineering Protocol for Infrastructure Vulnerability Assessment and Adaptation to a Changing Climate Change https://pievc.ca/ https://pievc.ca/sites/default/files/pievc-protocol-principles-guidelines-june-2016-part_1-e.pdf	
Climate Change Guide and Tool	Changing Climate, Changing Communities: Guide and Workbook for Municipal Climate Adaptation http://www.icleicanada.org/images/icleicanada/pdfs/GuideWorkbookInfoAnnexes_WebsiteCombo.pdf Building Adaptive and Resilient Communities (BARC) On-line Tool: http://www.icleicanada.org/adaptationtool/introduction	
Climate Change	Stormwater Management in Ontario: Legal Issues in a Changing Climate (2014) http://www.creditvalleyca.ca/wp-content/uploads/2014/05/Stormwater-Management-in-Ontario_Legal-Issues-in-a-Changing-Climate_2014.04.29.pdf	
Climate Change Guide	Canadian Climate Change Risk Assessment Guide (2014) https://www.iclr.org/images/CC_Risk_Assessment_Guide_Interim2_Jun_8_14_.pdf	

Climate Change Guide	Adapting to Climate Change: A Risk-based Guide for Local Governments Volume 1 https://www.fcm.ca/Documents/tools/PCP/Adapting_to_Climate_Change_a_Risk_Based_Guide_for_Local_Governments_EN.pdf	
Climate Change Guide	Human Health in a Changing Climate: A Canadian Assessment of Vulnerabilities and Adaptive Capacity (2008) http://publications.gc.ca/collections/collection_2008/hc-sc/H128-1-08-528E.pdf	
Climate Change Guide	Guide for Assessment of Hydrologic Effects of Climate Change in Ontario http://waterbudget.ca/climatechangeguide	
Climate Change Data (modelling)	Downscaled data sets from Global Climate Models (GCMs) Ontario Ministry of Northern Development, Mines, Natural Resources and Forestry http://climate.aquamapper.com/ Ontario Climate Data Portal www.ontarioccdp.ca Predicted IDF Curves under Climate Change IDF CC Tool University Wester Ontario and the Canadian Water Institute http://www.idf-cc-uwo.ca/default.aspx	

	Ontario Ministry of Transportations' IDF Curve Lookup www.mto.gov.on.ca/IDF_Curves/	
Other Climate Change Tools & Resources	ISO 31000 Risk Management https://www.iso.org/iso-31000-risk-management.html Canadian Institute of Planners Policy of Climate Change Model Standard of Practice Climate Change Adaptation Plans Case Studies https://www.cip-icu.ca/ClimateChange# Soak it Up! toolkit developed by Green Communities Canada http://www.raincommunitysolutions.ca/en/toolkit/.	
Planning Level Modelling Tool (Class A)	LID Treatment Train Tool (LID TTT) http://www.sustainabletechnologies.ca/wp/low-impact-development-treatment-train-tool/	
LID Performance Resources	Sustainable Technologies Evaluation Program available http://www.sustainabletechnologies.ca/wp/publications/ https://sustainabletechnologies.ca/app/uploads/2019/10/STEP_Bioretention-Synthesis_Tech-Brief-New-Template-2019-Oct-10.-2019.pdf 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.	

	USEPA data quality assessment: statistical methods for practitioners: https://www.epa.gov/sites/production/files/2015-08/documents/g9s-final.pdf Landscape Architecture Foundation: Evaluating Landscape Performance: A guidebook for methods and metrics selection. 2018	
Other Resources	Sustainable Technologies Evaluation Program (STEP): www.sustainabletechnologies.ca/ STEP Resources, Studies and Reports: Green Infrastructure Map Stormwater Infiltration in Cold Climates Review (2009) Stormwater Management and Watercourse Impacts: The Need for a Water Balance Approach Preserving and Restoring Healthy Soil: Best Practices for Urban Construction LID Discussion Paper Urban Water Balance LID "Barrier Buster" fact sheet series STEP Featured Studies and Resources: Bioretention and Rain Gardens Green Roofs Soakaways, Infiltration Trenches and Chambers Permeable Pavement Swales and Roadside Ditches Perforated Pipe Systems Rainwater Harvesting Residential Stormwater Landscaping Water Balance for the Protection of Natural Features	

APPENDIX 4 – LID ECONOMICS

When focusing on individual budget line items for capital projects, one tends to assume that LID BMPs increase project costs, however past project experience in Ontario, Canada and the United States have repeatedly shown that by implementing well-chosen, planned and sited LID BMPs can save money for developers, property owners, and communities while protecting and restoring water quality (EPA, 2007; CMHC, 2017 and CVC, 2014). Appendix 4 provides cost information related to LID and conventional stormwater management facilities.

When discussing the cost economics of LID BMPs, it is important to recognize and acknowledge several fundamental concepts:

LID BMPs can cost more to construct and maintain, but they do not have to. Implementation costs vary significantly between the various individual LID BMPs, with green roofs, permeable pavements and rainwater harvesting representing higher cost LID BMPs and downspout disconnection, soil amendments and soakaways representing lower cost LID BMPs. With more than a dozen LID BMPs to choose from (including the better site design approaches), careful evaluation and selection by practitioners will result in the best and least costly approach being selected to meet the required targets.

Comparisons of costs for LID BMPs vs. conventional practices (or business as usual) using different SWM targets and criteria is not a realistic or accurate way to compare project costs. Project approaches must provide the same function i.e. water quality control, water balance etc. and must at a minimum achieve the minimum requirements. It's important to recognized that municipal stormwater management systems provide protection of Ontario's environment and valuable service to the people and businesses in the community when they are built and operated to meet the objectives of stormwater management outlined in Section 1.3. A stormwater management system that achieves many, if not all of the objectives of stormwater management provides a higher level of protection of the environment and as well can have economic benefits that may be appropriate to consider as part of benefit-cost analysis for stormwater management systems.

Assessment of LID BMPs costs can be significantly influenced by personal attitudes towards the technology relating to risk, reliability, performance and operation and maintenance resulting from a lack of knowledge or experience. Many resources are available which can help to overcome and address these issues and provide practitioners with confidence in their design or strategy (see the Resource Directory).

Excessive water quality treatment redundancies can lead to the design and construction of unnecessary or duplicate infrastructure which will significantly increase project costs. Canadian and US LID BMP performance data is widely available, including for cold climates, and can be used to provide practitioners, agencies and approval staff with confidence in the proposed design or strategy which can help to eliminate the need to duplicate infrastructure. Custom elements within LID BMPs can significantly increase capital and life cycle costs. Consider using standard products or elements within designs to limit project cost, provided they provide a similar function that does not compromise the LID BMP.

Savings will continue as costs for LID technologies such as permeable pavement and bioretention media decrease with demand. For example, in 2005, the City of Chicago paid about $145 (USD) per cubic yard of permeable concrete and in one year the cost dropped to only $45 per cubic yard (LID Centre, 2008).

While cost analysis are project or site specific, additional information and examples of capital costs, life cycle costs and O&M costs are provided below.

Capital Costs

In many cases LID BMPs can be constructed with less expense than conventional drainage infrastructure for both new developments and retrofits, including LID BMPs constructed within road ROW. Capital cost savings can be directly linked to the key principles of LID discussed in Section 1.5 and the use of better site design approaches described in Section 1.5.1.1, as well as resulting from:

- Reduced land clearing and excavation costs,
- Reduced infrastructure costs (reduced pipe lengths and fewer below-ground infrastructure requirements). From a lifecycle cost perspective, LID can reduce development costs because it can reduce the need for conventional infrastructure, such as curbing, piping, ponds, and catch basins (NOAA, 2011).
- Reduced impervious area which lowers runoff volumes and directly reduces the size of infrastructure required (i.e. pipe sizes and storage volume requirements)

A seminal study by the U.S. EPA entitled Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices (2007) was developed to overcome the preconceived notion that LID BMPs were too costly to construct. The study examined seventeen Greenfield and Redevelopment case studies from the U.S.A and Canada and provided a comparison of the construction costs of LID versus conventional stormwater management design. On average, the EPA found a construction cost savings ranging from 15% to 60%, with an average of 25% using LID BMPs as compared to conventional stormwater management. Table A4.1 provides a summary of the EPA study, and has been updated with additional case studies from Canada and the United States, with ROW project costs highlighted.

Table A4.1 - Summary of Construction Cost Comparison for Selected LID Case Studies

Project	Project Type and LID Technology	Conventional Stormwater Management Cost	LID Cost	Cost Difference	Cost Savings
SEA Street Retrofit, WA	ROW Retrofit 1,3,4,6	$868,803	$651,548	$217,255	25%
Crown Streets, BC	ROW Retrofit 1, 6	$364,000	396,000	-$-32,000	-9%
Lakeview ROW Retrofit, ON	ROW Retrofit 1,5A, 9	$795,507	$772,466	$23,042	3%
Elm Dr ROW Retrofit, ON	ROW Retrofit 1, 5A	$1,090,000[†]	$895,000	$195,000	18%
Habitation Jean Mance, Montréal, QC, (2010)	Institutional (Community Housing) Redevelopment 1,3,4,6	$350,000	$250,000	$100,000	28%
Credit Valley Conservation Head Office, Mississauga, ON	Institutional Redevelopment 4, 5A, 11	$unknwn *	$91,500	$unknwn *	n/a
Boulder Hills - Roadway, sidewalk & driveway, NH	New ROW 5B	$4,389,454	$4,340,326	$49,128	1%
Bellingham, WA	Institutional Parking Lot Retrofit 1	$27,600	$5,600	$22,000	80%
Tellabs Corp. Campus, IL	New Commercial 1,4,6,7	$3,162,160	$2,700,650	$461,510	15%
Greenland Meadows, NH	New Commercial 5B	$10,590,300	$9,660,300	$930,000	9%
Bellingham Donovan Park	New Commercial 1	$52,800	$12,800	$40,000	76%
Prairie Glen, IL	New residential & commercial 1,2,3,4,6,7	$1,004,848	$599,536	$405,312	40%
Auburn Hills, WI	New Residential 1,3,4,6,7	$2,360,385	$1,598,989	$761,396	32%

Project	Project Type and LID Technology	Conventional Stormwater Management Cost	LID Cost	Cost Difference	Cost Savings
LID Subdivision – Frederick, MD	New Residential	$unknwn *	$ -360,000	$360,000	n/a
Somerset, Maryland	New Residential 1,4	$2,456,843	$1,671,461	$785,382	32%
Gap Creek, ARK	New Residential 6, 10	$4,620,600	$3,942,100	$678,500	15%
Laurel Springs, WA	New Residential 1,2,3,4	$1,654,021	$1,149,552	$504,469	30%
Popular Glen, NC	High Density Residential 1,4,7	$unknwn *	$unknwn *	$175,000	72%
Mill Creek, IL	New Mixed use Residential 2,3,4	$12,510	$9,099	$3,411	27%

1-Bioretention, 2-Reduced lot area, 3-Reduced Impervious Area, 4- Swale, 5-Permeable Pavements (A – pavers, B- asphalt, C- concrete), 6-Vegetative Landscaping, 7-Wetlands, 8-Green roofs, 9 – Perforated Pipes, 10 – Reduced Roadway width (non-standard), 11- RWH
* Cost unknown or not published.
† Assumes construction of end-of-pipe facility to provide equivalent level of stormwater treatment
Source: US EPA (2007), CHHC (2017-18), (CVC, n.d.)

Conclusions from the 2007 EPA document, reiterated in literature and in other Canadian municipalities, are as follows:

- In the vast majority of cases, implementing well-chosen LID BMPs saves money for developers, property owners, and communities while protecting and restoring water quality.
- Site specific factors influence project outcomes, but in general, for projects where open spaces were preserved and cluster development designs employed as part of better site design, infrastructure costs were lower.
- In some cases, initial costs might be higher because of the cost of green roofs, increased site preparation costs, or more expensive landscaping practices and plant species. However, in the vast majority of cases, significant savings were realized during the development and construction phases of the projects due to reduced costs for site grading and preparation, stormwater infrastructure (pipes, inlets, outlets, etc.) site paving, and landscaping.

Capital Costs – Road Right-of-Ways (ROW)

The implementation of LID BMPs as part of municipal road works projects has been shown through studies and construction projects in Ontario (Table A4.1 and others) that capital costs can be neutral to or slightly higher than the cost of upgrading a municipal road ROW with a traditional storm sewer system design when construction is undertaken as part of planned or routine ROW activities. As discussed previously, with multiple LID BMPs to choose from (including the better site design approaches), careful evaluation and selection by practitioners will result in the best and least costly approach being selected to meet the required targets.

The incremental capital costs of implementing LID BMPs as part of road resurfacing and reconstruction project is demonstrated in Table A4.2.

Table A4.2 - Average Incremental Construction Cost to Implement LID BMPs as part of Planned or Routine Road Works

Treatment Measure	Road Resurfacing (percentage of $ increase)	Road Reconstruction (percentage of $ increase)
Bioretention	14%	6%
Dry Swales (bioswales)	n/a	11%
Perforated Pipe	n/a	0%

In general, where added costs are to be incurred in the implementation of LID BMPs within the road ROW, these costs can generally be attributed to greater level of water quality control treatment provided as well as the decrease in stormwater runoff volumes. Additional costs associated with perforated pipe systems, bioretention and dry swales (bioswales) are generally offset by savings in:

- traditional storm sewer required as part of the road works; and
- end-of-pipe infrastructure required to provide equivalent water quality control for the collected drainage area (wet ponds, wetland and or underground end-of-pipe facilities) at the end of the drainage system.

Lifecycle Costs

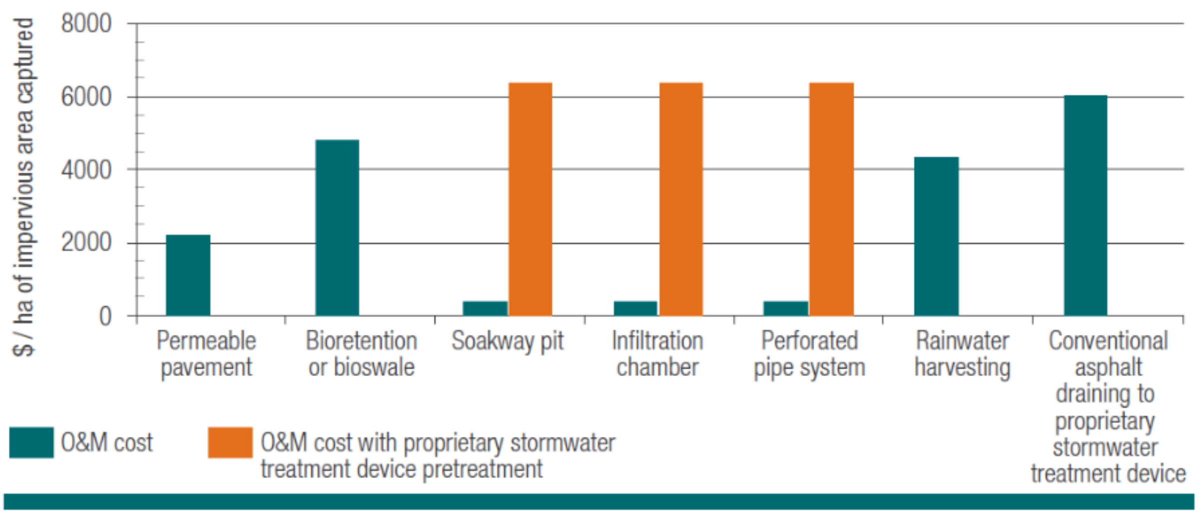
A recent Canadian study conducted by the Sustainable Technology Evaluation Program (STEP) compared all costs associated with a variety of LID BMPs over a 50-year life cycle (TRCA/ STEP 2013). For a link to this study, see the Resource Directory.

These costs included O&M activities expected both annually and at less frequent intervals. Figure A4.1 prorates these annual costs based on a 1 ha impervious drainage area. For this figure, perforated pipe systems, though not included in the STEP study, were assumed to have similar annual maintenance to that of a soakaway.

It should be noted that for soakaways, infiltration chambers and perforated pipe systems, O&M costs are greatly reduced when the catchment areas are restricted to relatively clean sources of water such as roofs and pedestrian areas. When a proprietary stormwater treatment device unit was used for pre-treatment of parking lot and road sources, costs were much higher.

The STEP study also found that although the capital cost of the asphalt and proprietary stormwater treatment device option was less than all LID options (except for the enhanced swale), the permeable pavement, infiltration trench with inlet, and enhanced swale options showed lower life-cycle costs largely due to reduced O&M and rehabilitation costs. When the same practices are compared based on dollars spent per kilogram of annual suspended solid load reduction, all LID options are more cost effective than conventional asphalt draining to a proprietary stormwater treatment device unit.

Figure A4.1: Annual O&M cost per ha of Impervious Area (Source: TRCA/STEP,2013; CVC, n.d.)



O&M Costs

Generally, LID BMPs have lower long-term life cycle costs, perform better and provide additional community benefits as compared conventional stormwater infrastructure. LID BMPs generally have a lower initial cost (see Table A4.1) with operation and maintenance costs typically separated by the extent and type of vegetation incorporated into the design.

LID BMPs vegetated with perennials, shrubs and trees typically require more ongoing maintenance in the early years of establishment, whereas turf area require substantially less. After they are established the maintenance requirements of most LID BMPs have little difference from most turf, landscape or natural areas and do not require new or specialized equipment. See Chapter 8 for additional discussion regarding O&M.

LID BMPs such as perforated pipe systems and permeable pavements typically have the lowest operation and maintenance costs. In fact, a substantial benefit of porous asphalt is the reduced need for de-icing in winter. Researchers observed that winter maintenance of porous asphalt requires between zero and 25% of the salt routinely applied to impervious asphalt to achieve equivalent, or better, de-icing and traction (UNHSC, 2007) and the maintenance cost of permeable concrete sidewalks in Olympia, Washington was found to be 9% less than traditional concrete sidewalks (EPA, 2008).

O&M - LID BMPs vs. Stormwater Management Ponds

As summarized in the Low Impact Development Road Retrofits: Optimizing Your Infrastructure through Low Impact Development (CVC) – See the Resource Directory - municipalities who are concerned that LID results in increased maintenance costs need only consider the large-scale and complex rehabilitation activities required for conventional stormwater management ponds to realize how LID can save money.

To maintain design depths, stormwater management ponds require sediment removal, which is typically the responsibility of the municipality. Since some Ontario municipalities have not yet planned or executed these activities, the life-cycle costs of maintaining these ponds are largely unknown. However, there is a growing concern that dredging and disposal will be costly, particularly if the sediment is contaminated and requires specialized disposal.

Maintenance of ponds also plays a crucial role in meeting the requirements of environmental compliance approvals. A recent Lake Simcoe Region Conservation Authority (LSRCA) study found the effluent water quality of wet ponds deteriorates over time due to sediment accumulation and other chemical processes within the pond so that wet ponds can transform particulate phosphorus into dissolved phosphorus discharged to receiving water bodies if not properly maintained. In general, reduction of the wet storage area in wet ponds due to sediment accumulation tends to reduce the water quality and quantity control capacity of the facility and increases erosion and flood risk.

The LSRCA study found that the costs for pond maintenance can range from $267,000 up to $1.6 million. In comparison, the Toronto and Region Conservation Authority (TRCA) found that maintenance costs for LID within road right of ways varied from an average of $732 per 100m^2 per year for bioretention to $1,255 per 100m^2 per year for infiltration trenches and chambers over the life of the practices (50 years).

APPENDIX 5 – MODEL SELECTION, DEVELOPMENT AND DATA AVAILABILITY

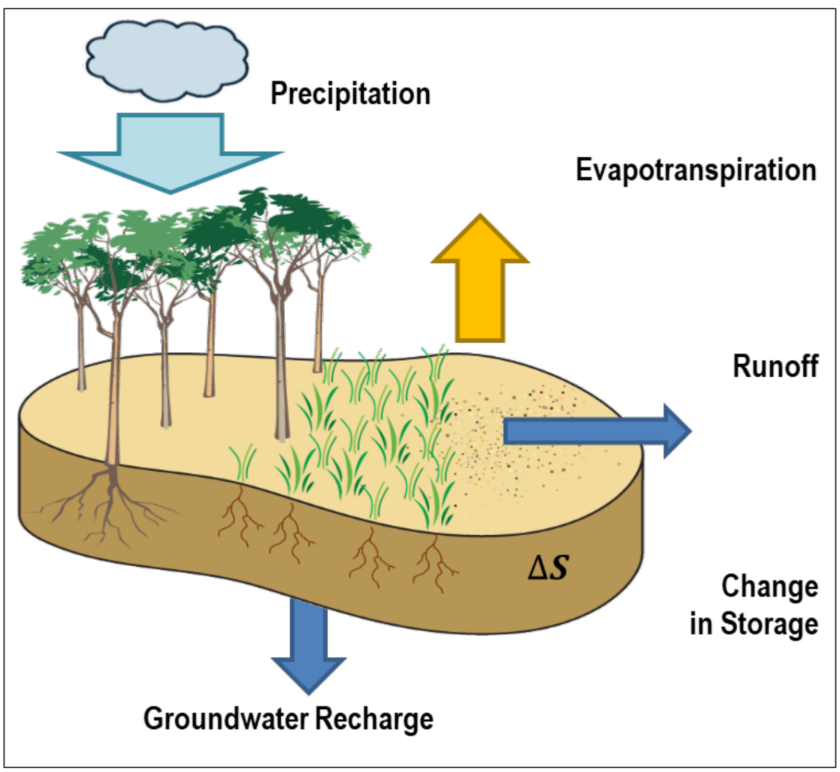
A5.1 Model Types

In this section of **Appendix 5**, each class of model is briefly described and examples are presented illustrating the level of detail provided for LID assessment. Broadly, each class reflects a family of tools with a similar level of explanatory power. The classification of the model types follows a basic hierarchy shown in Figure 5.1 of Chapter 5.

A5.1.1 Class A: Water Balance Frameworks

A water balance framework can be used to quantify the site-scale water budget at a basic level. In simplest terms, a water balance sums up the flows contributed by each of the components of the hydrologic cycle, attempting to balance precipitation inputs with losses such as runoff or evapotranspiration and/or changes in soil water storage (Figure A5.1). They can be used to determine amounts of water that should be infiltrated to compensate for reductions caused by increased paved areas and rooftops and/or changes to vegetation (MOE, 2003). The water balance approach was originally developed by Thornthwaite and Mather (1957) and has been widely applied in Ontario. Many other, more rigorous approaches have since been developed. Water balance calculations can be done using a spreadsheet or simple computer codes.

Figure A5.1 - Hydrologic components of simple water balance (modified from Toews, 2007)



Key model inputs include daily or monthly temperature and precipitation, along with estimates for parameters controlling canopy interception losses, depression storage losses, infiltration, overland runoff, potential and actual evapotranspiration, and soil water holding capacity. Estimates of controlling parameters can be obtained from regional mapping of soils and surficial sediments, modelling studies in similar settings, or book values. Local site investigations are recommended for ground truthing of information derived from regional mapping.

Critical outputs from the water balance include daily or monthly estimates of infiltration, overland runoff, actual evapotranspiration, and groundwater recharge. Model parameter estimates can be refined through model calibration, by adjusting parameter values within reasonable ranges until the water balance matches observed outputs such as gauged streamflow and estimated baseflow at outlets from the model area.

The water balance framework has modest data requirements and has been employed in the analysis of small development sites for relatively simple assessments of pre- and post-development conditions. The methods, however, are generally unsuitable for complex settings or larger-scale problems because they do not account for variation in the physical setting across the site or the spatial variability of the controlling parameters. There is no standardized format for a water balance calculation; the processes represented, or the level of detail within each component and the hierarchy of processes can vary widely from model to model. A good overview of the water balance framework approach, prepared as part of the Toronto and Region Conservation Authority (TRCA) Sustainable Technologies Evaluation Program, can be found in Gartner Lee Limited (2006). A brief introduction to water balance concepts is presented below.

Basic Function

The primary input of most water balances is daily or monthly precipitation (rainfall plus the equivalent water contributed by snow) and temperature. Some of the precipitation can be intercepted by trees and shrubs (interception storage). This water is assumed to be lost to evaporation over time. Rainfall in excess of available interception storage is termed throughfall or net precipitation. Some of the more complete water balance frameworks consider snowpack accumulation and melt which are critical processes to consider when computing an annual water balance in Ontario. Throughfall can be added to the snowpack in winter months (based on the input temperature) or applied directly to land surface in warmer months. Snowmelt is added to throughfall in spring until the snowpack is depleted.

Water falling directly on land surface can be captured by leaf litter and by small depressions (collectively referred to as depression storage) on pervious and impervious surfaces. Water in depression storage is assumed to be lost to evaporation over time, although some models assume that some depression storage can be lost as infiltration to the underlying soil zone. Water in excess of depression storage can be partitioned between infiltration and overland runoff. More complex models use physical relationships to determine the infiltration capacity of the soil. Runoff (referred to as infiltration-excess or Hortonian runoff) occurs when the rainfall rate exceeds the infiltration capacity of the soil. Simpler models use infiltration factors, runoff factors, or Soil Conservation Service Curve Number (CN) to partition infiltration and runoff. Typical Infiltration factors for Southern Ontario (modified from Table 3.1 in MOE 2003) are provided in Table A5.1. Hortonian runoff can be high in urban areas due to impervious surfaces and compacted soils. Runoff can also occur when the soils are saturated (either locally due to perched water table conditions or due to a high regional water table). Saturation-excess runoff (also referred to as Dunnian runoff) often occurs in lowland areas and riparian areas adjacent to streams. However, processes controlling Dunnian runoff are rarely represented in simple water balance frameworks. Regardless of the generating mechanism, overland runoff is assumed to eventually arrive at a stream or other water body.

A portion of the water infiltrating the soil can be lost through the combined processes of evaporation and transpiration (evapotranspiration). Potential rates of evapotranspiration (PET) can be estimated from observed pan evaporation data or by theoretical relationships between temperature, humidity, incoming solar radiation, wind, and crop type. These relations are of varying complexity and simple water balance frameworks typically use relationships dependent on temperature and solar radiation (often estimated based on the hours of sunshine per day at the latitude of the site). Actual evapotranspiration (AET) is typically often lower than PET because the amount of water available in the soil may not be sufficient to meet the ET demand. Water is retained in the soil zone against gravity by capillary forces. The volume retained is defined as the “field capacity” of the soil which is high for fine-grained soils (silts, clays, and loams) and lower for sands and gravels. Water can be extracted from the retained soil water by plant roots until the soil dries to the “wilting point” whereupon ET is curtailed.

Water in excess of field capacity is assumed to drain rapidly and can be further partitioned into water available for percolation (vertical movement through the unsaturated zone above the water table) and interflow (water moving laterally through the soil zone to reach a stream or other water body). Percolating water eventually reaches the water table as groundwater recharge. Interflow is not explicitly represented in many water balance frameworks, and usually lumped with recharge or percolation processes. Groundwater recharge is eventually conveyed to streams and emerges as groundwater discharge. Groundwater discharge is a large component of baseflow in Ontario streams.

A simple site-based water balance for an area can be written as:

Inputs = Outputs + Change in Storage

$$P = Int + AET + DS + IF + GW + RO + \Delta s$$

Here:	P	=	precipitation
	Int	=	interception by the vegetative canopy (lost to evaporation)
	AET	=	actual evapotranspiration

DS	=	depression storage on impervious surfaces (lost to evaporation)
IF	=	interflow to streams
GW	=	groundwater discharge
RO	=	overland runoff to streams (Hortonian and Dunnian)
Δs	=	change in groundwater and soil moisture storage

Solving for the change in storage, this equation can be written as:

$$\Delta s = P - Int - AET - DS - IF - GW - RO$$

The storage term (Δs) reflects that, due to seasonal or year to year variations in precipitation, annual or shorter-term water budgets may not balance exactly. Water can be stored in the system in wet periods as a temporary increase in the soil moisture and/or an increase in groundwater levels compared to long-term average levels. During dry periods, water is removed from storage by decreasing soil moisture and lowering of groundwater levels.

Water balances can be done at different time scales, continuous water balance models operating on daily or monthly time steps are used to estimate the seasonal variability of soil moisture and AET. Models can also be developed on a long-term average annual basis where natural changes in storage are assumed to be small.

Anthropogenic changes can affect components of the water balance, for example by increasing depression storage losses (from impervious surfaces), and Hortonian runoff through increased imperviousness. These changes must be balanced by a decrease in other components such as decreased infiltration and soil moisture with a corresponding decrease in groundwater discharge to streams. Similarly, deforestation will decrease canopy interception and AET, leading to increased runoff and, depending on soil conditions, some increase in baseflow.

Table A5.1 - Typical Infiltration factors for Southern Ontario (modified from Table 3.1 in MOE 2003)

Factors	Description	Infiltration Factor
Topography	Flat land, average slope < 0.6 m/km	0.3
	Rolling land, average slope 2.8 m to 3.8 m/km	0.2
	Hilly land, average slope 28 m to 47 m/km	0.1
Non-Frozen Soils	Tight impervious clay	0.1
	Medium combinations of clay and loam	0.2
	Open Sandy loam	0.4
Cover	Cultivated Land	0.1
	Woodland	0.2

Note: The infiltration factor (F_{INFIL}) is determined by summing a factor for topography, soils and cover. The overland runoff factor is equal to 1- F_{INFIL}.

LID Representation Within Water Balance Models

Evaluating the effectiveness of LID BMPs can be done within the water balance framework. The standard methodology is to do a “with” and “without” comparative analysis. A baseline scenario would be done to represent current or “pre-development” conditions. For example, if a farm property is being converted to a residential development, a baseline analysis would compute the monthly water balance for the area based on reasonable estimates of the current canopy cover, percentage impervious cover, depression storage, runoff factors, soil moisture retention, and potential ET demand. The monthly water balance analysis would then be re-computed but with adjustments to canopy cover, percentage impervious cover, depression storage, and runoff factors to account for changes likely to occur under “post-development with no LID BMPs” conditions. Computed values for the water balance components (e.g., total runoff and recharge) for the post-development scenario would be subtracted from the baseline to determine the likely change. The monthly water balance analysis would be re-computed for a third scenario with adjustments to canopy cover, percentage impervious cover, depression storage, and runoff factors to account for changes likely to occur under “post-development with LID BMPs” conditions. The third scenario would be compared to the baseline to determine final values for the change in water balance components. The third scenario would also be compared to the second to determine how effective the LID BMPs were in mitigating any adverse changes. An example is presented below illustrating how the method is applied.

Representing LID BMPs within a water balance model depends on the complexity of the model selected and the type of LID measure being represented. For example, if the water balance considers canopy interception in the computation, then LID BMPs that increase canopy cover (e.g., tree plantings) can be represented. For example, if the predevelopment conditions have a woodlot with 25% coverage that yields an estimated summer interception of 5 mm per month, then removing 40% of the trees could be assumed to reduce interception losses by a similar ratio (to 3 mm/month). If the LID BMPs include planting across the site to restore the coverage back to 20% then the interception loss would be increased to 4 mm/month (note, this doesn’t consider the period during which vegetation grows to full maturity.) In a similar manner, changes such as adding rain barrels or green roofs that store water falling on impervious rooftops could be represented with depression storage. Bioswales (i.e., areas that infiltrate water that would have otherwise run off impervious areas) can be represented by decreasing the effective impervious area. Although this scaling approach to estimating the effects of LID BMPs does not provide detailed spatial representation of where these features are implemented, the approach is consistent with the simplicity inherent in the water balance method.

Example: Spreadsheet Water Balance

Tables A5.2 and **A5.3** present a hypothetical example for a small-scale development with 40% of the area converted from vacant land in an upland area (with poor mixed shrub and tree coverage) to impervious surfaces. The LID BMPs include tree planting, porous pavement for driveways, bioswales to infiltrate roof runoff, green roofs on the multiple housing units, and a rain garden to infiltrate the additional road runoff. The climate data are the monthly average rainfall for Toronto based on 30-year climate averages (normals). Climate normals for Environment and Climate Change Canada stations in Ontario can be found at http://climate.weather.gc.ca/climate_normals/index_e.html (climate inputs are discussed further in Section A5.3.1 and in Section 6.9.2).

Table A5.2 - Simple spreadsheet based water balance example

SIMPLE MONTHLY WATER-BALANCE MODEL - Existing Conditions		Location		Latitude		Max. Soil Moisture (SM_{Max})				Runoff Factor (RF)			
		Toronto		43.8 degree			25 mm					0.10		
		J	F	M	A	M	J	J	A	S	O	N	D	Year
Monthly Temperature (Tmon)	*Observed*	-3.7	-2.6	1.4	7.9	14.1	19.4	22.3	21.5	17.2	10.7	4.9	-0.5	
Monthly Precipitation (Precip)		61.5	55.4	53.7	68.0	82.0	70.9	63.9	81.1	84.7	64.4	84.1	61.5	831
Monthly Rainfall (Rain)	*Observed*	29.1	29.7	33.6	61.1	82.0	70.9	63.9	81.1	84.7	64.3	75.4	38.2	
Monthly Snowfall (Snow)	*Observed*	32.4	25.7	20.1	6.9	0.0	0.0	0.0	0.0	0.0	0.1	8.7	23.3	
Monthly Canopy Interception (Int)	*Estimated*	1.0	1.0	1.5	2.0	3.0	5.0	5.0	5.0	4.0	2.0	1.0	1.0	32
Monthly Detention Storage Loss (DT)	*Estimated*	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	60
Melt Fraction[1] (MF)	*(1-Snow/Precip) (empirical)*	0.5	0.5	0.6	0.9	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.6	
Monthly Snow Pack (Pack)	*(1-MF)*(Snow+Pack* $_{Mon-1}$*)*	21.9	22.1	15.8	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.9	9.2	
Monthly Snowmelt (Melt)	*MF*(Snow+Pack* $_{Mon-1}$*)*	19.7	25.5	26.4	20.4	2.3	0.0	0.0	0.0	0.0	0.1	7.8	15.0	
Monthly Throughfall (Thru)	*Rain - Int+Melt-DetStor*	42.8	49.2	53.5	74.5	76.3	60.9	53.9	71.1	75.7	57.4	77.2	47.2	
Monthly Runoff	*RF*Thru*	4.3	4.9	5.3	7.4	7.6	6.1	5.4	7.1	7.6	5.7	7.7	4.7	74
Monthly Infiltration (Infil)	*(1-RF)*Thru*	38.5	44.3	48.1	67.0	68.7	54.8	48.5	64.0	68.1	51.7	69.5	42.5	666
Monthly Potential ET[2] (PET)	*Hamon Eqn. (see note)*	0.0	0.0	26.7	46.5	75.5	108.7	126.3	111.6	77.6	45.6	27.4	0.0	646
Monthly Soil Moisture (SM)	*IF(Infil>PET) Min((Infil-PET+SM* $_{Mon-1}$*),SMmax)*	25.0	25.0	25.0	25.0	19.0	2.2	0.1	0.0	0.0	6.0	25.0	25.0	
	IF(Infil<PET) SM $_{Mon-1}$ **EXP(-(PET-Infil)/SM* $_{Max}$*))*													
Increase/Decrease in Soil Moisture	*SM-SM* $_{Mon-1}$	0.0	0.0	0.0	0.0	-6.0	-16.8	-2.1	-0.1	0.0	6.0	19.0	0.0	
Monthly Actual ET	*IF(Infil>PET) PET else (Infil+SM* $_{Mon-1}$ *-SM)*	0.0	0.0	26.7	46.5	74.7	71.6	50.6	64.1	68.1	45.6	27.4	0.0	475
Recharge		38.5	44.3	21.4	20.5	0.0	0.0	0.0	0.0	0.0	0.0	23.1	42.5	190

1- Empirical relation for this example *2 - PET = 924*DaylightHours*0.611*EXP(17.3*Tmon/(Tmon+237.3))/(Tmon+273.2)*

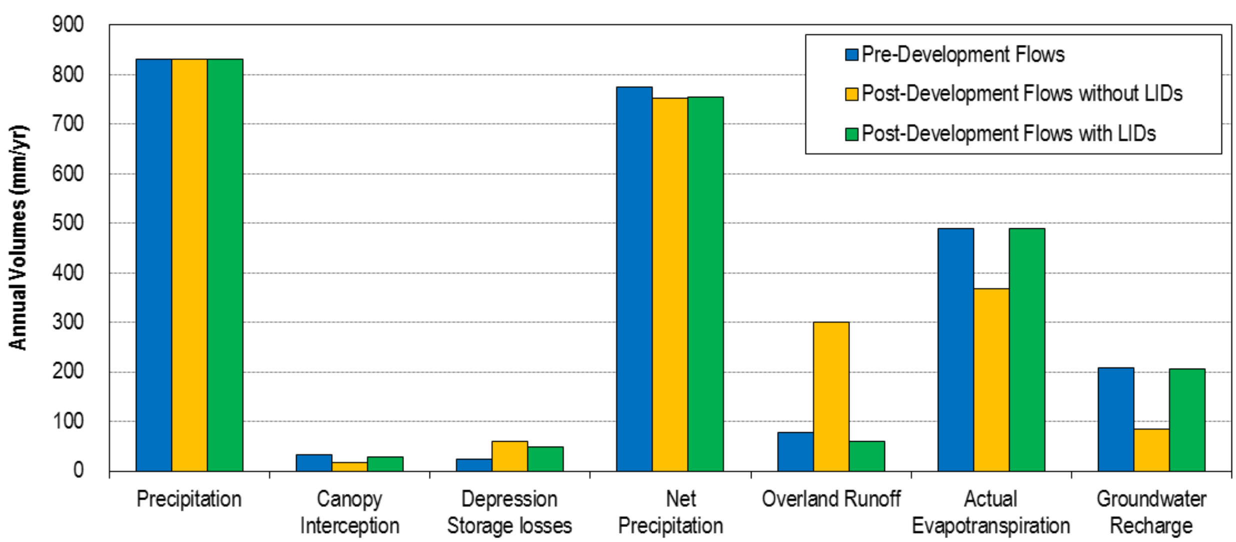
SIMPLE MONTHLY WATER-BALANCE MODEL - Post-Development with no LIDS		Location		Latitude		Max. Soil Moisture (SM_{Max})				Runoff Factor (RF)			
		Toronto		43.8 degree			25 mm					0.40		
		J	F	M	A	M	J	J	A	S	O	N	D	Year
Monthly Canopy Interception (Int)	*Estimated*	0.5	0.5	1.0	1.0	2.0	3.0	3.0	3.0	2.0	1.0	0.5	0.5	18
Monthly Detention Storage Loss (DT)	*Estimated*	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	30
Monthly Runoff	*RF*Thru*	18.3	20.9	22.6	31.2	31.9	26.2	23.4	30.2	32.1	24.4	32.1	20.1	313
Monthly Infiltration (Infil)	*(1-RF)*Thru*	27.5	31.3	33.9	46.8	47.9	39.2	35.0	45.4	48.1	36.5	48.1	30.1	470
Monthly Potential ET[2] (PET)	*Hamon Eqn. (see note)*	0.0	0.0	26.7	46.5	75.5	108.7	126.3	111.6	77.6	45.6	27.4	0.0	646
Monthly Actual ET	*IF(Infil>PET) PET else (Infil+SM* $_{Mon-1}$ *-SM)*	0.0	0.0	26.7	46.5	64.6	47.0	35.5	45.4	48.1	36.5	27.4	0.0	378
Recharge		27.5	31.3	7.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.9	92

SIMPLE MONTHLY WATER-BALANCE MODEL - Post-Development with LIDS		Location		Latitude		Max. Soil Moisture (SM_{Max})				Runoff Factor (RF)			
		Toronto		43.8 degree			25 mm					0.08		
		J	F	M	A	M	J	J	A	S	O	N	D	Year
Monthly Canopy Interception (Int)	*Estimated*	0.8	0.8	1.5	2.5	4.0	4.0	4.0	4.0	3.0	1.5	0.8	0.8	28
Monthly Detention Storage Loss (DT)	*Estimated*	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	36
Monthly Runoff	*RF*Thru*	3.6	4.1	4.4	6.1	6.2	5.1	4.6	5.9	6.3	4.8	6.4	4.0	61
Monthly Infiltration (Infil)	*(1-RF)*Thru*	41.4	47.4	51.1	69.9	71.1	58.8	52.3	68.2	72.4	55.1	73.1	45.5	706
Monthly Potential ET[2] (PET)	*Hamon Eqn. (see note)*	0.0	0.0	26.7	46.5	75.5	108.7	126.3	111.6	77.6	45.6	27.4	0.0	646
Monthly Actual ET	*IF(Infil>PET) PET else (Infil+SM* $_{Mon-1}$ *-SM)*	0.0	0.0	26.7	46.5	75.2	76.9	55.0	68.3	72.4	45.6	27.4	0.0	494
Recharge		41.4	47.4	24.3	23.4	0.0	0.0	0.0	0.0	0.0	0.0	30.2	45.5	212

Table A5.3 - Pre- and Post- Development water balance elements with and without LID BMPs

Water Balance Component	Pre-Development Flows (mm/yr)	Post-Development Flows without LID BMPs (mm/yr)	Post-Development Flows with LID BMPs (mm/yr)
Precipitation	831	831	831
Canopy Interception	32	18	28
Depression Storage losses	60	30	36
Net Precipitation	*739*	*783*	*767*
Overland Runoff	74	313	61
Actual Evapotranspiration	475	378	494
Groundwater Recharge	190	92	212

Figure A5.2 - Pre- and Post- Development water balance elements with and without LID BMPs



As shown in Table 5.3 and Figure A5.2, the "Post-Development without LID BMPs" scenario features a decrease in canopy interception and an increase in depression storage losses. Overland runoff has correspondingly increased significantly due to greater imperviousness and groundwater recharge has decreased in response to decreased infiltration. The "Post-Development with LID BMPs" scenario shows an increase in canopy interception due to tree-planting and a smaller increase in detention storage losses (some of the decrease in detention storage due to porous pavement is offset by the increase depression storage attributed to green roofs). Overland runoff to streams is slightly decreased and groundwater recharge, and ultimately baseflow, has been maintained at near natural conditions due to enhanced infiltration.

Considerations: Temporal Scale

Water balances conducted on daily basis will be more accurate than those on a monthly basis by taking into account daily variation in temperature, rainfall, and solar radiation. This is because some components, such as infiltration excess runoff, are very sensitive to the rate of precipitation (intensity) and/or to the amount of water in the soil at the start of a storm event. For example, if monthly rainfall of 75 mm is spread evenly over the month, about 2.5 mm/d, the amount of infiltration excess runoff would be negligible. However, if the rainfall actually fell in five daily events of 12, 18, 17, 5, 23 mm/d, the computed monthly-averaged volume of infiltration excess runoff computed using a daily time step would be higher. Accordingly, water balances done on an event (storm basis) would be more accurate than those done on a daily basis if infiltration excess runoff is a large component of the water balance. In all cases, the period of analysis for the daily or monthly water balance studies should be sufficiently long (5-20 years) to incorporate climate data with a wide range of events and antecedent conditions.

When completing water balance on a catchment basis, the parameters used in the water balance lose their physical meaning. For example, the runoff factor used in the monthly water balance is intended as a general estimate of the partitioning of monthly rainfall volumes but is not meant to represent the non-linear partitioning that occurs on a per storm basis. Ideally, the values used should reflect an average of many simulations done on a finer time-scale.

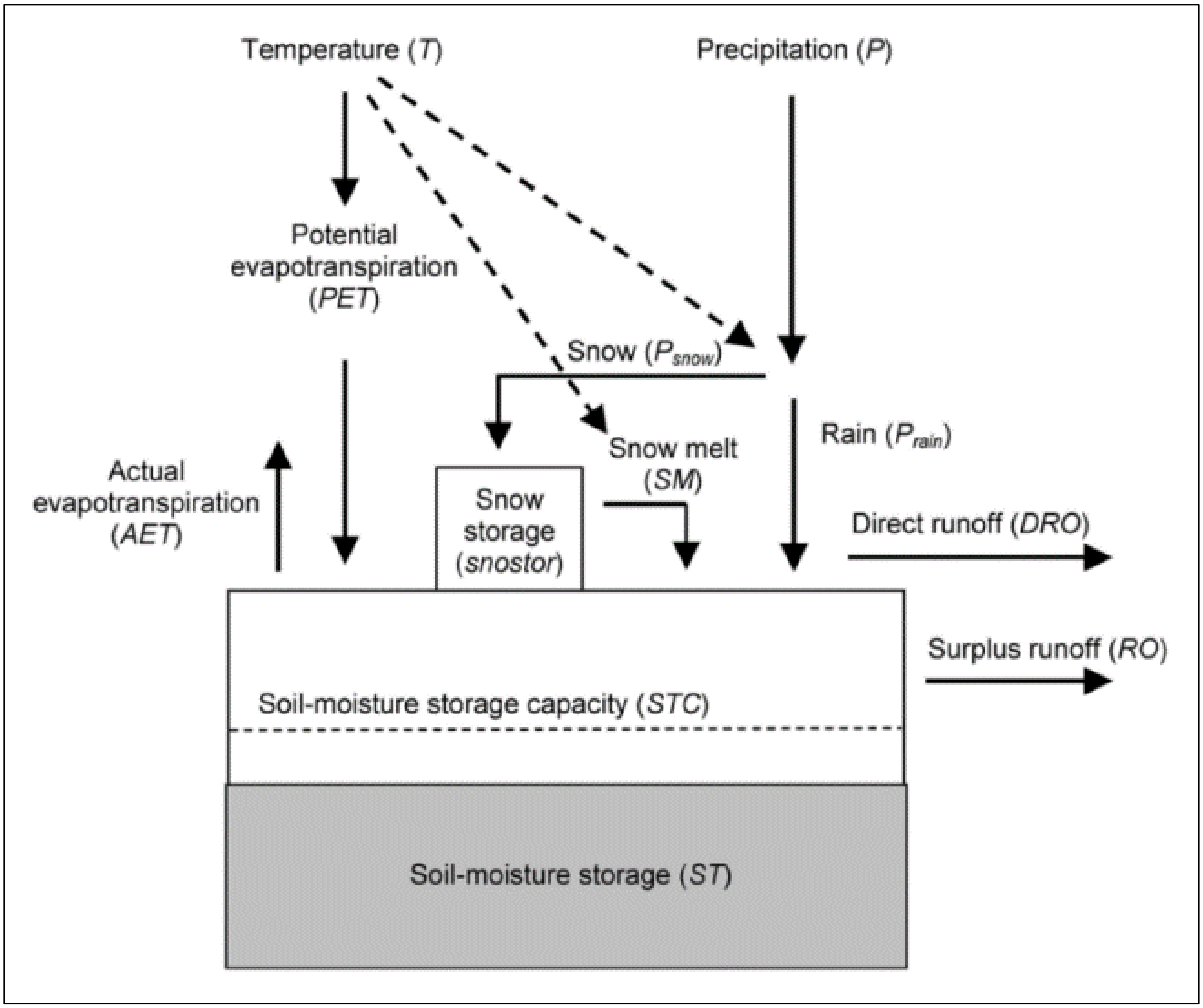
Considerations: Spatial Scale

Water balances can be done at different spatial scales, from a lot-sized analysis to regional watershed studies. It can be difficult to measure many of the terms in the water balance directly; ideally it is best to conduct the analysis on a gauged catchment so that results can be verified. Precipitation can be estimated from rain gauge data, potential evapotranspiration can be estimated from observed temperature and solar radiation data (or simply latitude), and other input terms (such as canopy interception, detention losses, and runoff coefficients) can be estimated using reasonable hydrologic assumptions. Total gauged streamflow can be separated into baseflow (GW), interflow, and runoff using baseflow separation techniques such that total streamflow can be compared against the predicted values of precipitation minus evapotranspiration, and baseflow can be compared against predicted groundwater recharge to see if the model predictions are reasonable. If they appear too low or too high, then model assumptions need to be checked and/or model parameters may need to be revised.

Considerations: Winter Conditions

Water balance codes vary as to whether they represent winter processes. Some models, such as the USGS Thornthwaite Monthly Water Balance model (**Figure A5.3**), can account for snow accumulation and snow melt using a temperature or energy balance method. Frozen ground can restrict infiltration and becomes a significant process in northern regions. The process of freezing and thawing the soil zone requires a more complex energy balance than typically included in simple water budgets. The model would need to adjust the thickness of the soil as if freezes from above in the early winter and as it thaws from above and below in the spring. The rates of rain and snowmelt runoff and infiltration would change accordingly, based on the volume of water in the soil and the by the effective thickness of the upper part of the soil zone. Pomeroy *et al.* (2007) provides further discussions on methods for representing these processes. The cold weather processes represented in the model should be considered when selecting any of the model codes discussed in this chapter.

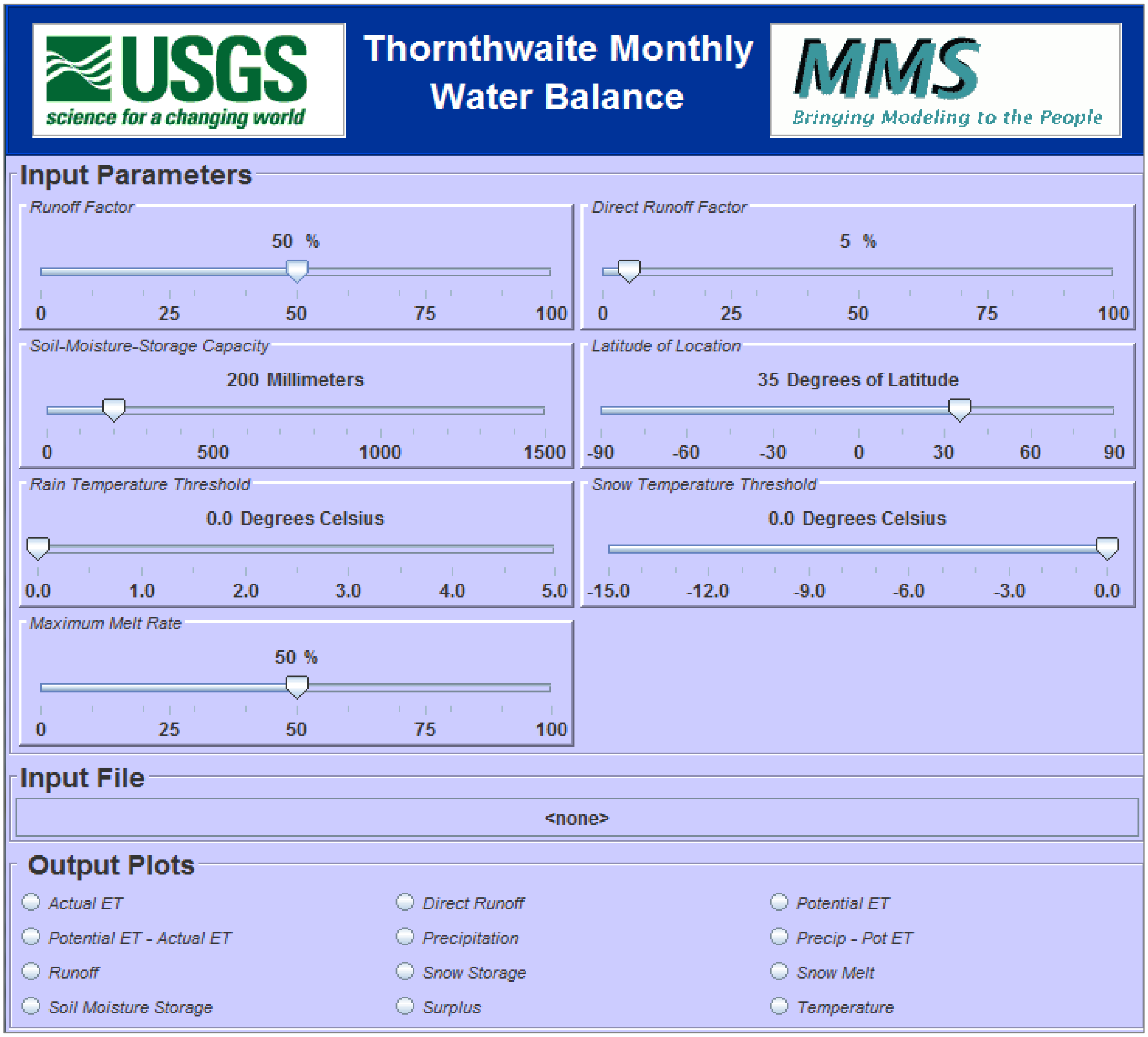
Figure A5.3 - Process schematic from the USGS Thornthwaite Monthly Water Balance model (McCabe & Markstrom, 2007)



Common Model Codes

Several water balance codes have been developed. Some are general models but can be adapted to simulate the incremental effects of LID BMPs. Others have been specifically developed to aid in LID assessments. Several common codes employed in Ontario are discussed in this section.

Figure A5.4 - USGS Thornthwaite Monthly Water Balance Model (McCabe & Markstrom, 2007)



The U.S. Geological Survey (USGS) has developed the Thornthwaite Monthly Water Balance as a simple tool to undertake monthly water balances (McCabe and Markstrom, 2007). The code documentation is available online. The program is an open-source and freely available Java application and can be run most computing platforms. The model is set up to run for a series of monthly values (rather than the climate normals used in the previous example). The assumption is that the average of 30-years of response to variable monthly inputs should be a better predictor than response to the 30-year average inputs. Like all models, this model has simplifications and assumptions. For example, the model does not explicitly account for canopy and detention storage losses or transfers of runoff from impervious surfaces to pervious, all features which prove useful for LID analysis. However, the model does account for some cold weather processes such as snow melt and reduced infiltration during winter months.

LIDRA (Low Impact Development Rapid Assessment Tool) developed by Drexel University and eDesign Dynamics LLC, is a web-based tool (www.llidratool.net) for rapidly assessing the cost-effectiveness of various Low Impact Development (LID) strategies as a means of reducing annual runoff in urbanized watersheds. The model was developed to enable users to rapidly and comprehensively compare different combinations of LID scenarios, implemented gradually over periods of up to 30 years on parcels and streets.

The **Water Balance Model powered by QUALHYMO** was developed for the Partnership for Water Sustainability in British Columbia as a decision support tool for LID implementation. Two different rainfall-runoff simulation models were merged to create a tool that can represent sites along with nearby streams within a watershed context. Flow routing can be done by adding flows at a specific location, or by routing them through a stream channel. This model can represent a large number of different project configurations and has been applied to a wide variety of watersheds containing mountainous, flat, and rolling terrain with varying degrees of development.

A **Minimal Impact Design Standards (MIDS) calculator** was developed by the Minnesota Pollution Control Agency to assist designers and regulators in determining conformance to best management practices (http://stormwater.pca.state.mn.us/index.php/MIDS_calculator). The MIDS Best Management Practices (BMP) calculator is a tool used to determine stormwater runoff volume and pollutant reduction capabilities of various low impact development BMPs. The MIDS calculator estimates the stormwater runoff volume reductions for various BMPs based on the MIDS performance goal (1.1 inches of runoff from impervious surfaces) and annual pollutant load reductions for total phosphorus (including a breakdown between particulate and dissolved phosphorus) and suspended solids (SS). The MIDS calculator operates in Microsoft Excel to allow the user to organize and modify the input parameters. The Excel spreadsheet conducts the calculations and stores parameters, while the GUI provides a platform that allows the user to enter data and presents results in a user-friendly manner.

The USEPA **National Stormwater Calculator** is a tool developed for computing small site hydrology for any location within the U.S. (http://www.epa.gov/nrmrl/wswrd/wq/models/swc/). The calculator estimates the amount of stormwater runoff generated from a site under different development and control scenarios over a long-term period of historical rainfall. The analysis takes into account local soil conditions, slope, land cover and meteorology. Different types of low impact development (LID) practices (also known as green infrastructure in this tool) can be employed to help capture and retain rainfall on-site. Future climate change scenarios taken from climate change projections can also be considered. The calculator's primary focus is informing site developers and property owners on how well they can meet a desired stormwater retention target.

Table A5.4 - Available water balance frameworks

Model Name	Source	Reference
Thornthwaite Monthly Water Balance	USGS	http://pubs.usgs.gov/of/2007/1088/pdf/of07-1088_508.pdf. https://wwwbrr.cr.usgs.gov/projects/SW_MoWS/Thornthwaite.html
LIDRA (Low impact development rapid assessment)	Drexel University and eDesign Dynamics LLC	http://www.lidratool.net
Water Balance Model (powered by QUALHYMO)	Partnership for Water Sustainability in British Columbia	https://waterbalance.ca/tools-resources/
Minimal Impact Design Standards (MIDS) calculator	Minnesota Pollution Control Agency	http://stormwater.pca.state.mn.us/index.php/MIDS_calculator
National Stormwater Calculator	USEPA	http://www.epa.gov/nrmrl/wswrd/wq/models/swc/

A5.1.2 Class B: Surface Water Runoff (Hydrologic) Models

There are a wide variety of surface water models available that can generally be classified as either hydrologic, hydraulic, or water quality models. Hydrologic models are typically the most relevant to LID analysis and are used to estimate runoff volumes, peak flows, and the temporal distribution of runoff at a particular location resulting from the observed precipitation or a design storm event. Generally, hydrologic models include most of the processes found in Water Balance models, but with better spatial and temporal resolution. Hydrologic models synthesize site or catchment topography, soil characteristics, and land cover to determine how these factors control the rates of runoff and groundwater recharge. Many hydrologic models also include relatively simple procedures to route runoff through storage areas or channels, and to combine flows from multiple watersheds.

Hydraulic models are used to predict the water surface elevations, energy grade lines, flow rates, velocities, and other flow characteristics throughout a drainage network that result from a given runoff hydrograph or steady flow input. Generally, the output (typically as runoff) from a hydrologic model is used in one way or another as the input to a hydraulic model. The hydraulic model then uses various computational routines to route the runoff through the drainage network, which may include channels, pipes, control structures, and storage areas. Combined hydraulic and hydrologic models provide the functions of both hydraulic models and hydrologic models in one framework. A combined model takes the results from the hydrologic portion of the model and routes it through the hydraulic portion of the model to provide the desired estimates. Where projects require a detailed analysis of the effects of a proposed development or retrofit on existing sewers, a combined model may be advantageous. A stand-alone hydraulic model could be used to evaluate the performance of dual drainage systems or existing stormwater infrastructure. Stand-alone hydraulic models such as HEC-RAS or MIKE11/MIKE21 represent critical tools for evaluating the flood and high water response within a channelized system; however, these tools are not capable of generating a water budget and are not discussed in detail within this chapter.

Models that describe surface runoff are also often modified to address water quality concerns. Water quality models are used to evaluate the effectiveness of a BMP, simulate water quality conditions in a lake, stream, or wetland, and to estimate the loadings to water bodies. Often the goal is to evaluate how some external factor (such as a change in land use or land cover, the use of best management practices, or a change in lake internal loading) will affect water quality. Parameters that are frequently modelled include total phosphorus, suspended solids, and dissolved oxygen.

The types of surface water oriented models described in this section are mainly intended for run-off dominated impact assessments, where the focus of the analysis is on the reduction of peak flows through retention, detention or diversion of water to mitigate the end of pipe peak flows. These models often do not account for interaction with the underlying groundwater system. As such, they may not be appropriate for use in areas with sensitive groundwater receptors or groundwater-fed natural features. As infiltration represents a major design consideration for LID BMPs, the assumptions made in the model regarding in the infiltration of water into the groundwater system should be reviewed and explicitly-stated when reporting on findings. Models that consider impacts to the groundwater system are discussed in Section A5.1.3.

Considerations: Temporal Scale - Event Based or Continuous

Hydrologic simulations can be conducted on an *event based* or *continuous* basis. An *event-based* simulation is one that represents a single runoff event occurring over a period of time ranging from about an hour to several days. Single event modelling uses discrete design storm events derived from rainfall statistics obtained from local climate station data to simulate the runoff response of the basin. Generally, each storm represents a specific return period frequency (i.e. probability of occurrence) based on the individual characteristics of the rainfall such as maximum average intensity, rainfall volume, and storm duration. In the case of an extreme event, this type of model is applied to determine the "worst case" scenario of peak flows, runoff, runoff duration and various contaminant concentrations in runoff. At the beginning of the model run, initial conditions (antecedent conditions) must be known or assumed. Event-based modelling is typically used to assess potential impacts from storm events or to test and optimize the engineering design of stormwater management facilities. It represents a commonly applied engineering method for design and performance assessment of stormwater systems.

Modelling of discrete events permits the simulation of accepted Provincial flood standards based on a previously experienced historical storm, such as the Timmins and Hurricane Hazel storms. Event-based models tend to focus on hydrodynamics and may omit one or more of the hydrologic surface and subsurface components (such as infiltration and evapotranspiration) when the focus is on flood prediction as design storms tend to overwhelm these mechanisms for attenuating flow. Event based simulations may therefore not be appropriate for evaluating the function of LID BMPs which rely on these processes. Furthermore, simulations which consider only a single event cannot demonstrate volume retention, evapotranspiration, percolation, and the distribution of retained water along natural pathways which control the performance of many LID BMPs.

A *continuous* simulation is one that operates over an extended period of time and typically incorporates multiple storm events and the intervening time over periods ranging from weeks to years. If a longer time scale is desired for simulation (often a requirement when evaluating LID performance), then a continuous model should be selected. A continuous hydrologic model marches through time with a time-step spanning 1 minute to 24 hours and keeps a running account of the volumes of moisture stored in or moving through each numerical reservoir (e.g., canopy storage, depression storage, snowpack, and soil zone). Sub-daily, daily, monthly, and annual water budgets can be derived by aggregating the volumes produced each time step.

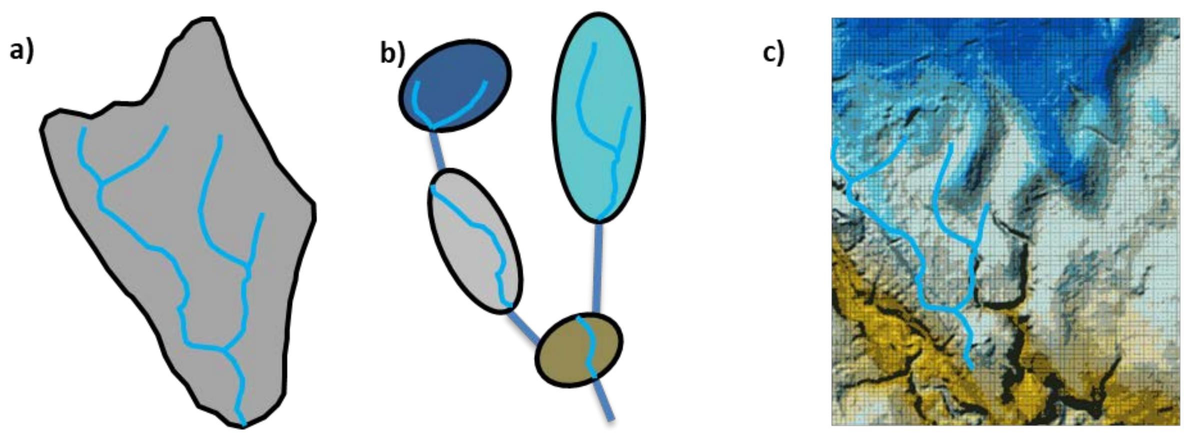
As with an event-based simulation, the initial conditions must be known or assumed. However, the effect of the selection of those initial conditions decreases rapidly as the simulation advances. Often the models are allowed to “spin-up” for a period of months or years until the system stabilizes and early results are discarded. Continuous modelling is often required for water resources planning, particularly where low-flow conditions are of importance and where cumulative impacts on stream quality or erosion are of concern. Long-term continuous simulations are preferred when analysing LID BMPs which rely on volume retention, infiltration, or evapotranspiration to achieve a reduction in runoff. Continuous modelling is generally not required when attempting to analyse the runoff response of a proposed stormwater design to large rainfall events.

Some models have the capability of both single-event and continuous simulation (e.g., SWMM, GAWSER, SWMHYMO, and PRMS). For example, PRMS normally simulates hydrologic response in the study area using a daily time step but can switch to a 5-minute time step when “storm mode” is specified. These models may be used for both planning and design. For planning, the model is used for an overall assessment of stormwater management and water quality problems; usually with a continuous simulation for spanning several years using observed precipitation, temperature, solar radiation, and other climate data.

Considerations: Spatial Scale - Lumped vs. Distributed Models

Hydrologic models can be broadly classified as *lumped-parameter or distributed-parameter* models (Figure A5.5). *Lumped-parameter models* are, by far, the most widely-used and represent the study area as a single watershed or a collection of catchments. Hydrologic processes are generally assumed to occur uniformly over the catchment and average values are assumed for physical parameters. In many cases, the physical values match the aggregate response of the catchment but are not necessarily representative of any one area. For example, the canopy interception storage value may represent an equivalent average value that, once calibrated, represents an average for all vegetative types in the catchment. Each component of the water budget (precipitation, canopy interception, AET, interflow, or recharge) is computed as a single value for the time step. Some models, such as HSPF (version 12 and later) allow for the presence of multiple land classes within each catchment, (for example, forest and agricultural land classes) with unique values calculated for each subarea. In either case, spatial resolution is sacrificed in return for fast computational speed and conceptual simplicity. Finer resolution models can usually be achieved by refining and subdividing the simulated catchments. The lumped parameter approach (with lack of spatial resolution) can be justified in models that are used to answer questions related to the general behaviour of a watershed.

Figure A5.5 - Schematic representations of a) lumped, b) semi-distributed, and c) fully distributed hydrologic models



A *distributed-parameter model* places more emphasis on local spatial heterogeneity of hydrologic properties. The study area is divided into multiple subareas - often referred to as "hydrologic response units" (HRUs) each with unique physical properties. The assumption is that the parameter values for the refined HRUs better represent "true" physical properties and that when individual HRU responses are aggregated over the study area, the response will match the observed response. While it would seem that the difference between distributed model and a lumped parameter model with many subcatchments would be blurred, it should be noted that each subcatchment has an outlet in these semi-distributed models and is assumed to contribute to some reach of a stream. Fully distributed models, however, require mechanisms that convey overland runoff, interflow, and even groundwater from one HRU, which could be located in an upland area, to the next and eventually to surface water body. Mechanisms include kinematic wave and diffusive wave modelling and cascade-flow routing. There are some advantages to this approach, such as allowing runoff from one HRU to infiltrate the soils in an adjacent HRU with more permeable soils, but the additional mechanisms can add a great deal of complexity to the models. The coupling of groundwater models to the distributed to lumped parameter models to represent the transfer of groundwater between HRUs or subcatchments is discussed in Section A5.1.4.

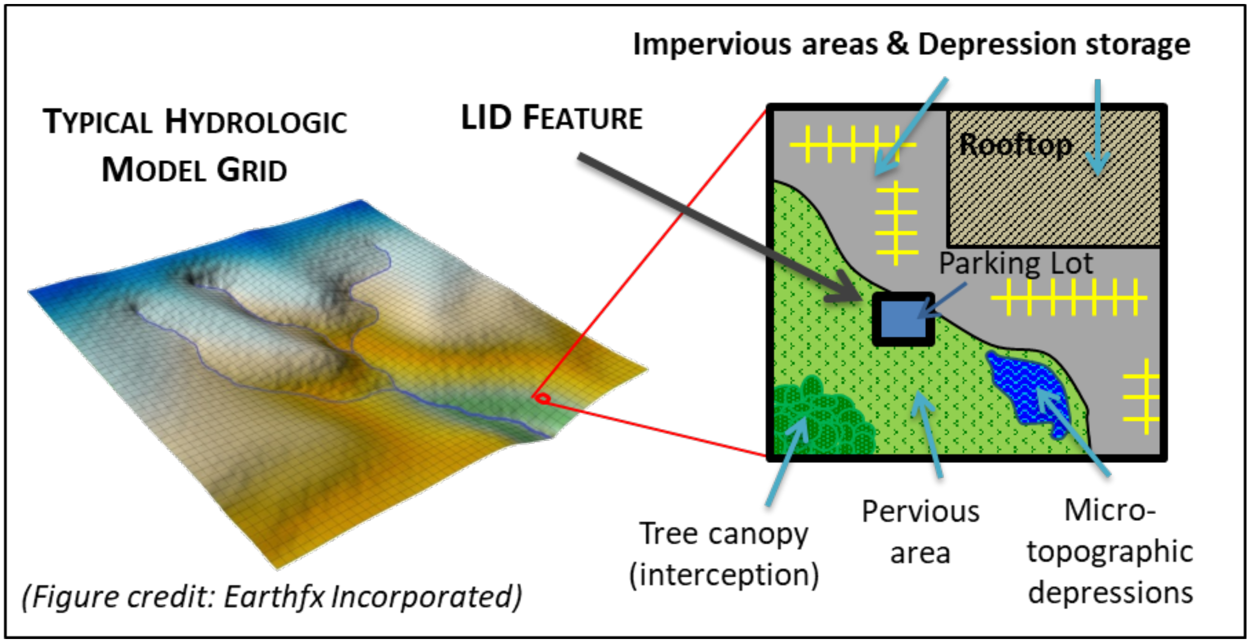
The level of spatial refinement (number of subcatchments or HRU size) is dependent on the level of detail required at each stage of the planning analysis. Simple water budgets from the catchment to the lot scale can be completed with lumped models. However, these models may be of limited use when attempting to predict how development within the model area will affect the components of the water balance. The need to analyze the effects of development on specific features such as streams or individual stormwater ponds usually leads to some level of granularization during a modelling exercise (for example to represent specific lots or stormwater features). The analysis of the behaviour, function, and ultimate performance of LID BMPs within a comprehensive stormwater management plan requires, as a starting point, that the LID BMPs and elements be uniquely represented within the model.

Considerations: Water Quality

This chapter primarily discusses modelling approaches suitable for use in a water budget study. Accordingly, there is a significant focus on hydrologic process representation. However, water quality is also a very important consideration when undertaking either the design or analysis of a stormwater system. Often, stormwater designs must demonstrate 80% Suspended Solids removal (MOE, 2003) and in some jurisdiction's proponents are required to minimize or reduce phosphorus loadings. In areas where runoff may enter sensitive aquatic habitat, offsite flows may also require thermal mitigation. Each of these considerations may require modelling to demonstrate there is no negative impact to surface water quality.

Water quality models are used to evaluate the effectiveness of a best-management practice (BMP), simulate water quality conditions in a lake, stream, or wetland, and to estimate the loadings to water bodies. Often the goal is to evaluate how an external factor (such as a change in land use or land cover, the use of best management practices, or a change in lake/pond sediment loadings) will affect water quality. Water quality parameters that are frequently modeled include total phosphorus, suspended solids, and dissolved oxygen. Some models (such as HSPF) directly incorporate the simulation of water quality parameters such as transport, load and concentration of contaminants, contaminant migration, salinity intrusion, and sediment transport (scour and deposition). Generally, these process modules require calibration to match water quality observations.

Figure A5.6 - Pervious and impervious portions a typical hydrologic model cell or HRU with the integration of a LID Reservoir



Some of the hydrologic models discussed in this chapter do not incorporate any representation of water quality parameters. There may be situations where a model is selected based on its suitability to address the hydrologic conditions within the study site, but it cannot account for surface water quality. In this situation, the modelled flows could be post-processed to estimate critical water quality values. In some cases, it may be more advantageous to construct a second model to derive post-development water quality values. The discussion of Common Model Codes below includes a brief description of capabilities of each model to represent water quality parameters.

LID Representation Within a Hydrologic Model

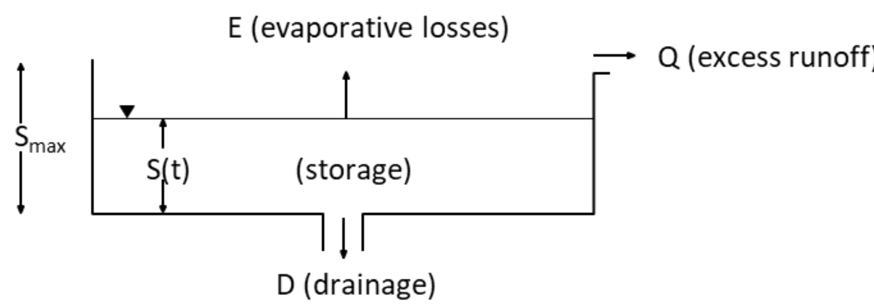
Hydrologic models can simulate a number of complex processes within each subcatchment, HRU, or model cell. A portion of each cell can be specified as impervious to represent paved areas, buildings and roofs (Figure A5.6). On this impervious area, net precipitation is first captured in depression storage, and the excess is considered as direct runoff. On the adjacent pervious portion of the cell, tree-canopy interception, surface depression storage (micro-topography) and soil zone processes all occur. A portion of runoff from the impervious areas can also be directed to the pervious areas.

Many models represent LID BMPs at the sub-HRU (sub-cell) level through the addition of an in-cell reservoir. LID strategies that include some form of runoff detention can be conceptualized using a simple reservoir shown in Figure A5.6 (this simple bucket model is sometimes referred to as a Budyko-Manabe reservoir after Budyko, 1956 and Manabe, 1969). Based on storage depth and spatial extent, the area-weighted linear storage capacity (S_{max}) can be determined. The reservoir storage at a given time can be depleted through three mechanisms:

- Evaporative losses (E), can be estimated from pan evaporation data or from calculated rates of potential evapotranspiration PET;
- Reservoir drainage (D), a user-defined drainage rate that either represents an infiltration rate set to the local vertical hydraulic conductivity (K) or water use for irrigation; and
- Excess Runoff (Q) that occurs when the storage S(t) exceeds S_{max}, and represents a simple overflow mechanism.

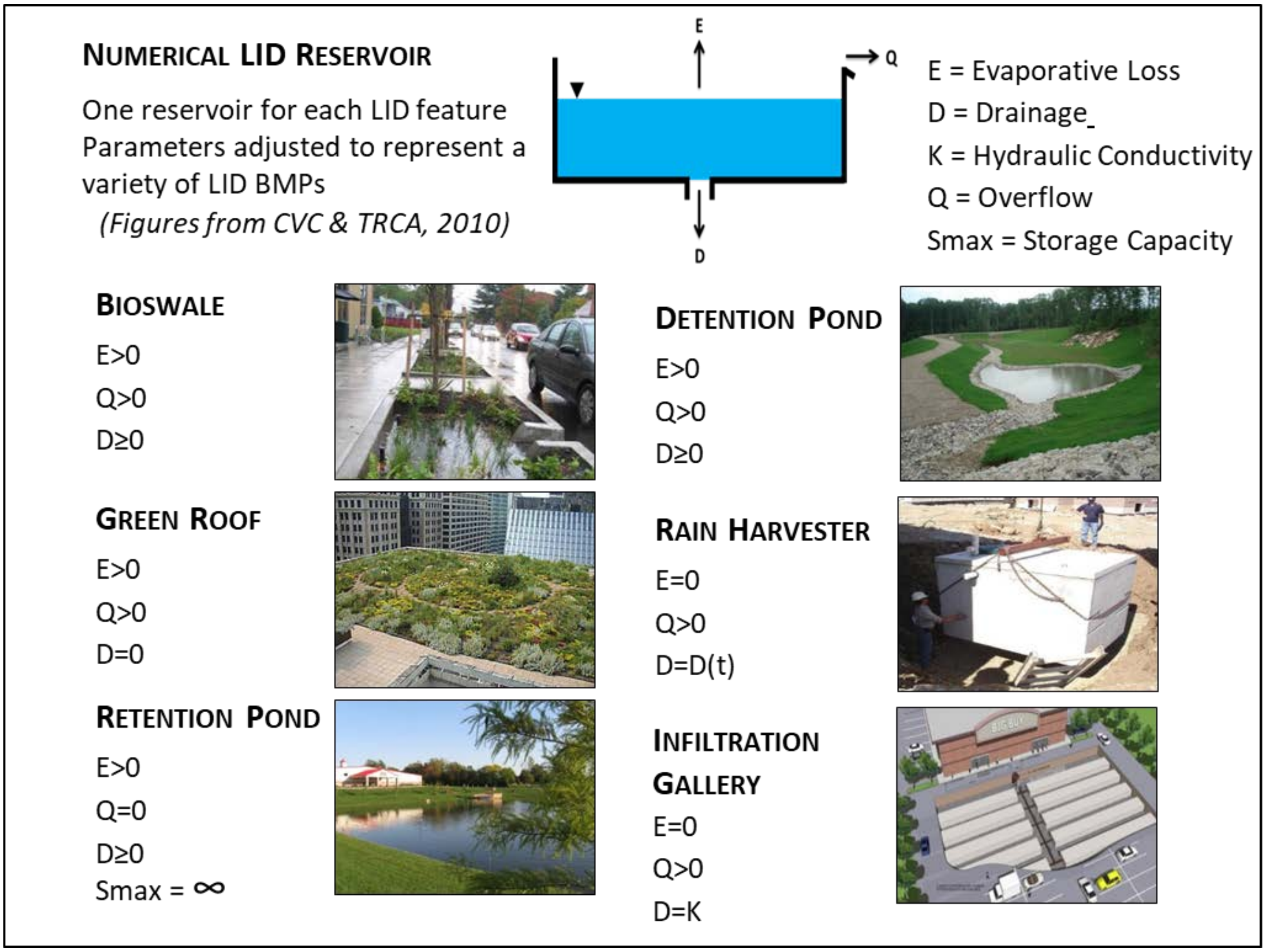
From this simple conceptualization, many LID strategies can be simulated by adjusting the values of E, Q and D (Figure A5.7).

Figure A5.7 - A simple numerical reservoir used to model LID functionality is applied on a grid cell-by-cell basis



Alternative LID designs can be represented in the existing pervious/impervious model structure of most hydrologic models. Pervious (porous) paving can be modelled by reducing the sub-cell effective impermeability, and downspout disconnects (i.e., roof to lawn) can be simulated by routing a portion of the runoff generated over impervious area to the pervious area within every grid cell. With these modifications and a high spatial distributed resolution, the cumulative impacts and benefits of a number of different LID design scenarios can be predicted. If impacts on existing stormwater systems are to be evaluated, the model should likely include some representation of the hydraulic connections to storm sewers or ponds.

Figure A5.8 - Representation of various LID BMPs varying the numerical parameters of the LID reservoir



Example: SWMM Modelling to Evaluate LID Performance

A case study of the USEPA SWMM model for assessing LID BMPs at the Honda Campus in Markham Ontario, was prepared as part of the TRCA lead STEP program (STEP, 2015). Some of the significant technical findings include:

LID BMPs reduced outflow volumes from the site by 30% to 35% during the eight-month study period through a combination of infiltration, evapotranspiration and water reuse.

Peak flow rates were significantly reduced by the LID controls and were maintained below design thresholds during the study period.

Approximately 6% of rainfall on the site was stored and reused for grounds irrigation over an eight-month period.

Water budget analysis showed that the LID BMPs dramatically altered the proportion of water allocated to evapotranspiration and runoff, without significantly changing land cover or buildable area.

Model simulations showed that the biofilters met the design objective of providing water quantity control for the post-development 100-year storm.

Development and calibration of three stormwater management models for simulating LID performance and function showed that calibrations improved with increasing model complexity.

Figure A5.9 - Site plan of the Honda Campus showing locations of LID BMPs

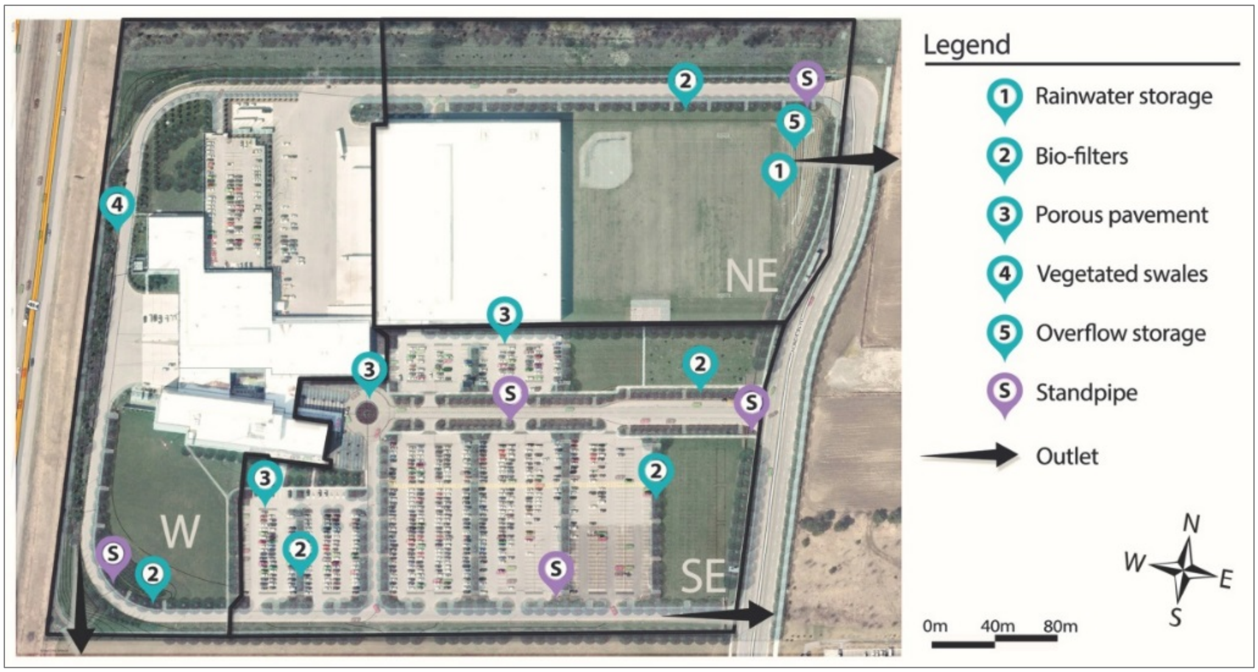
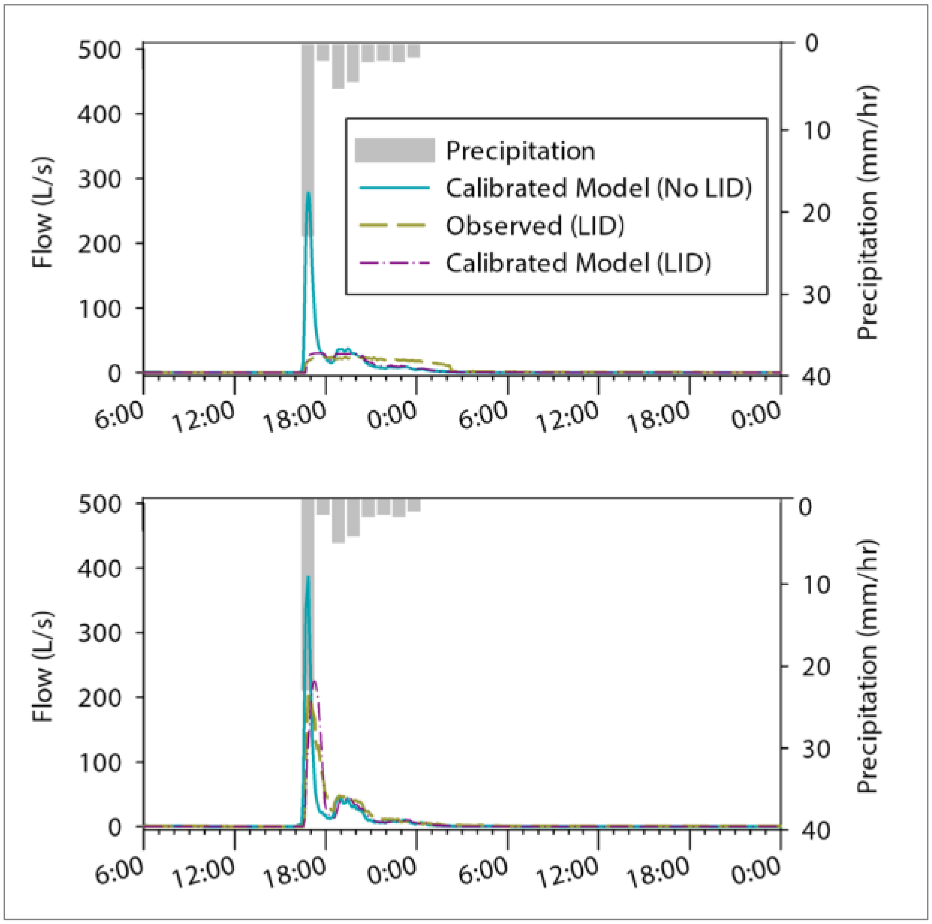


Figure A5.10 - Event hydrographs showing response to a July 8-9, 2013 storm event and USEPA SWMM model simulation of LID and No LID response to a storm event – Northeast (top) and West (bottom)

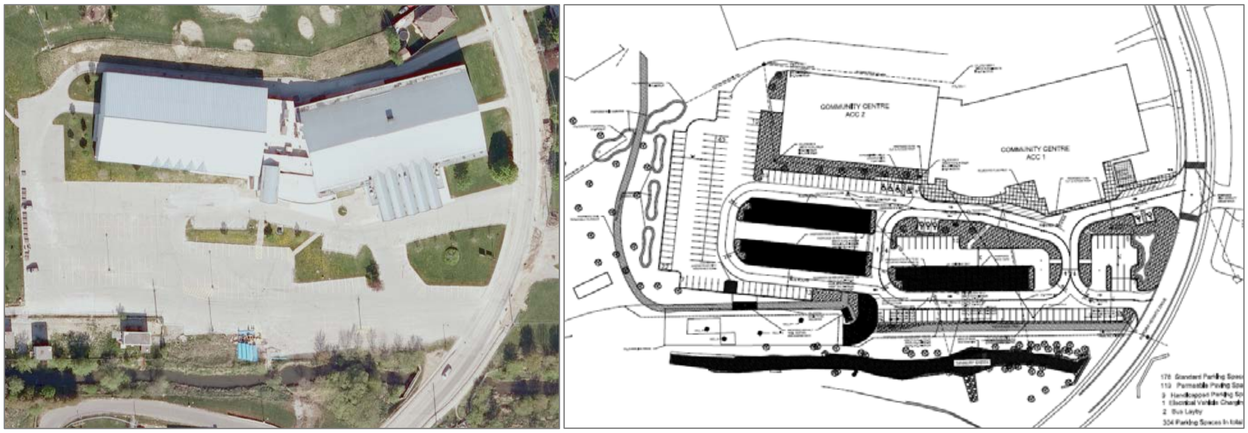


Further details and technical discussion relating to this study can be found online at the STEP website.

Example: The Aurora Community Centre Parking Lot and Stream Bank Improvements Design

The existing parking lot of the Aurora Community Centre (Figure A5.11a) was constructed in 1969 and is approximately 9,890 m^2 in area. A retrofit project has been undertaken to restore the existing parking lot as well as to implement LID BMPs to improve both water quality and downstream erosion.

Figure A5.11 - a) Existing condition of the ACC parking lot (left), with b) the proposed stormwater management and LID BMPs (right)



The proposed stormwater management and LID BMPs for the ACC parking lot (Figure A5.11b) included:

- Permeable pavements:
- Three centralized permeable interlocking concrete pavement (PICP) parking areas
- Two permeable turf reinforcement systems (Eco-Raster) to maintain access to the York Region wells
- Permeable interlocking concrete pavement (PICP) pedestrian trail/walkway
- Bioretention Facilities (Rain Gardens & Bioswales)
- Rain garden accepting runoff from the east entrance and northern most parking areas
- Rain garden accepting runoff from the roof of ACC #2. This facility replaces the existing dry pond facility to provide water quality control while maintaining the existing flood storage of 91 m^3
- Three bioswale facilities accepting runoff from the southern expansion of the parking surface area adjacent to Fleury Park
  A USEPA SWMM model was used to assess the effectiveness of the proposed retrofit measure. The modelling suggests the planned retrofit will result in the following improvement to water quantity and quality:
- Runoff volume reductions from the ACC Parking lot range from 68% to 16% for 25 mm to 100-year design rainfalls as a result of permeable pavement features
- Runoff volume reductions from the ACC complex range from 86% to 45% for 25 mm to 100-year design rainfalls as a result of bioretention facilities.
- 60% reduction in annual phosphorous loading resulted from LID infiltration and storage.

Common Model Codes

Table A5.5 provides a list of hydrologic models that run on a daily or shorter time step. Models developed by government agencies, such as the U.S. Environmental Protection Agency, U.S.

Geological Survey, and U.S. Army Corps of Engineers Hydraulic Engineering Center, are typically public domain and are available for free from the websites provided in the table. The models are well documented but user support can be limited. Proprietary models are available for licence fees and come with varying levels of support. The advantage of open-source models is that users with programming skills can follow the logic of the processes, debug their inputs when problems arise, and modify the codes for specific conditions if the needs arise. The inner workings of proprietary codes are not exposed and users must rely on the documentation of the processes involved.

Table A5.5 - Commonly used hydrologic models in Ontario (after Conservation Ontario, 2007)

Model Name	Lumped vs Distributed	Water Quality Processes	Source	Reference
SWMM	Lumped	Yes	USEPA	https://www.epa.gov/water-research/storm-water-management-model-swmm
PCSWMM	Lumped	Yes	Computational Hydraulics	http://www.chiwater.com/Software/PCSWMM/
XPSWMM	Lumped	Yes	XPSolutions	http://xpsolutions.com/Software/XPSWMM/
SWMHYMO	Lumped	Yes	J.F. Sabourin and Associates	www.jfsa.com/hydrologic-modelling-swmhymo.php
HEC-HMS	Lumped /Distributed	No	USACE	http://www.hec.usace.army.mil/software/hec-hms/
SWAT	Lumped	Yes	USDA/Texas A&M	http://swat.tamu.edu/software/
HSPF	Lumped	Yes	USEPA, USGS	https://www.epa.gov/exposure-assessment-models/hspf
GAWSER	Lumped /Distributed	Yes	Schroeter and Associates	http://www.schroeter-associates.com/testweb2_005.htm
Visual OTTHYMO	Lumped	No	Civica	http://visualotthymo.com/
QUALHYMO	Lumped	Yes	Partnership for Water Sustainability in B.C.	http://waterbalance.ca/
PRMS	Lumped/ Distributed	No	USGS	http://wwwbrr.cr.usgs.gov/projects/SW_MoWS/PRMS.html

The models have been classified as either lumped parameter or distributed. The differences between the two classes are discussed above. Some models, such as PRMS can be run with the HRUs representing subcatchments with uniform parameters but can also be run on a grid-cell basis.

SWMM is a hydraulic and hydrologic modelling system that also has a water quality component. The Stormwater Management Model (SWMM) was originally developed for the Environmental Protection Agency (EPA) in 1971. SWMM is a dynamic rainfall-runoff and water quality simulation model, developed primarily but not exclusively for urban areas. Version 5 of SWMM was developed in 2005 and has been updated multiple times since. The Stormwater Management Model (SWMM) is a comprehensive computer model for analysis of quantity and quality problems associated with urban runoff. Both single-event and continuous simulations can be performed on catchments having storm sewers, or combined sewers and natural drainage, for prediction of flows, stages and pollutant concentrations. Modules are available to solve the complete dynamic flow routing equations (St. Venant) for accurate simulation of backwater, looped connections, surcharging, and pressure flow. A modeller can simulate all aspects of the urban hydrologic and quality cycles, including rainfall, snow melt, surface and subsurface runoff, flow routing through drainage network, storage and treatment. Statistical analyses can be performed on long-term precipitation data and on output from continuous simulation. SWMM can be used for planning and design. Planning mode is used for an overall assessment of urban runoff problem or proposed abatement options. Current updates of SWMM includes the capability to model the flow rate, flow depth and quality of Low Impact Development (LID) controls, including permeable pavement, rain gardens, green roofs, street planters, rain barrels, infiltration trenches, and vegetative swales. The SWMM program is available to the public. The proprietary shells, PC-SWMM, InfoSWMM, and Mike Urban, provide the basic computations of EPASWMM with a graphic user interface, additional tools, and some additional computational capabilities.

XPSWMM is a propriety model that originally began as a SWMM based program. The model developer, XP Software Company has developed many upgrades that are independent of the USEPA upgrades to SWMM. Because of these upgrades the two software platforms are no longer interchangeable. XPSWMM does have a function that allows model data to be exported in SWMM format. Comparison of model results between the two models will result in similar, but not identical, results. XPSWMM's hydrologic and hydraulic capabilities includes modelling of floodplains, river systems, stormwater systems, BMPs (including green infrastructure), watersheds, sanitary sewers, and combined sewers. Pollutant modelling capabilities include pollutant and sediment loading and transport as well as pollutant removal for a suite of BMPs. XPSWMM is available from XP Solutions.

SWMHYMO is a proprietary model that is a successor of OTTHYMO originally developed at the University of Ottawa. It is a lumped hydrologic model that can be used for the simulation and management of stormwater runoff in either small or large rural and urban areas. Based on watershed or sewershed information, SWMHYMO can use single rainfall events (observed or synthetic) or continuous rainfall records to simulate the transformation of rainfall into surface runoff. Computed hydrographs can be routed through pipes, channel or stormwater control ponds and reservoirs. The latest version of SWMHYMO can be used to integrate the effects of a number of LID BMPs such as rain barrels, infiltration trenches, water cisterns, infiltration ponds and permeable pavements.

HEC-HMS is a hydrologic rainfall-runoff model developed by the U.S. Army Corps of Engineers that is based on the rainfall-runoff prediction module originally developed and released as HEC-1. HEC-HMS is used to compute runoff hydrographs for a network of watersheds. The model evaluates infiltration losses, transforms precipitation into runoff hydrographs, and routes hydrographs through open channel routing. A variety of runoff calculation methods can be selected including SCS curve number, Green and Ampt infiltration; Clark, Snyder or SCS unit hydrograph methods; with Muskingum, Puls, or lag streamflow routing methods. Precipitation inputs can be evaluated using a number of historical or synthetic methods with one evapotranspiration method. HEC-HMS is used in combination with HEC-RAS for calculation of both the hydrology and hydraulics of a stormwater system or network.

The Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) model is a multipurpose surface water environmental analysis system developed by the U.S. Environmental Protection Agency's (EPA's) Office of Water. The model was originally introduced in 1996 and has had subsequent releases in 1998 and 2001. BASINS allows for the assessment of large amounts of point and non-point source data in a format that is easy to use and understand. BASINS incorporates a number of model interfaces that it uses to assess water quality at selected stream sites or throughout the watershed. These model interfaces include: **WinHSPF**, a watershed scale model for estimating in-stream concentrations resulting from loadings from point and non-point sources; SWAT, a physical based, watershed scale model that was developed to predict the impacts of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land uses and management conditions over long periods of time; and PLOAD, a pollutant loading model;

Hydrological Simulation Program - FORTRAN (HSPF) is a comprehensive package for simulation of watershed hydrology and water quality for both conventional and toxic organic pollutants. This model can simulate the hydrologic and associated water quality processes on pervious and impervious land surfaces and in streams and well-mixed impoundments. HSPF incorporates the watershed-scale ARM and NPS models into a basin-scale analysis framework that includes fate and transport in one-dimensional stream channels. It is the only comprehensive model of watershed hydrology and water quality that allows the integrated simulation of land and soil contaminant runoff processes with in-stream hydraulic and sediment-chemical interactions (Gaber *et al.*, 2009).

The Guelph All-Weather Sequential Event Runoff Model (GAWSER) was developed by the University of Guelph in the mid 1970's and was refined in the late 1980's to predict streamflow from rainfall, snowmelt, or combined rainfall/snowmelt events. Streamflow can be modelled for long periods of time and the model has also the ability to simulate loading, pollution wash off, and water temperature. The model accounts for full water budget, runoff, infiltration, evaporation, interflow, and deep groundwater percolation. Runoff amounts are determined through the use of the Green & Ampt approximations for infiltration. The runoff response is determined using the area/time method to distribute runoff with time. The unit hydrographs are then routed through the river channel by using Muskingum-Cunge method of channel routing. Reservoir routing is represented by the Puls routing method with controlled releases.

The Low Impact Development Treatment Train Tool (LID TTT) has been developed by the Lake Simcoe Region Conservation Authority (LSRCA), Credit Valley Conservation (CVC) and the Toronto and Region Conservation Authority (TRCA) as a tool to help developers, consultant, municipalities and landowners understand and implement more sustainable stormwater management planning and design practices in their watersheds. The tool can be used for planning and design; in design charrettes; and for pre-consultation.

The purpose of this planning level tool is to analyze annual and event-based runoff volumes and pollutant load removals by the use of conventional and LID BMPs as part of the treatment train approach. The LID TTT provides preliminary water balance analysis (i.e. surface ET, surface runoff and infiltration to soil) and pollutant load removal estimates for pre- and post-development scenarios. The tool is built upon the open source EPA SWMM5 model providing a user-friendly interface and cross-compatibility with SWMM5 for further model development.

Features of the tool include:

- Tailored to Ontario climate and geologic conditions;
- Hydraulic routing to better predict flow volumes and rates;
- Capable of estimating pre and post water budget;
- Accommodate high number of stormwater management best management practices (BMPs), including Low Impact Development (LID) features, treatment trains, and/or end-of-pipe facilities;
- User friendly GUI, Open-Source; and
- Generate results in accordance with local targets and criteria (i.e., volume reduction, Suspended Solids and Total Phosphorus water quality reduction, and water budget estimates).

The tool can be run on continuous rainfall time-series or a design storm event. The intensity-duration-frequency curves for the area municipalities of the three conservation authorities are hardwired into the program. As well, the SCS and Chicago storm distributions are provided in the tool for user-specified rainfall depths. The LID TTT can export files for continued design development / refinement using SWMM.

The LID Treatment Train Tool for Ontario (LID TTT) is capable of considering one LID feature or multiple LID features to simulate treatment train benefits. The LID TTT computes pollutant concentration and loading entering (inflow) and leaving (outflow) each BMP and for the catchment as a whole. These calculations are based on default or user defined concentration-based removal efficiencies and land cover-based event mean concentrations (EMC).

More information about the tool and download of the tool is available at:
https://sustainabletechnologies.ca/low-impact-development-treatment-train-tool/

A5.1.3 Class C: Groundwater System Models

Groundwater models are tools that can be used to analyze changes in the subsurface water balance. More specifically, these models simulate the response of groundwater levels to changes in groundwater recharge and groundwater discharge to surface water bodies such as streams, lakes, and wetlands. The simulated groundwater levels can, in turn, be analyzed to determine directions and rates of groundwater flow, rates of groundwater discharge to surface water bodies, and changes in groundwater storage. The geologic units underlying a site are generally characterized as aquifers (units capable of transmitting significant quantities of water) and aquitards (units that restrict the flow of groundwater). Groundwater recharge, discharge to surface water bodies, and the properties of the aquifers and the aquitards control groundwater levels and, therefore, the rate and direction of groundwater movement.

Urbanization typically leads to an increase in impervious surfaces. Without stormwater management practices that provide for infiltration, new developments can lead to reduced groundwater recharge. Reductions in recharge may reduce groundwater discharge (baseflow) to local streams and wetlands, leading to the impairment of aquatic habitat. Urbanization over significant groundwater recharge areas can ultimately reduce the quantity of groundwater available for domestic, agricultural, or other uses in areas that are hydraulically connected to the recharge area. In recent years, increased emphasis has been placed on predicting and mitigating the negative impacts of urbanization on the surface water and groundwater systems. LID techniques can be applied to maintain or increase rates of groundwater recharge to ensure that groundwater-supported features are not adversely affected. A number of recent large-scale development projects in southern Ontario were required to predict the effects of urban development on the subsurface portion of the hydrologic cycle. These studies were conducted using a groundwater modelling or integrated surface water/groundwater modelling approach (see Section A5.1.4).

There are two general types of groundwater models used in common practice: *analytical* and *numerical* models. ***Analytical models*** provide an exact solution to the governing equations of groundwater flow. They are restricted to relatively simple physical conditions. For example, aquifer properties are typically assumed to be uniform and the aquifer geometry must be simple as well. The solutions may be exact, but they often are in terms of complex mathematical functions. ***Numerical models*** use numerical techniques (finite-element or finite-difference methods, discussed further on) to determine an approximate solution to the governing equations for groundwater flow. However, model complexity can quickly increase in heterogeneous conditions.

As the rate of groundwater movement is relatively slow and the overall range in groundwater levels and flow rates is limited, many studies have used ***steady-state*** groundwater models. These studies apply long-term average rates of groundwater recharge and discharge to determine equilibrium, or long-term average, groundwater levels and flow rates. Analyses of changes to the groundwater recharge or discharge rates assume that the new equilibrium condition will be achieved within a reasonably short period. The focus is on the difference between the two end states (e.g. pre- and post-development) and not on how the transition occurs.

In reality, the shallow groundwater system is always in transition, responding to recharge events, pumping, and to changes in stage in lakes and streams. ***Transient*** groundwater models can simulate the daily, seasonal and inter-annual variations in the groundwater system but require spatially-distributed estimates of groundwater recharge on an annual, monthly, or daily basis and information on changing water levels in connected surface water bodies. These can be obtained through simplified water budget analyses, stand-alone hydrologic models, or by coupling a hydrologic model to the groundwater model. Transient groundwater simulations can consume a great deal of computational effort with long run times compared to surface water models. Transient groundwater modelling is justified when simulating shallow water table conditions where the groundwater response to recharge events, drought, and climate change is of concern. For LID analysis, determining the effect of development on nearby groundwater-dependent natural features (such as changes to baseflow or wetland hydroperiod) would require a transient analysis. The response of the water table to increased recharge is an important consideration when assessing the effectiveness of infiltration-based LID BMPs.

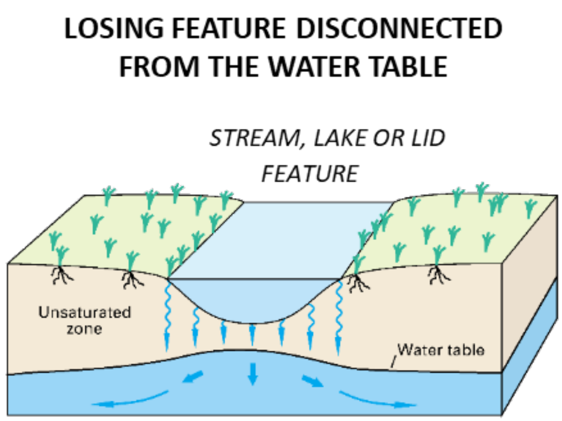
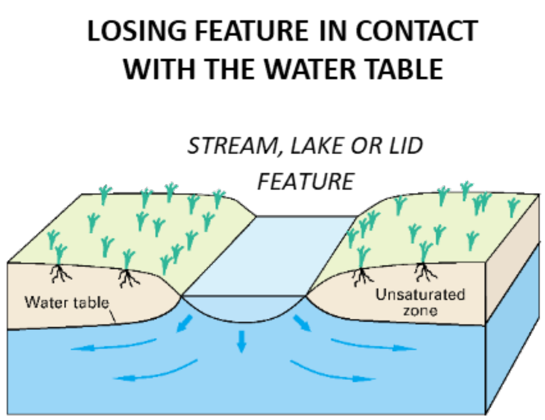
Considerations: Boundary Conditions

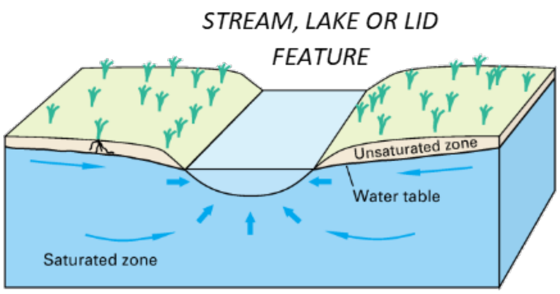
All groundwater models require information about what is occurring at the boundaries of the model area. For analytical models, these define the extent of the model area as either finite or infinite. Numerical models can have irregular boundaries representing natural features and *boundary conditions* are specified for cells or elements that lie along lines corresponding to the physical boundaries of the groundwater flow system. Three general types of boundary conditions are used in a groundwater flow model: specified head, specified flow, and head-dependent discharge boundaries.

Specified head boundaries are applied along model boundaries corresponding to areas where the heads are assumed to be constant or known over time. For example, a model bounded by Lake Ontario could assume that water levels are likely to be close to average lake stage and will not be affected by changes to recharge or pumping within the model area. Specified flow boundaries are applied along model boundaries corresponding to areas where the inflows to or outflows from the model are assumed to be constant or known over time. The time-varying recharge across the top surface of the model is a specified flow boundary. A no-flow boundary is a special type of specified flow boundary and can be applied across the bottom of the model or along major watershed divides and presumes that the inflows/outflows are negligible and not likely to be affected by changes to recharge or pumping within the model area.

Head-dependent flux boundaries are used represent to groundwater/surface water interaction beneath streams and lakes within the model area (see Table A5.6). Water is assumed to be exchanged as “leakage” across stream or lake beds. The rate of leakage is proportional to the difference between the aquifer head and the stream/lake stage, the hydraulic conductivity of the bed sediments (usually assumed to be lower than the aquifer hydraulic conductivity), and the wetted area and inversely proportional to the thickness of the stream/lake bed. While the other parameters tend to remain constant, stage and wetted area may vary widely over time. Simple groundwater models often assume that stage is maintained at average levels for the analysis time period (for example, the RIVER and DRAIN modules in the MODFLOW code assume constant stage over each model “stress period”). Other, more advanced, modules for MODFLOW add flow routing and lake water balancing to compute transient lake and stream stage. These advanced features could be used to represent groundwater interactions with LID BMPs such as infiltration basins, stormwater detention and retention ponds, and engineered wetlands (a case study is presented in Section A5.1.4).

Table A5.6 - Groundwater surface water interactions and their implications on the natural systems and LID implementation (modified from Alley *et al.*, 1999)

Type of Groundwater Interaction	Implications for Natural Features	Implications for LID BMPs
	Perched conditions are atypical for most streams in Ontario. May occur in some areas only under drought or late summer (low water table) conditions Condition can be found in vernal pools, bogs, and other wetland features that are disconnected from the groundwater system Conditions can vary seasonally where the feature can be better connected during wet periods with high water table	Ideal conditions for an infiltration dependant LID feature The subsurface and groundwater system likely has high capacity to accept inflows
	Frequently observed state in streams and wetlands Can be a highly transient process May occur seasonally under high flow conditions such as during the freshet or storm events when stream stage is elevated	Infiltration capacity of LID feature may be limited by interactions with the water table Infiltration rates are limited by the ability of the receiving aquifer to move water away from the feature Interaction with the water table is dependent on the available head in the LID feature

GAINING FEATURE  	Common condition found in most streams and some wetlands in Ontario Groundwater inputs form a component of baseflow in streams Discharge supports groundwater-dependent ecosystems and other sensitive natural features Conditions can vary seasonally with groundwater table fluctuations	Adverse conditions for infiltration dependant LID BMPs Groundwater discharge limits the available storage in the soil zone and in the LID feature Interaction with the water table is dependent on the available head in the LID feature Marginal LID implementations should consider the full range of possible seasonal hydrologic conditions

Considerations: Groundwater Quality

Infiltration of water and percolation to the water table as recharge is assumed to generally have positive effects on groundwater quality. Precipitation is low in dissolved solids content and low concentrations of contaminants picked up from the surface are usually filtered out and/or biodegraded as the water percolates through the soil zone. LID BMPs that enhance infiltration are also presumed to have a benefit through filtration, adsorption, and biodegradation of common contaminants such as sediment, nutrients, metals, bacteria, oil and grease. A study of 12 stormwater practices at the Seneca College campus showed that small distributed stormwater infiltration practices did not contaminate underlying soils, even after more than 10 years of operation (TRCA, 2008). However, water can pick up dissolved non-reactive contaminants in urban settings prior to infiltration, typically from road salt, lawn fertilizers, and pesticides. These can reach the water table below the infiltration feature and then migrate with the flowing groundwater. The rate of dispersive mixing in groundwater is relatively small and the increase in the width of the contaminated area transverse to the direction of flow will be limited. Concentrations will be attenuated down gradient of the source due to dispersive mixing with recharge and non-contaminated groundwater.

There are several analytical models (e.g., Cleary, 1978 or Wexler, 1992) that simulate dispersive mixing down gradient of a contaminant source. Numerical models can also be used to simulate flow and contaminant transport. Typical codes are discussed further on. It should be noted that much more detailed site information is needed to reliably simulate contaminant transport in complex settings. Unless there are specific concerns regarding sensitive receptors, this type of analysis is usually beyond that required for a typical site development.

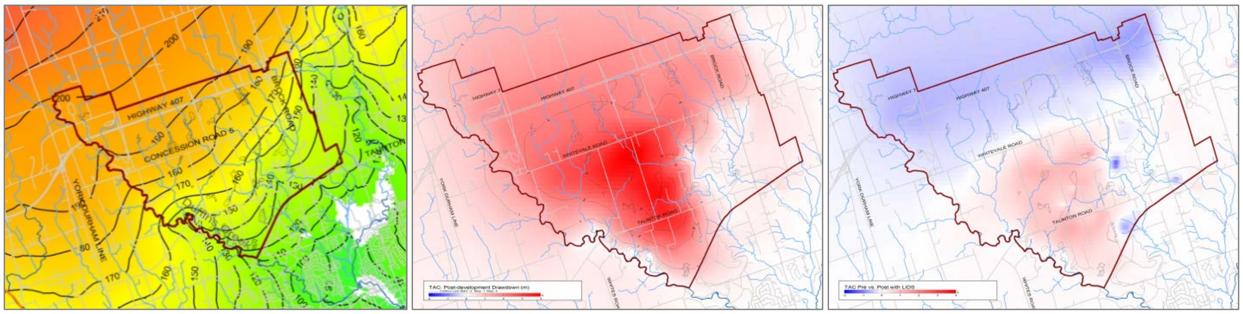
LID Representation Within Groundwater System Models

As was noted above, a transient groundwater model requires information on the spatial and temporal distribution of groundwater recharge. The estimates are obtained through water budget analyses or hydrologic models. The recharge values are typically treated as being somewhat uncertain and are often adjusted within reasonable ranges during the process of model calibration, until the simulated heads (groundwater levels) match observed water levels measured in wells.

Evaluating the effect of LID BMPs on the groundwater system can be done through a "with" and "without" comparative analysis. A baseline scenario would be simulated with the groundwater model using recharge estimates determined to represent current or "pre-development" baseline conditions. Next, the resultant changes to the rates of groundwater recharge would be estimated for the "with LID BMPs" and "without LID BMPs" scenarios using the same estimation methodology. The groundwater model would then be run for the two scenarios. By subtracting heads for the "without LID BMPs" scenario from the baseline conditions, the maximum drawdowns (i.e., change in head) due to decreased recharge over the site would be determined. Subtracting heads for the "with LID BMPs" scenario from the baseline conditions, should yield smaller drawdowns if the LID BMPs are effective in increasing or restoring groundwater recharge rates to baseline levels. Similar analysis would be conducted on the estimated groundwater discharge to streams which would be used to estimate the likely effects of development on baseflow to nearby streams (Table A5.6).

This process is illustrated in the figures below. The first figure shows the simulated head under baseline conditions. Changes due to a reduction in recharge are often small relative to the magnitude of the heads and are difficult to discern in maps of showing the heads under the different scenarios. Instead, the second figure shows the drawdowns (difference in simulated water levels) due to the development without LID BMPs. The areas in red show that water levels will decrease. The third figure shows the drawdowns under LID implementation. The red areas are reduced while the blue levels indicate that water levels will increase relative to base line conditions in areas of focussed recharge.

Figure A5.12 – Simulated groundwater a) head in the Thorncliffe Aquifer Complex (left); b) drawdown due to development (middle); and c) drawdown due to development with LID implementation (right)



Example: Analytical Solution to Groundwater Mounding at a Bioswale

The most recognized transient analytical solution is the Theis equation (Theis, 1937) for the drawdown (change in water level from initial conditions) at some time and radial distance from a well located in a confined aquifer of infinite extent. This equation is often applied as an inverse method where the observed drawdowns for a well pumping at a specified rate are analyzed to determine the aquifer transmissivity and storage coefficients.

A second and more relevant example is the simulated change in water levels at a distance perpendicular to a long recharge feature such as a bioswale or unlined stormwater pond (**Figure A5.13**). A solution developed by Hantush (1967) is given as:

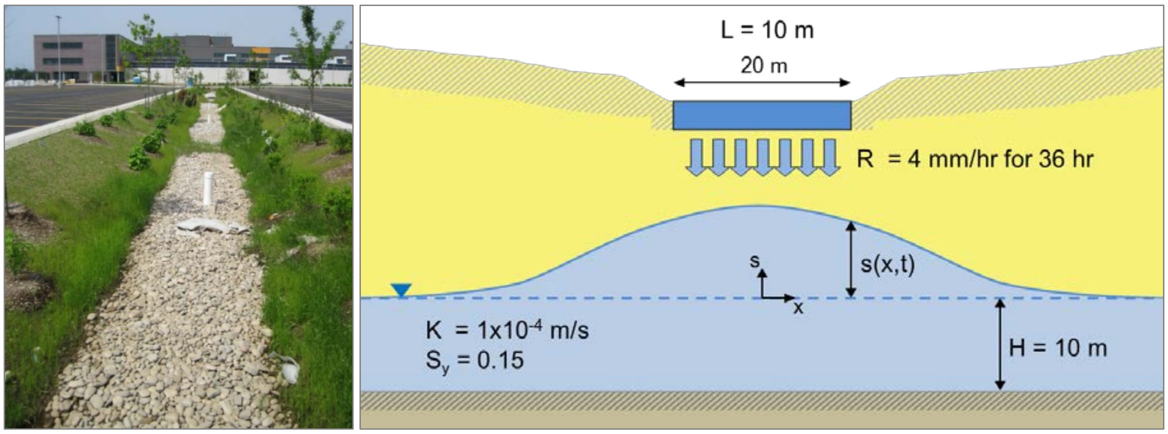
$s_1(x,t) = \frac{4R\bar{H}t}{S_y}\left[-i^2erfc\left(\frac{L-x}{2\sqrt{F \cdot t}}\right) - i^2erfc\left(\frac{L+x}{2\sqrt{F \cdot t}}\right)\right]$ beneath the recharge strip

$s_2(x,t) = \frac{4R\bar{H}t}{S_y}\left[-i^2erfc\left(\frac{L+x}{2\sqrt{F \cdot t}}\right) - i^2erfc\left(\frac{x-L}{2\sqrt{F \cdot t}}\right)\right]$ outside the recharge strip

$$F = \frac{K\bar{H}}{S_y}$$

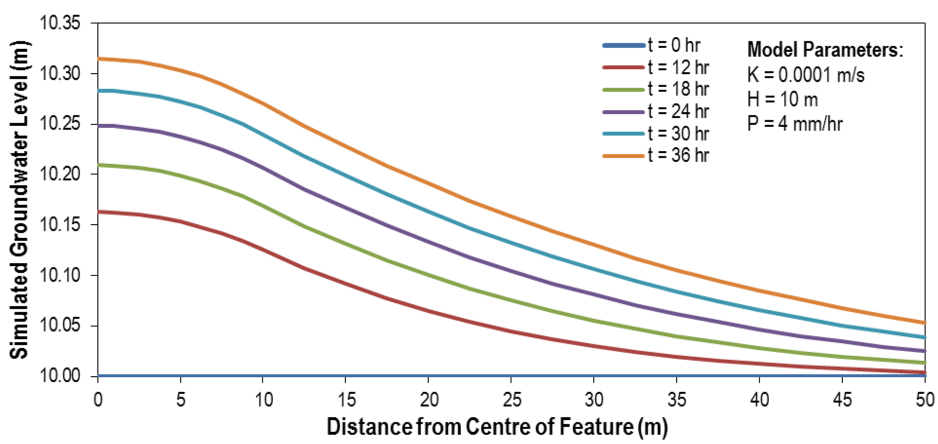
R	=	rate of recharge from the feature
S_y	=	specific yield (effective porosity) of the aquifer
H	=	average saturated thickness of the aquifer
K	=	hydraulic conductivity of the aquifer
t	=	time
x	=	the distance from centre of the feature
L	=	half the width of the feature
i^2 erfc	=	the second repeated integral of the error function

Figure A5.13 - Typical bioswale (Conestoga College, Cambridge Campus. Photo credit: CVC) (left) and site sketch of the bioswale problem (right)



The function i^2erfc is the second repeated integral of the error function (Abramowitz and Stegun, 1965, p.299). Although it appears complex, these equations can be evaluated using tables provided in Abramowitz and Stegun, 1965, p.317) or can be programmed as a macro in a spreadsheet. Figure A5.14 shows the change in the height of the recharge mound due to infiltration from a 20 m wide bioswale, on a sandy aquifer with an initial saturated thickness of 10 m, a hydraulic conductivity of $1x10^{-4}$ m/s, and a specific yield of 0.15. The bioswale is assumed to provide constant recharge at 4 mm/hr for 36 hours.

Figure A5.14 - Simulated groundwater levels adjacent to a 20-m wide bioswale after 36 hrs of infiltration at 4 mm/hr based on an analytical solution by Hantush (1967)



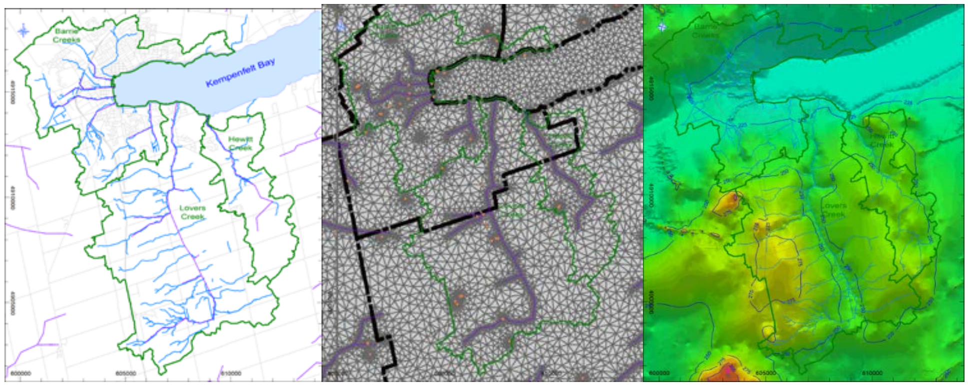
As noted earlier, the analytical models require the assumptions of simple geometry and uniform properties. For example, the solution above assumes that the aquifer is infinite in areal extent. Since the early 1960's, researchers have developed solution for increasingly complex systems. For example, Rao and Sarma (1980) discuss solutions for a recharge pond in a rectangular aquifer. Still, the real-world conditions must often be idealized to match the requirements of many analytical solutions.

Numerical Models

Numerical models use numerical techniques to determine an approximate solution to the governing equations for groundwater flow. The advantage of numerical models is that they can be applied to systems with complex geometries, complex boundaries, and heterogeneous aquifer and aquitard properties. Two common methods are used, the *finite-difference method* and the *finite-element method* although other techniques (e.g. finite volume or analytical element method) also exist. The ***finite-difference method*** works by first subdividing the area of interest into numerous small rectangular blocks. The method approximates a groundwater balance for each the block where the flow across each face of the block depends on the difference between the groundwater level in the centroid of the block and the centroid of the adjacent block. Horizontal flows within the unit, as well as flows from above and below, can be represented. The finite-difference method progresses through time in small increments, by determining the heads in each block at the end of each time step. In addition to specifying aquifer hydraulic conductivity and storage properties for each cell, conditions must be specified along the boundaries of the model. These can be in terms of known water levels, for example, if the aquifer is bounded by a large surface water body such as a lake, or by known inflow or outflow rates, such as the recharge rate across the top face of all blocks in the upper layer or by assuming that there is a negligible amount of lateral groundwater flow across a watershed divide.

The ***finite-element method*** is similar in many respects although there is more flexibility in the shape and size of the small elements used to represent the area of interest. For two-dimensional models, the elements can be triangles or quadrilaterals and for three-dimensional models these can be triangular prisms, tetrahedra, or quadrilateral blocks. The water levels are determined at nodes located at the vertices of the element. Boundary conditions specifying known water levels and flows are applied along model boundaries. For transient analyses, the model marches through time in small steps in a similar manner as the finite-difference method. A5.15 **(a)** shows the stream network in the Lovers, Hewitt, and Barrie Creek subwatersheds near the City of Barrie. A5.15 **(b)** shows a portion of the triangular finite-element mesh in the lower part of the subwatershed developed by AquaResource Inc. and Golder Associates Ltd. (2010) as part of a Tier 2 Source Protection Study for the South Georgian Bay - West Lake Simcoe Study Area. Note the extremely small size of the triangles used in the vicinity of the municipal wells and major stream tributaries that were represented in the model. Figure A5.15 **(c)** shows the simulated groundwater levels in the same area.

Figure A5.15 - a) Watershed boundaries and stream network (left), b) finite-element numerical mesh (middle), and c) simulated groundwater levels in the Lovers, Hewitt, and Barrie Creek subwatersheds which drain into Lake Simcoe, Ontario (right)



Numerical groundwater models are calibrated to match observed groundwater levels, baseflows in streams, and groundwater response to seasonal and event-driven recharge. Models can be employed to evaluate the sensitivity of the system to reduced recharge to assess how urbanization may ultimately affect water levels, baseflow to streams and wetlands, and longer-term effects on water users and/or aquatic habitats. Once developed, the groundwater model may also be used to evaluate alternative mitigation techniques and to compare development conditions to pre-development (natural or baseline) conditions.

Computer codes based on the finite-difference and finite-element models are widely available. The computer codes are set up in a generic way so that the users can supply information about the hydrostratigraphy, boundary conditions, aquifer and aquitard properties, recharge and discharge rates to create a representative model of their specific study area. **MODFLOW-2005** and **MODFLOW-NWT** are two examples of free, non-proprietary finite-difference codes developed by the U.S. Geological Survey. **FEFLOW** (WASY, 2005) is a widely-used proprietary code based on the finite-element method. Generally, the models are run to simulate flow in three-dimensions. Models can also be run in the x-y plane to simulate flow in a single aquifer and, under certain conditions, the models can be run in the x-z plane to simulate flow in a cross-section. These models are discussed further below.

There are also a number of guidelines and texts on groundwater modelling; a useful textbook is Anderson and Woessner (2002). The Australian groundwater modelling guidelines (Barnett et al, 2012) provide a thorough and in-depth discussion of the development, calibration, and application of groundwater models. A number of technical standards are available from the American Society for Testing and Materials (ASTM) also related to these topics.

Example: Numerical Model Solution to Groundwater Mounding at a Bioswale

A finite-difference model of the bioswale problem introduced above was set up using the MODFLOW finite-difference model. Figure A5.16 (a) shows a portion of a finite difference grid composed of variable sized cells with the cells at 1.25 m x 1.25 m in size in the vicinity of the 20-m wide bioswale. Figure A5.16 (b) shows the simulated heads near the bioswale after 36 hours using a uniform time step of 0.25 hrs. Figure A5.17 shows the simulated heads over time and the values correspond quite closely to those obtained with the analytical model. As a general rule, the smaller the time steps and grid size, the more accurate the solution will be; the trade-off is an increase in computational time.

Figure A5.16 - a) portion of finite-difference grid in the vicinity of the 20-m wide bioswale (left); and b) simulated groundwater levels at the end of 36 hrs of infiltration at 4 mm/hr with MODFLOW (right)

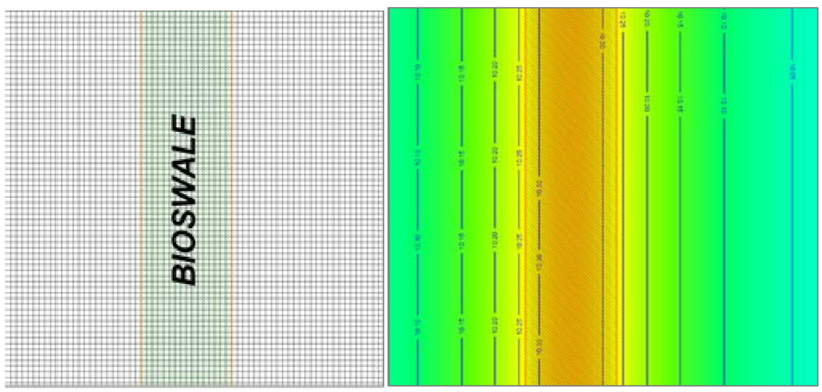
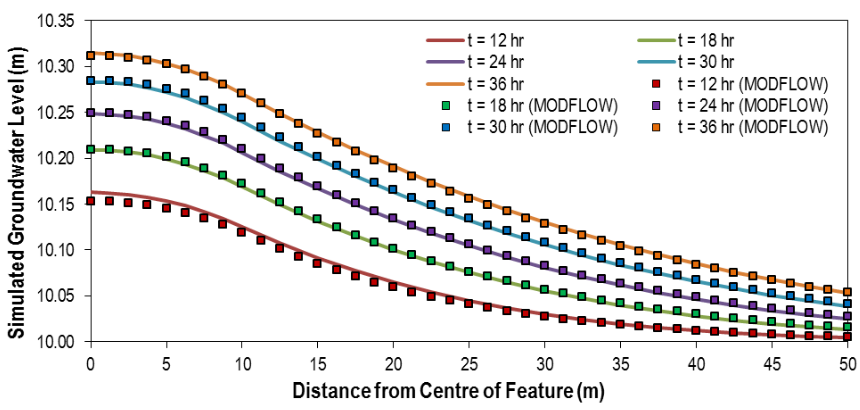


Figure A5.17 - Simulated groundwater levels adjacent to a 20-m wide bioswale after 36 hrs of infiltration at 4 mm/hr based on a numerical MODFLOW model



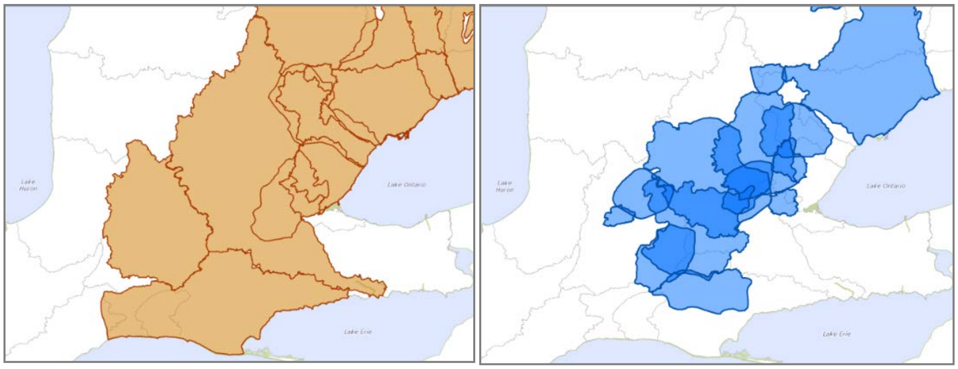
Source Protection Program Modelling Resources

In response to the May 2000 Walkerton tragedy, the Ontario government enacted the *Clean Water Act, 2006* and began implementing a watershed-based source protection program. The first watershed characterization and Tier 1 water budget studies were initiated in 2005. The Tier 1 studies used simple water budget models to determine which watersheds were potentially “stressed” from a water quantity perspective. At the same time, studies were carried out to delineate wellhead protection areas around municipal supply wells and to identify water quality threats. Stressed watersheds with municipal supply wells were subjected to further analysis at the Tier 2 level, using numerical groundwater flow and continuous hydrologic models. The watersheds which were confirmed to be stressed at the Tier 2 level progressed to the Tier 3 level of analysis which focused on the sustainability of the municipal wells. The Tier 3 studies were conducted at the watershed scale using even more sophisticated loosely-coupled or integrated surface water and groundwater models to study (1) impacts of future development on the municipal wells, (2) the effects of the wells on nearby coldwater streams and provincially significant wetlands, and (3) the impact of long-term drought on the water supply.

Between 2005 and 2010, the Ontario government dedicated considerable financial resources to conduct the water quantity and water quality threats assessments. The models developed during these studies represent a valuable source of information and many could serve as a framework for evaluating the effects of medium to large scale developments with and without LID BMPs. Locations and extents of the groundwater models for the Tier 1, Tier 2 and Tier 3 Assessments are shown in Figure A5.18. Given the investment in these models they should be used into the future as tools to aide in the management of Ontario’s water resources. Guidance for managing the models developed under the source protection program has been prepared to help inform municipal and provincial planning for the models. The key messages of A Guide for Actively Managing Watershed-Scale Numerical Models in Ontario (Marchildon, M. et al, August 2017) include, in part:

- Consider partnerships for modelling studies as it allows for the sharing of information technology investments and for the effective exchange of knowledge, services, tools, documentation, guidelines, training materials, and staff.
- Avoid costly modelling for simple situations. There may be opportunities for the use of traditional non-modelling approaches, such as field monitoring programs. Complex models are best suited to determine risk levels in situations where sufficient observation data exists and system behavior is not intuitive.
- Model results must be reproducible such that positions can be defended, corroborated, refined, updated, or adjusted if needed.
- Plan ahead for modelling knowledge needs. The data required for most modelling studies can be anticipated and thus should be collected and processed at the earliest opportunity.

Figure A5.18 - Groundwater models created for (a) Tier 1 and Tier 2 Assessments (left), and (b) Tier 3 Assessments under the Ontario Source Water Protection Program (right)



It should be recognized that all numerical groundwater and hydrologic model codes have their strengths and weaknesses. The Tier 3 source protection models, although highly detailed, were developed primarily to focus on the municipal wells. In some cases, the municipal wells are located in deeper aquifers and detail regarding the shallow subsurface and surface water features may be lacking in the numerical model. The existing models should be carefully reviewed prior to use in a LID analysis to be sure that their scale is appropriate and that the processes of concern, such as changes in land cover and site topography, can be properly represented. Refinements to the model by qualified and experienced hydrologists and/or hydrogeologist may be needed before the model can be applied.

Common Groundwater Model Codes

The most frequently applied numerical code applied in Ontario is **MODFLOW**. MODFLOW is a groundwater flow code developed by the U.S. Geological Survey (USGS) in 1989 for the numerical simulation of groundwater flow. MODFLOW has been applied to simulate groundwater flow in groundwater resource evaluation studies for municipal water supply, contaminant migration and remediation, and mine and construction dewatering. The code is open-source, well-documented, and freely distributed. The latest version is called **MODFLOW-2005** (Harbaugh, 2005) to distinguish it from earlier versions. **MODFLOW-NWT** (Niswonger *et al*, 2011), a variant of MODFLOW-2005, is a particularly stable code and is useful for simulating thin aquifers in the shallow subsurface and where steep gradients exist such as along the Niagara Escarpment. MODFLOW simulates steady and transient flow in an irregularly shaped flow system in which aquifer layers can be confined, unconfined, or a combination of confined and unconfined. Flow from external stresses, such as flow to wells, areal recharge, evapotranspiration, flow to drains, and flow through riverbeds, can be simulated. Hydraulic conductivities, transmissivities, and storage coefficients may vary spatially within each model layer. Model layers can represent different hydrostratigraphic units or a sub-layer within a thick unit. Specified head and specified flux boundaries can be simulated across the model's outer boundary. Head dependent flux boundaries are used to represent surface water features and allow water to be supplied to a model cell at a rate proportional to the difference between stage in the water body and head (groundwater level) in the boundary cell. MODFLOW is currently the most used numerical model in the U.S. Geological Survey for groundwater flow problems. MODFLOW has a modular structure that allows it to be easily modified to adapt the code for a particular application. Many new capabilities have been added to the original model including the ability to simulate flow in the unsaturated zone, streamflow routing and stream/aquifer interaction, lake water balances and lake/aquifer interaction, and land subsidence. Many commercially-available graphical user interfaces are available to help create the required input data sets and post-process and visually display MODFLOW results. Related programs, such as MT3D-USGS (Bedekar, 2016), are available to simulate contaminant transport using results of the MODFLOW model simulations.

FEFLOW (Finite Element subsurface FLOW system, DHI Inc.) is a closed-source, proprietary software package for modelling groundwater flow and solute transport processes in porous media under saturated and unsaturated conditions. Key components are interactive graphics, a GIS interface, data regionalization and visualisation tools and powerful numeric techniques. These components aid in an efficient work flow building the finite element mesh, assigning model properties and boundary conditions, running the simulation, and visualizing the results. FEFLOW major features are:

- 2D or 3D modelling
- Steady and transient simulation
- Computation of saturated, variable saturated, or unsaturated conditions
- Computation of mass and/or heat transport (purchase of add-ons required)
- Integration of chemical reactions, adsorption, and degradation mechanisms
- Consideration of variable fluid density because of temperature or (salt) concentration
- 1-D or 2-D finite elements for flow and transport in fractures, channels or tubes

FEFLOW has been widely used in Ontario for water supply and dewatering studies and has been linked with the **MIKE-11** streamflow routing code to simulate stream/aquifer interaction. FEFLOW also has model extensions for simulating contaminant transport.

Table A5.7 - Groundwater models commonly applied in Ontario.

Model Name	Source	Code	Technique	Reference
MODFLOW-2005	USGS	Open-source	Finite-Difference	water.usgs.gov/ogw/modflow/MODFLOW.html
MODFLOW-NWT	USGS	Open-source	Finite-Difference	http://water.usgs.gov/ogw/modflow-nwt/
FEFLOW	DHI Inc.	Proprietary	Finite-Element	https://www.mikepoweredbydhi.com/products/feflow

A5.1.4 Class D: Loosely-coupled, coupled, and integrated groundwater/surface water models

This section describes the application of uncoupled or coupled groundwater/surface water models for large, complex assessments. In complex or challenging settings, both the surface water and groundwater domain should be considered together to assess potential impacts due to urban development and LID implementation. The advantage of the combined modelling approach is that feedback between the groundwater and surface water systems can be evaluated more rigorously. This assessment can become more critical when considering LID performance, where previously disparate hydrologic processes such as evaporation and groundwater recharge must be considered together. In situations where the groundwater table is shallow, high infiltration rates from LID BMPs may not be possible during some months. However, the shallow system may be supporting adjacent natural features, and the natural recharge volumes and patterns must be maintained by the proposed LID solution. Determining the balance between completing design considerations is where a coupled modelling approach can offer powerful benefits. Models of this nature can be complex to develop and require quality hydrologic and transient groundwater data to calibrate. Even within the models described within this section, complexity and effect can vary significantly depending on the setting and scale of a proposed development.

A source for background information on some common integrated models is the “Integrated Surface and Groundwater Model Review and Technical Guide” prepared for MNDMNRF by AquaResource Inc. in 2011. Some of the models discussed in the technical guide AquaResource (2011a) would be suitable for large-scale development and for modelling complex surface water and groundwater resources settings and areas of sensitive environmental features or large water taking or in close proximity to municipal water supply wells or intake zones.

Background

There has been a long history of separate and distinct approaches to groundwater and surface water modelling. This may have been a product of the different time scales involved in groundwater and surface water flow (days to months versus seconds and minutes), the different methods of measurement (a network of wells versus a single gauges), and the general “siloing” of scientific disciplines. Typically, hydrologic models are catchment-based and represent precipitation, infiltration, overland flow, ET, and soil zone processes in great detail yet simplify the groundwater system as a single or linked reservoir. In most cases, “losses” to the groundwater system are treated as an unknown term in the model that is adjusted as part of the calibration process. Hydraulic models tend to focus on channel and off-channel processes in great detail and, because of their event-based focus, typically simplify other hydrologic processes and often ignore the groundwater system. Groundwater flow models are fully-distributed and represent the subsurface in great detail. Near-surface processes, such as groundwater recharge, ET, and discharge to streams, are represented in most groundwater models but, with a few exceptions, the representations generally fail to capture the dynamics of these processes. In many cases, groundwater recharge is treated as an unknown input to the model that is adjusted as part of the calibration process.

Loosely-Coupled Modelling Exercises

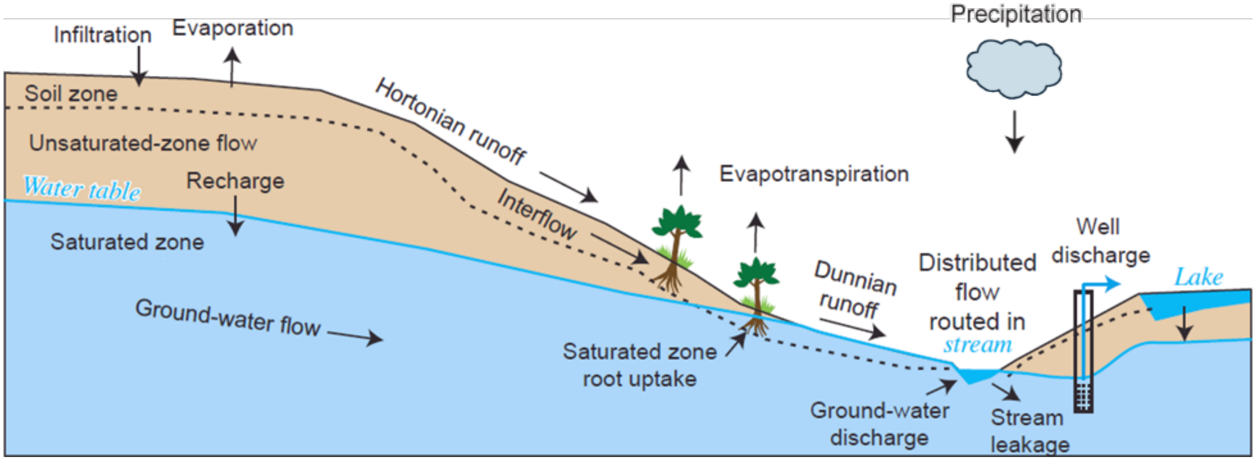
Linked groundwater/surface water models can be classified as loosely-coupled, coupled, and integrated groundwater/surface water models. In a loosely-coupled model, the hydrologic model and groundwater models are run separately. Recharge rates and overland runoff to streams predicted by the hydrologic model can be post-processed and supplied as a time-series of recharge values to the groundwater model. In turn, information such as groundwater discharge to streams, cross-catchment flows, and depth to water can be extracted from the groundwater model. The linkage can be done manually or automated through use of an intermediating processor. The linkage can be done in a semi- iterative manner, i.e., periodically updating each model based on results from the other until reasonably consistent model results are obtained. An implicit assumption in this approach is that the groundwater and surface water systems are reasonably independent over most of the study area.

A simple example is the Tier 1 source protection study conducted for the Central Lake Ontario Conservation Authority (Earthfx, 2008). A distributed hydrologic model for the CLOCA watersheds was developed using the PRMS code (Leavesely and others, 1983) and calibrated to flows at six Water Survey of Canada gauges. Average annual recharge computed from a 19-year simulation was applied to a three-dimensional groundwater model and used to estimate groundwater discharge to streams and cross-watershed flows. These cross-watershed flows were significant in several of the watersheds and the information was used to adjust the calibration of the hydrologic model.

Couple or Integrated Modelling Exercises

Integrated hydrologic models, on the other hand, attempt to consider the hydrologic, hydraulic, and groundwater flow process simultaneously (Figure A5.19), and allow feedback from one process to be considered by the other. Interaction occurs predominantly in (1) areas of shallow water table; (2) at the edges of streams, lakes, and wetlands, and (3) as cross-watershed flows. For example, an area of shallow water table will have higher ET due to greater amounts of available soil moisture; and will generate higher runoff due to saturation excess (Dunnian) processes. Decreases in the volume available for groundwater recharge, in turn, affect the position of the water table. Groundwater discharge to the edges of streams, lakes, and wetlands, occurs when the stage is lower than the head in the underlying aquifer; while water is recharged to groundwater when the stage is higher such as when a flood wave passes. By considering the dynamics of all processes, a more complete water budget analysis can be undertaken. By carefully analyzing the processes and the feedback mechanisms, a more complete understanding of watershed behaviour and sensitivity to change can be obtained.

Figure A5.19 - Hydrologic, hydraulic, and groundwater flow processes typically represented in an integrated model



Where feedback between the groundwater and surface water systems is a dominant process in the study area, a tighter linkage is required. Models such as **GSFLOW** and **MIKE-SHE** are examples of coupled surface water groundwater models where the hydrologic and groundwater models are treated as sub-models linked through a master controller. Similar to the loosely-coupled models, each submodel is run separately and data is exchanged between the two submodels. The master controller handles the information exchange and determines when the iterative linkage has converged (i.e. water levels converge on final values for the time step and mass balance is maintained).

One benefit of the coupled model is that the separate models can often be developed and pre-calibrated separately and then combined. This allows the modellers to focus on key processes within each system and allows the work load to be broken up among multiple practitioners. The disadvantage, however, is that in areas of strong groundwater surface water interaction, the final linking may require substantial additional calibration. For example, a hydrologic model developed with no water table feedback may compensate by over predicting ET demand and the contribution of Hortonian runoff to streamflow. This would need to be corrected when feedback mechanisms are added which generate higher Dunnian runoff and shallow water table ET.

HydroGeoSphere is an example of an integrated model where all soil zone, unsaturated zone, and hydrodynamic processes are represented as being part of one continuum and all processes are solved simultaneously. The integrated model approach is much more elegant from a theoretical point of view and avoids some of the technical problems of linking two independently-developed models with possible differences in conceptualization of the hydrologic processes, but it comes at a cost of computational complexity.

Considerations: Complexity

Integrated models can provide a more complete representation of the hydrologic processes and provide immediate feedback between the soil zone, land surface processes, stream/wetland/lake processes and the groundwater system. However, these models are more complex to develop and require good quality hydrologic and transient groundwater data to calibrate. It also requires an interdisciplinary approach with good communication between the surface water and groundwater modellers.

AquaResource (2011a) noted that despite the benefits, due to the increased complexity integrated models had not seen widespread application within Ontario. However, coupled and integrated models have since been applied successfully in several Tier 3 source protection studies and Lake Simcoe Protection Plan studies in Ontario. The development of open source model codes has seen the rapid adoption of integrated models in the United States to assess a range of complex water management challenges.

LID Representation Within Loosely-Coupled, Coupled and Integrated Groundwater/Surface Water Models

Most of the available integrated models incorporate a distributed hydrologic submodel as the means of estimating runoff, recharge, and ET processes. The hydrologic submodel can simulate LID BMPs by altering land cover and percentage imperviousness within each HRU (hydrologic response unit) or model cell. As noted in in Section A5.1.2, pervious paving could be modelled by reducing the sub-cell effective impermeability, and downspout disconnects (i.e., roof to lawn) could be simulated by routing a portion of the runoff generated over impervious area to the pervious area within every grid cell. Changes to the local water balance, and in particular, changes to the rate of groundwater recharge due to these modifications can be represented with high spatial resolution.

The hydrologic submodels can represent more complex LID BMPs through the addition of an in-cell LID reservoir (Figure A5.7) or similar scheme as was discussed in Section A5.1.2. The storage capacity of the features is determined by the storage depth and areal extent. Properties controlling rates of storage depletion by evaporative losses and drainage processes can be specified for each type of LID, thus enabling representation of bioswales, retention/detention ponds, green roofs, rain barrels, and infiltration galleries all with the same basic model mechanism. The difference between the integrated model and a separate stand-alone hydrologic model is that, in the integrated model, the groundwater submodel would provide feedback, in terms of depth to the water table, which would alter the rates of drainage and evaporation from the LID feature when the water table is near surface.

Evaluating the effect of LID BMPs on the surface water and groundwater system would still be done with a “with” and “without” comparative analysis. A baseline scenario would be simulated with the integrated model calibrated to match observed streamflow, wetland and lake stage, and transient groundwater levels. Matching all these observations often takes a larger degree of effort than with stand-alone models but provides a higher level of certainty regarding the parameter values selected for the integrated model and the uniqueness of the model calibration. Next, changes to imperviousness, land cover, and the placement of stormwater detention measures would be input to the integrated model for simulating the “without LID BMPs” scenario and additional changes to imperviousness, land cover, and the placement of LID BMPs would be input to the integrated model for simulating the “with LID BMPs” scenario.

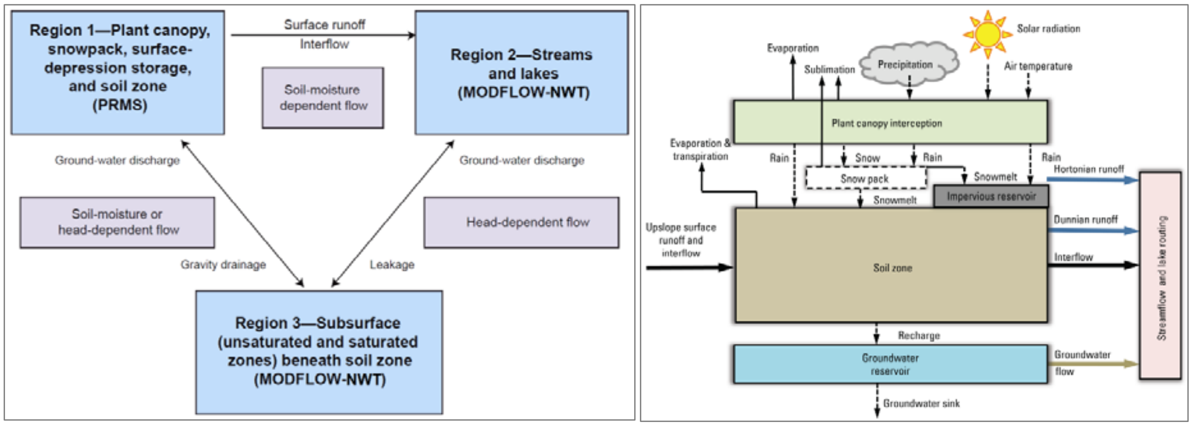
The advantage of the integrated model in these analyses is that all aspects of the water budget can be compared between model scenarios. Similar to Section A5.1.3, subtracting heads for the “without LID BMPs” scenario from the baseline conditions, the maximum drawdowns (i.e., change in heads) due to decreased recharge over the site can be determined. Subtracting heads for the “with LID BMPs” scenario from the baseline conditions, should yield smaller drawdowns if the LID BMPs are effective in increasing or restoring groundwater recharge rates to baseline levels. Similar analysis would be conducted on spatially distributed runoff, actual ET, interception and depression storage losses. Estimated overland runoff and groundwater discharge to streams which would be used to estimate the likely effects of development on streamflow and baseflow in nearby streams. Changes to wetland stage and wetland hydroperiod (the number of days per year the soils remain saturated) could be determined for all wetlands represented in the integrated model.

Common Model Codes

There are a number of integrated modelling codes available (See Table A5.8). AquaResource (2011a) compared several including GSFLOW, MIKE-SHE, HydroGeoSphere, MODHMS, and ParFlow. Of these, the first three have been used more widely in Ontario and are described briefly below. As noted earlier, Hydrogeosphere is a fully-integrated model while GSFLOW and MIKE SHE are fully-coupled models that solve the surface and subsurface flow equations separately but iteratively within each time step, with the corresponding heads or fluxes acting as a common internal boundary condition. All three models are physically based.

GSFLOW (Markstrom, *et al.*, 2008) combines two recognized U.S. Geological Survey codes; PRMS (Leavesley *et al.*, 1983) and MODFLOW-NWT code (Niswonger *et al.*, 2011). The code is open source, freely distributed, and well documented. The linkages between PRMS, MODFLOW-NWT, and the Streamflow-Routing module and the hydrologic processes represented within each “region” are illustrated in Figure A5.20a. PRMS computes a water balance for each Hydrologic Response Unit (HRU). In the original PRMS model, the HRU represented a sub-catchment; within GSFLOW, HRUS can also represent a cell within a model grid. A large number of small HRUS would be used to represent an area with high spatial variability. Each HRU overlies a part of or one or more MODFLOW grid cells providing a large degree of flexibility in creating grids to design the PRMS and MODFLOW grids.

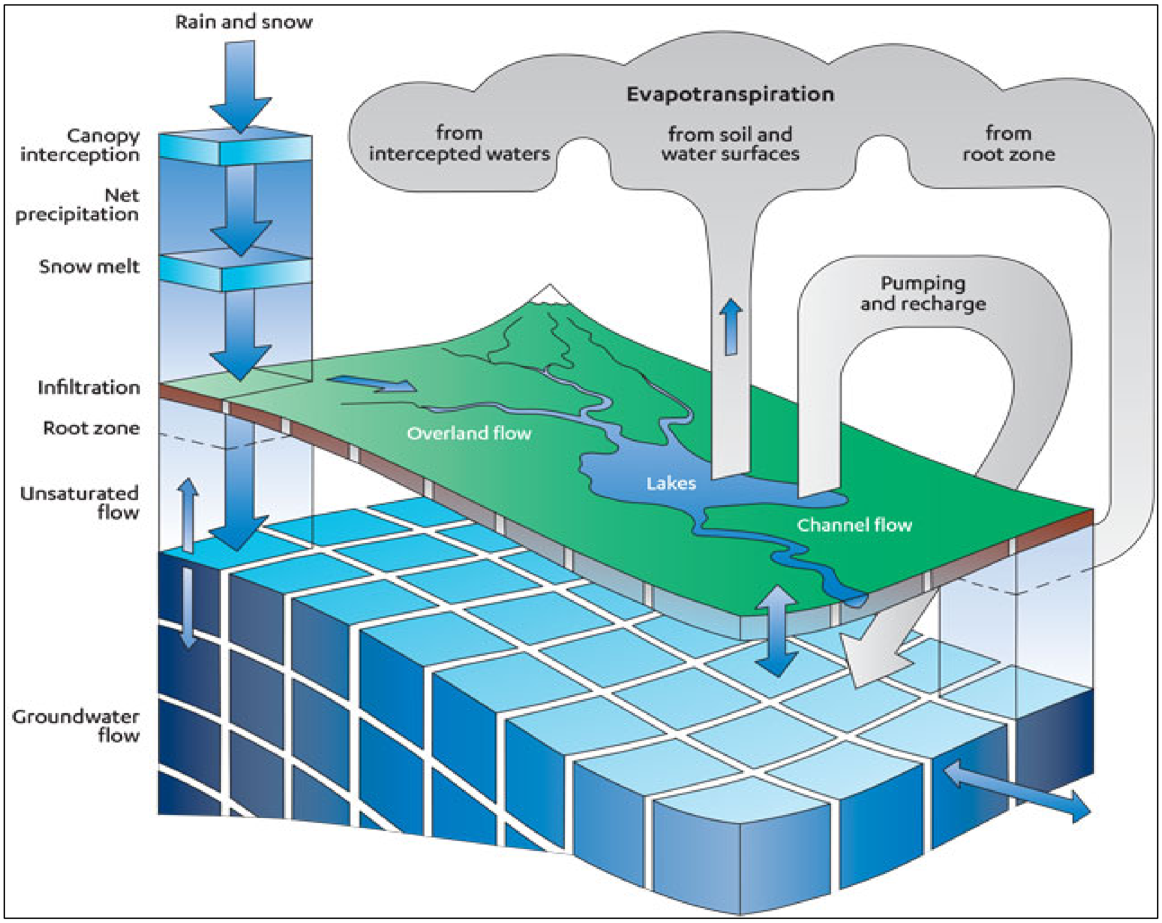
Figure A5.20 – (left) Interaction between the various submodels within the GSFLOW code (modified from Markstrom *et al.*, 2008); and, (right) hydrologic processes represented in PRMS (from Markstrom, *et al.*, 2015)



PRMS processes daily climate data and then partitions it between all the storage reservoirs (e.g., canopy storage, snowpack, depression storage, and soil moisture storage) and flows (e.g., evapotranspiration, overland runoff, interflow and groundwater recharge) as shown in the flow chart in Figure A5.20a and b. The main part of MODFLOW-NWT simulates saturated groundwater flow. Unsaturated flow between the soil zone and the water table, surface water routing (streamflow) and the lake water balances are simulated by additional modules within the MODFLOW-NWT code.

MIKE SHE is a combination of the SHE hydrologic model, the MIKE-11 channel routing model, and a finite-difference groundwater model developed by the Danish Hydrologic Institute (DHI, 2009). The code is proprietary and available for purchase by through DHI: www.mikepoweredbydhi.com.

Figure A5.21 - Key processes in the MIKE-SHE model

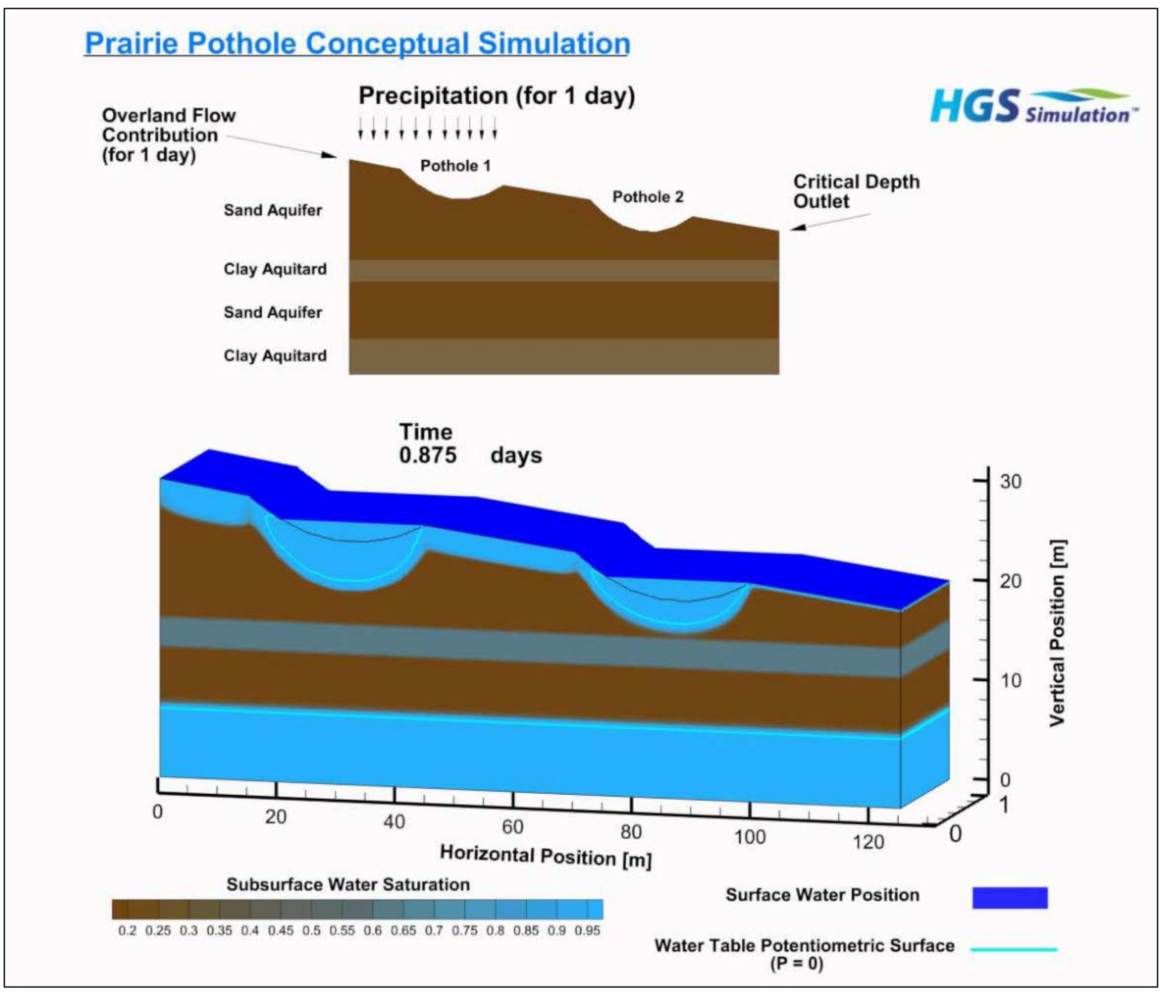


The SHE model computes precipitation, unsaturated flow, overland flow, and saturated flow on the same, uniform grid. The code offers users a wide range of choices for the methods used internally. After accounting for canopy interception and snowmelt, water is supplied to the ground surface. Unsaturated zone (either a 1-D finite difference approximation of the Richards equation; gravity flow; or a 2-layer water balance with or without Green-Ampt infiltration) is used to compute vertical flow in the unsaturated zone. When groundwater heads are greater than the ground surface, groundwater discharge occurs as Dunnian runoff. Hortonian runoff can also be generated when net precipitation is greater than the infiltration rate. Overland runoff can be simulated either in (1) a lumped approach where the model domain is divided into catchments and runoff is directly routed to the MIKE-11 channel network located within the catchment or (2) with a distributed approach using the 2-D diffusive wave approximation. Runoff from one cell flowing to an adjacent cell is available for infiltration in the adjacent cell. Saturated flow can be represented by (1) a linear groundwater reservoir or (2) a 3-D finite-difference method (similar to MODFLOW). Groundwater discharge to streams is calculated based on the difference between g groundwater heads and the stage in the Mike-11 channel. Additional information on MIKE-SHE can be found in AquaResource (2011a).

HydroGeoSphere (HGS) is a fully integrated, distributed model developed by researchers at the University of Waterloo, Université Laval, and HydroGeoLogic, Incorporated (Therrien *et al.*, 2010). The code is proprietary and available for purchase by contacting sales@aquanty.com.

The surface flow module of HydroGeoSphere is based on a modification of the Surface Water Flow Package of the MODHMS model. Model processes include rainfall, evapotranspiration and interception, 2-D overland and channel flow using a 2-D diffusive-wave approximation, and 3-D variably-saturated flow in the subsurface using Richards equation. HydroGeoSphere employs the control volume finite element (CVFE) method for subsurface flow and can represent fractures, macropores and tile drains in the subsurface. HydroGeoSphere is unique in that the user does not specify the layout of the drainage network. Rather, the model determines where water forms channels based on simulated pressure and the supplied DEM. This can limit the degree of resolution at which channels are represented and, as well, HydroGeoSphere cannot presently simulate hydraulic control structures.

Figure A5.22 - Example of a HydroGeoSphere application to simulate prairie potholes in Saskatchewan



In Hydrogeosphere, all processes are solved simultaneously and the model proceeds at a time step determined by the most dynamic processes considered (for example, unsaturated zone response to a storm event use very small time steps while saturated groundwater flow processes use relatively large time steps). Depending on the dynamics of the watershed, a significant computational overhead may be incurred. HydroGeoSphere employs an adaptive time stepping to optimize time step sizes and aid convergence of the iterative solver. Additional information on HydroGeoSphere can be found in AquaResource (2011a).

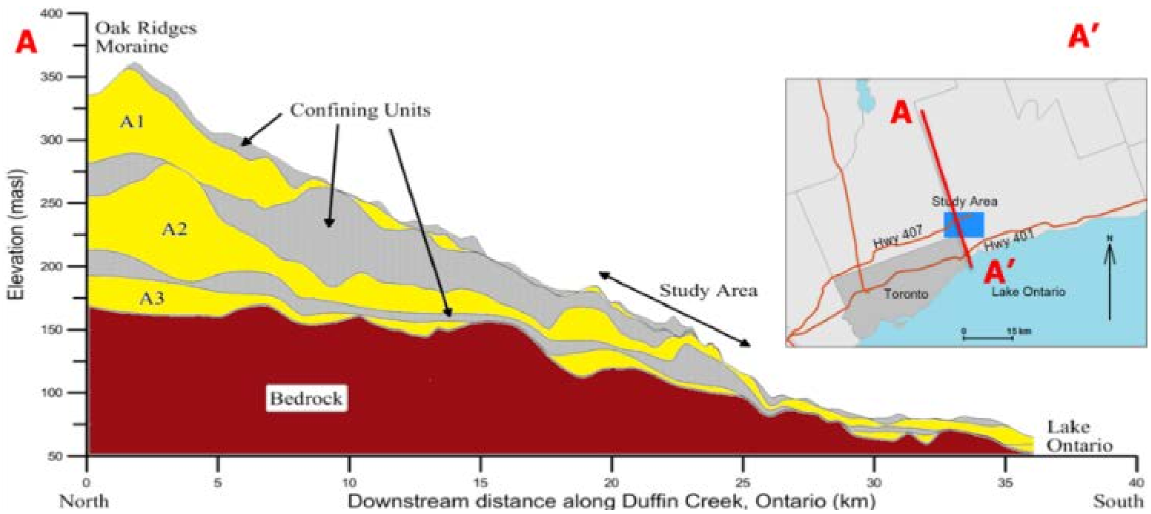
Table A5.8 - Integrated modelling codes commonly applied in Ontario

Model Name	Source	Code	Reference
GSFLOW	USGS	Open-source	http://water.usgs.gov/ogw/gsflow/
MIKE-SHE	DHI Inc.	Proprietary	https://www.mikepoweredbydhi.com/products/mike-she
HydroGeoSphere	Aquanty Inc.	Proprietary	https://www.aquanty.com/hydrogeosphere/

Example: Coupled Analysis for the Seaton Lands Master Environmental Servicing Plan

As a result of provincial efforts to protect the Oak Ridges Moraine and create the Ontario Greenbelt, a number of proposed land developments were relocated and consolidated into a new community for 70,000 residents located north of Pickering, Ontario. This proposed community of Seaton is located on the southern flank of the moraine, on a till plain that is dissected by incised streams, ponds, and wetlands that was to be protected from the effects of urban development (Figure A5.23). Regional groundwater flow emanating from the moraine as well as from local surficial sand and gravel deposits support groundwater-fed wetlands and baseflow to streams. The detailed assessment of this new community, at the Master Environmental Servicing Plan (MESP) level, provides insight into the coupled analysis of groundwater and surface water impacts for a large and complex land development project.

Figure A5.23 - North-South hydrogeologic section through the proposed Seaton lands development

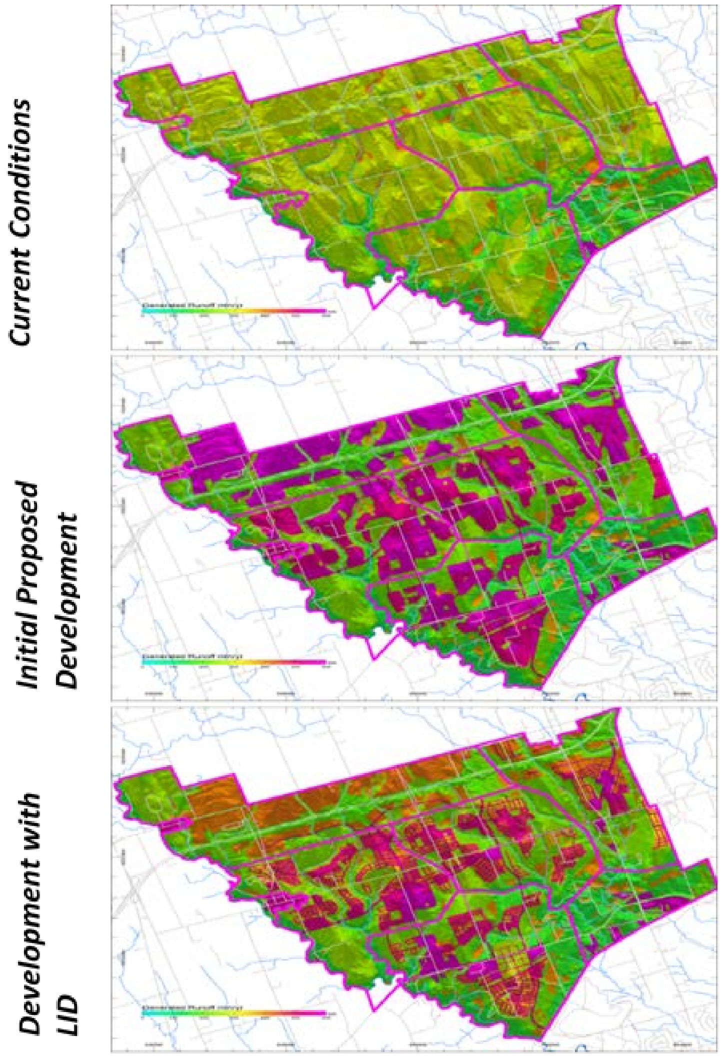


The cumulative impact of development on the wetlands and streams, as well as reductions in groundwater levels, was of regulatory concern. The variable nature of the soil and subsurface conditions, the locations of ponds and wetlands, and the types of development planned (e.g., residential or commercial) helped in the selection and design of LID strategies.

A loosely-coupled surface water/groundwater model was used to assess the site. A sub regional model was extracted for the Rouge River/ Creek watersheds from an existing regional-scale groundwater model (and Wexler, 2006) based on the USGS MODFLOW code. The sub regional model was locally refined to reflect data obtained from on-site drilling, field investigations, and aquifer testing. Particular attention was given to refining the shallow layer aquifer geometry in the groundwater model and ensuring consistency between new surficial geologic mapping and the subsurface model layers. A regional-scale hydrologic model, based on the USGS PRMS code, was available from a Tier 1 source protection study and was further refined to incorporate local site data and provide high spatial resolution (10 m cell size for HRUs) of soils and land use. The code was further modified so that LID BMPs could be represented using simple reservoirs.

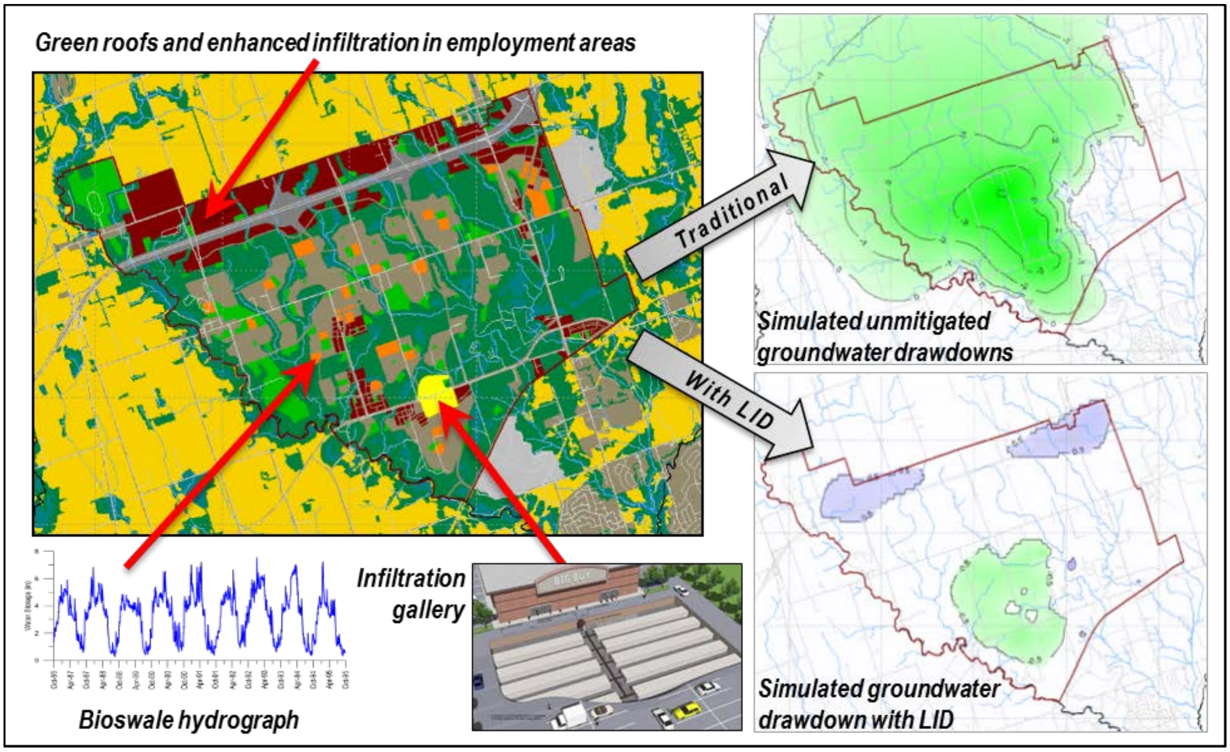
The updated groundwater and surface water models were used to simulate baseline runoff (Figure A5.24) and recharge rates, heads in each aquifer, and baseline groundwater discharge to the streams and wetlands. Land use types were then altered to reflect the planned development. Much of the planned development is concentrated in areas currently used for agriculture so natural features (wetlands and ponds) were not disturbed, but the function was not necessarily protected.

Figure A5.24 - Change in simulated runoff under various development scenarios



The models were run under various development conditions and the results were compared to baseline conditions. Under the “without LID BMPs” conditions, the reduction in recharge due to increased imperviousness and routing of storm runoff to stormwater management features (SWMFs) and nearby stream reaches, resulted in drawdowns in excess of 4.5 m (Figure A5.25). Significant decreases in groundwater discharge to wetlands and streams were also predicted.

Figure A5.25 - Assessment of surface water/groundwater interactions under different development scenarios (courtesy Earthfx Incorporated)



A variety of LID BMPs were integrated into the "with LID BMPs" scenario to (1) increase evaporative loss and reduce runoff volumes through green roofs, bioswales, increased soil depth, and increased vegetation density; (2) increased groundwater recharge through permeable/pervious/porous surfaces and by routing captured runoff to infiltration galleries under impervious surfaces; and (3) by use of infiltration ponds and routing roof-runoff to pervious areas though downspout disconnects.

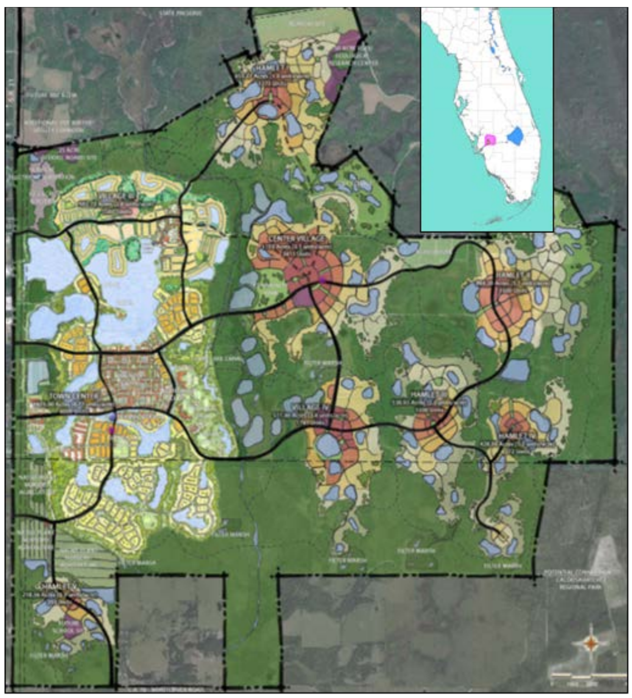
The coupled models were able to demonstrate improvements to both the surface water and groundwater system from the application of LID strategies. Comparing the "with LID BMPs" and "without LID BMPs" scenarios showed that the LID BMPs helped to reduce overall groundwater drawdowns by 86% (Figure A5.25), restored 42% of lost groundwater discharge to streams, and reduced increased runoff generation by 80%. The models were used to test other LID BMPs and results were provided to other members of the study team for use in improving LID design and assessing erosion. Simulated runoff volumes (Figure A5.24) were tabulated and provided to the stormwater management modelling team for simulating the SWMFs and channel hydraulics using Visual OTTHYMO.

The Seaton example demonstrates how a loosely coupled modelling approach can be used to assess a large-scale land development. Multiple modelling approaches were required to achieve all the project objectives, but each model benefited from the collaborative, integrated nature of the overall project elements.

Example: Integrated Analysis of the Proposed Babcock Ranch Community Development (Earthfx, 2013)

An integrated surface water/groundwater model was developed to predict the hydrologic change induced by the proposed Babcock Ranch Community (BRC) site in Lee County, FL (Figure A5.26). The 310 mi² study area encompassed three watersheds and is bounded to the south by the Caloosahatchee River. The BRC development is to have 19,500 homes in concentrated "development pods" with the remaining acreage to be left as wetland preserves and natural areas. The integrated model was applied to evaluate the stormwater management system proposed for the BRC and confirm that it would restore "natural" conditions for groundwater, wetlands, and streams.

Figure A5.26 - Proposed Babcock Ranch Community showing planned stormwater management system

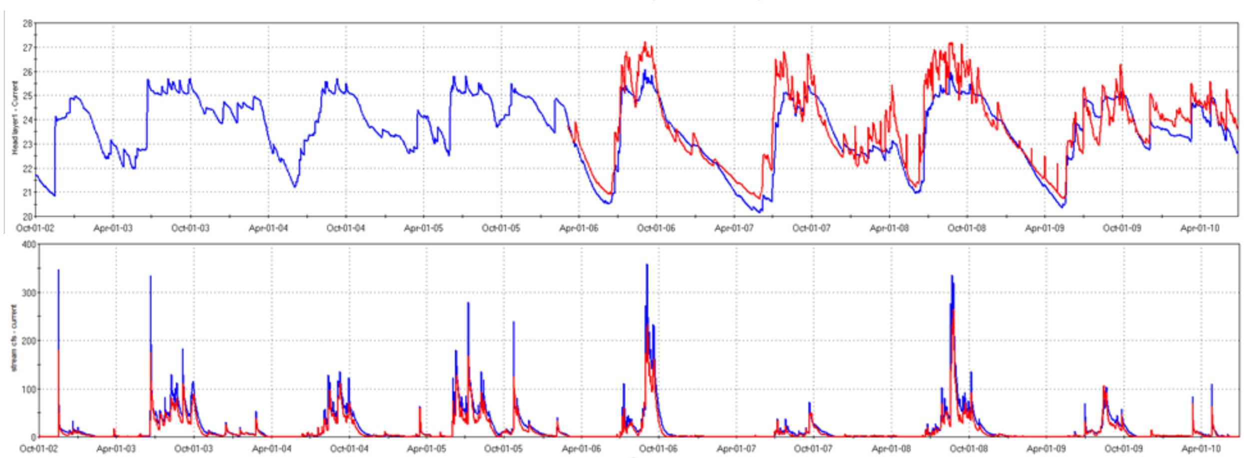


The integrated surface water/groundwater model was built using the USGS GSFLOW code. The PRMS submodel simulated soil processes while the MODFLOW submodel simulated transient groundwater flow as well as flow, stage, and groundwater interaction in the wetlands and streams. Both models used a 100x100 m grid. The PRMS submodel incorporated NEXRAD precipitation and other climate, soil property, vegetation, and land use data to produced daily estimates of overland runoff, infiltration, ET, and groundwater recharge. A cascading overland flow algorithm routed runoff and interflow. The groundwater system consisted of five aquifers and three aquitards. Over 500 shallow wetlands, lakes, and stormwater ponds were explicitly represented in the model along with their hydraulic control structures (Figure A5.27).

Figure A5.27 - Typical existing hydraulic structures incorporated into the integrated surface water/groundwater model (left, middle), and artist's rendering of planned mixed-use urban water feature (right)

The calibration period (presented on Figure A5.28) for Current Conditions extended from WY2007 to WY2010 and included an extreme dry year and several wet years. Observed flow at 10 gages on 13 streams, wetland stage data, and heads at 165 observation wells were used in model calibration. Hydrographs demonstrated that good matches were achieved to groundwater heads and streamflow.

Figure A5.28 - Simulated (blue) and observed (red): daily groundwater heads (top), and streamflow (bottom)



To represent Natural Conditions, anthropogenic features such as roads, ditches, berms and water control structures were removed from the model. For Post-development ("with LID BMPs") Conditions, all proposed stormwater management control structures, ponds and treatment marshes were added. Comparisons of simulated daily streamflow, wetland stage, and heads showed that leakage (infiltration losses) from the stormwater management BMPs under Post-development Conditions helped mitigate changes in groundwater recharge and decreased average daily discharge during storm events (Figure A5.30). The final design also moderated wetland hydroperiods (Figure A5.29) within the natural features in the BRC as compared to the Current Conditions.

Figure A5.29 - Increase in wetland/storm pond hydroperiod between current and post-development

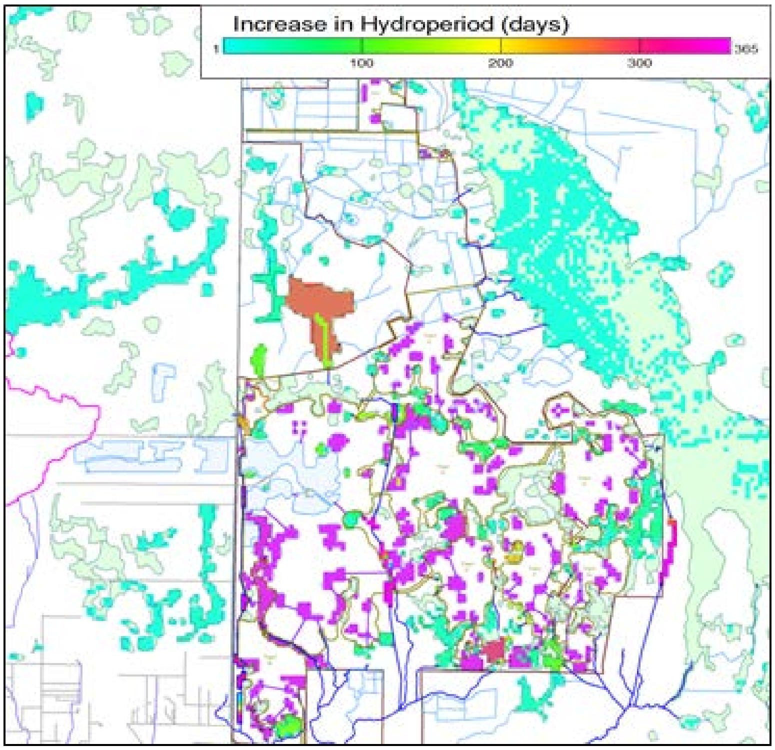
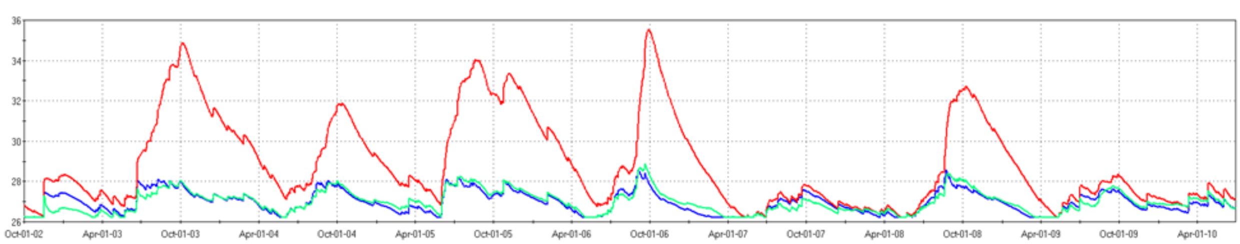


Figure A5.30 - Simulated wetland stage under current (red), natural (green), and post-development conditions (blue). Offsite runoff is reduced in the post-development scenario returning this feature to a nautual hydrologic regieme



A5.2 Model Selection Framework

This section of the appendix presents examples of the modelling selection framework presented in **Section 5.4** used to scope and evaluate a modelling approach.

A5.2.1 Example Application of Model Selection Framework – Seaton Lands MESP

The following demonstrates how the Model Selection Framework could be applied to evaluate the modelling approach employed in the Seaton Lands MESP study. A completed selection table is presented as Table A5.9, a discussion of the rationale by site factor is provided below.

Scale: The scale of this proposed development is large as it encompasses 3000 ha. The site both responds to and affects regional surface water and groundwater flow. Accordingly, a loosely-coupled approach (Class D) was taken to assess the site. A sub regional groundwater flow model was extracted from an existing regional-scale groundwater model (Kassenaar and Wexler, 2006) based on the USGS MODFLOW code, and was locally refined to incorporate new site-specific data. Similarly, a new, higher-resolution hydrologic model was developed from a regional-scale Tier 1 source protection hydrologic model, based on the USGS PRMS code, which incorporated local site data and represented planned modifications to the Seaton Lands. The loosely-coupled hydrologic and groundwater flow models were needed to assess and compare the effectiveness of LID BMPs across the large study area.

Site Conditions: Site conditions generally consisted of agricultural land on an extensive till plain but with significant natural heritage features in the river valleys. While the larger-scale geologic and surface water features were well understood, the hydrogeologic function of patchy Iroquois Beach sand deposits in supporting local ecological features (wetlands) and some headwater streams on the till plain, was of concern. Thus, the area was not fully-naturalized nor fully- agricultural. This, along with the complexity of some local settings and the number of heritage features in the river valleys, necessitated a combination of Class B and D modelling techniques for LID analysis.

Stormwater Management: Due to the scale of the site, the stormwater management Plan considered a large number (69) end-of-pipe SWMF along with other control measures. As well, LID BMPs were distributed across the site to reduce runoff and maintain natural water balances. A combined approach using Class B and Class D models was employed to assess their effectiveness. The Visual Otthymo model (Class B) was used to simulate peak flow rates for existing conditions and future conditions with and without LID BMPs. The loosely-coupled hydrologic and groundwater models (Class D) were used to provide recharge and groundwater baseflow estimates for use in Visual Otthymo simulations.

Stream Geomorphology and Erosional Impacts: Increased erosion in the developed areas and in the river valleys were of particular concern to the regulators. The study developed appropriate erosion thresholds and applied the QUALHYMO surface water model (Class B) to each subwatershed to evaluate erosion sensitivity under various conditions. Analyses were completed to determine the duration of flows within specified ranges above the critical flow rate for erosion and to recommend storage volumes and release rates for SWMF design. The loosely-coupled hydrologic and groundwater models (Class D) were used to provide recharge and groundwater baseflow estimates for use in QUALHYMO (Class B) simulations.

Proximity to Surface Water Dependant Natural Features: Surface-water dependant natural features (small wetlands and low-order streams) were mostly located on the low-permeability till plain and were functionally related to swales and undulations in the till surface. Feature-specific field assessments and local-scale water budgets were completed for these sensitive features. The surface water features were incorporated, where possible, into the LID design process and assessed using the loosely-coupled hydrologic and groundwater models (Class D).

Proximity to Groundwater-Dependant Natural Features: A large number of groundwater-dependant wetland and stream features were located in the incised river valleys. Additional groundwater-dependant features were located on the till plain and supported by local recharge from adjacent Iroquois Beach sand deposits. All wetland features were represented in the surface water/groundwater model (Class D) and changes in groundwater recharge and discharge was assessed under future development scenarios. Based on results, bioswales were proposed for placement in close proximity to these features, where possible.

Depth to Water Table: Because of the fine-grained soils, much of the area exhibits shallow depth to water. Wells were monitored continuously to identify areas where seasonally high water levels might limit the effectiveness of infiltration-based LID BMPs. Groundwater/surface water interaction was considered using the loosely-coupled surface water/ groundwater model (Class D). Minimizing drawdowns in the underlying aquifers was also considered an overall design goal. To assess the cumulative impact to groundwater, drawdown maps were prepared to compare simulated heads for alternative development scenarios to those of current conditions.

Soils and Surficial Geology: As noted above, the till covered areas exhibited low-permeability soils that would restrict the use of infiltration-based LID BMPs. Assessment of the effectiveness of infiltration-based LID BMPs was evaluated with the Class D models. The models also assessed recharge to the Iroquois Beach sands and demonstrated that these units had the capacity to accept focussed infiltration from the planned LID BMPs.

Conclusions: The Seaton land development impact analysis is an example of a large-scale, complex modelling assessment. Multiple models, each with specific strengths and areas of focus, were used in a coordinated and coupled manner to assess all aspects of the surface water and groundwater conditions and potential impacts from the proposed development.

Table A5.9 - Example Model Evaluation Exercise - Seaton Lands MESP

SITE FACTOR	RATIONALE	DETAILED CONSIDERATIONS	NOTES	INDICATED CLASS OF MODELLING EFFORT	(PROPOSED) CLASS OF MODELLING EFFORT (A/B/C/D)	JUSTIFICATION REQUIRED? (Y/N)
Scale of Proposed Development	*Level of effort required will reflect the physical scale of the proposed development. Larger developments will likely have more significant impacts than a relatively small infill or a retrofit and require more detailed models that consider a larger spatial extent and the impacts on groundwater and surface water.*	Small (0-20 hectares)	Minor impacts to the local hydrologic system expected	A		No
		Medium (20-250 hectares)	Should consider the local groundwater and surface water systems	B/C		
		Large (250+ hectares)	Must consider the local to regional scale water balance	D	**D**	
Pre-development Site Conditions	*Retrofits, redevelopments, or infill-developments in urbanized areas would have a low potential for measurably affecting the water balance and would generally require a limited level of analysis. Developments in fully naturalized sites would likely have the greatest relative change and would require more analysis. Existing stormwater infrastructure will need to be included in the modelling exercise.*	Full Naturalized	Significant potential for alteration of the hydrologic system	D		No
		Agricultural	Moderate to significant potential for alteration of the hydrologic system	B/C	**B & D**	
		Peri-Urban	Moderate to significant potential for alteration of the hydrologic system	B/C		
		Urban	Low potential for negative impacts to the hydrologic system	A		
Stormwater Management System Design	*The number and distribution of the LID BMPs is one consideration. A large number of widely distributed measures is more likely to affect the overall water balance and would need more in-depth analysis. The complexity of the stormwater management features is another consideration. Simple runoff models could be used to analyze standard measures like stormwater detention ponds, for example. The design and assessment of LID BMPs is more complex and requires more sophisticated models. Proposed stormwater sewer system and non-LID stormwater management measures should be included in the modelling.*	None/Evacuation	No stormwater management measures planned (*approach may not be acceptable to regulators or stakeholders*)	A		No
		Detention	Traditional stormwater management practices (*approach may not be acceptable to regulators or stakeholders*)	A/B		
		Focussed, localized infiltration and storage	Management plan considered some LID BMPs, mostly large scale, isolated components	B/C		
		Widespread, distributed infiltration and storage	Complex management plan, with many, distributed LID BMPs	B/C/D	**B & D**	
Stream Geomorphology and Erosional Impacts	*Changing the volumes and recurrence of stormwater flows can lead to increased erosion and changes in the geomorphology of reaches within and downstream of the development. Proposed developments in areas where streams are particularly sensitive to geomorphological change will likely generate greater concern from adjacent land owners, conservation authorities, and municipal or county agencies.*	Low likelihood of downstream impacts to channel stability	Sediment transport yields and stream channel stability is unlikely to be affected by planned alterations	A	**B & D**	No
		High likelihood of downstream impacts to channel stability	Changes to the runoff or land cover characteristics of the site have a high potential to either destabilize local stream systems or increase sediment yields	B/D		
Proximity to Surface water Dependant Natural Features	*Sensitive surface water features, such as runoff-dependent wetlands, headwater streams on low permeability materials, and some cold water streams, would require more in-depth analysis as they are sensitive to changes in the water balance resulting from the cumulative effects of development.*	Wetlands	Potential for offsite impacts through alteration of the site runoff characteristics (*unless feature is demonstrated to be disconnected from the surface water system*)	A/B/D	**D**	No
		Sensitive downstream habitat	Potential for offsite impacts through alteration of the site runoff characteristics	B/C/D		

SITE FACTOR	RATIONALE	DETAILED CONSIDERATIONS	NOTES	INDICATED CLASS OF MODELLING EFFORT	(PROPOSED) CLASS OF MODELLING EFFORT (A/B/C/D)	JUSTIFICATION REQUIRED? (Y/N)
Proximity to Groundwater-Dependant Natural Features	*Sensitive surface water features, such as groundwater-dependent wetlands, headwater streams that are groundwater fed, and cold water streams, would require more in-depth analysis as they are sensitive to changes in the water balance resulting from the cumulative effects of development. Features in areas designated as wellhead protection areas, highly vulnerable aquifers, high-volume recharge areas, and ecologically-significant recharge area would also require more in-depth analysis*	Wetlands	Potential for offsite impacts through alteration of the local groundwater flow system (*unless feature is demonstrated to be disconnected from the groundwater system*)	C/D	**C / D**	No
		Coldwater Streams	Potential for offsite impact to natural features through alteration of the local groundwater flow system	C/D	**C / D**	
		Streams with measured baseflow contribution (BFI > 0.5)		C/D	**C / D**	
		Ecologically Significant Groundwater Recharge Areas (ESGRAs)		C/D		
		Significant Groundwater Recharge Areas (SGRAs)/High Volume Recharge Areas (HVRAs)	Potential for impacts to the regional groundwater flow system	B/C/D		
		Wellhead Protection Areas (WHPAs) & Vulnerable Aquifers (HVAs)	Potential for impacts to municipal/regional water supply sources	B/C/D		
Depth to Water Table	*Analyzing the pre- and post-development water balance is areas with shallow depth to the water-table requires complex models to simulate the non-linear feedback between processes controlling Dunnian runoff, ET, and groundwater recharge.*	Shallow (Seasonal depth to water table < 4m)	Suggests high vulnerability to local changes in drainage and recharge, correct functioning of LID BMPs must be evaluated	B/C/D	**D**	No
		Deep (Seasonal depth to water table > 4m)	Suggests low vulnerability to local changes in recharge, potentially high capacity to accept additional infiltration/recharge	A/B		
Soils and Surficial Geology	*Areas with poor drainage and/or low-permeability soils, such as silts and clays, at surface clay can impair the effectiveness of infiltration-based LID BMPs. Analytical or numerical groundwater models would be needed to predict water table response to infiltration and examine how these features perform and to assess the need for underdrains.* *(* indicates the need for detailed field investigations)*	Thick (>5-8m), highly permeable soils (gravel to medium sand) at surface	High capacity to accept additional infiltration/recharge	A/B	**B & D**	No
		Thin (<5m), highly permeable soils at surface underlain with lower permeable soils	Moderate capacity to accept additional infiltration/recharge, may require further investigation	B/C/D		
		Moderately permeable (fine sands to sandy silts) soils at surface	Low capacity to accept additional infiltration/recharge	B*/C/D	**B & D**	
		Fine grained (silt, clays, silt/clay tills, and organics) at surface	Very low capacity to accept additional infiltration/recharge	B*/C/D	**B & D**	

A5.2.2 Example Application of Model Selection Framework – Wateridge Village Subdivision LID Design – Phase 1A

Scale: The total area of the proposed development was approximately 150 ha, which corresponds to a medium scale development site factor. Two significant studies were completed in anticipation of the proposed development. The “Former CFB Rockcliffe Community Design Plan” (August 2015) included a Draft Preferred Plan that defined the overall land use, road and block pattern for the community. The “Former CFB Rockcliffe Master Servicing Study” (August 2015) included a plan for provision of major infrastructures needed to support the proposed development. With respect to stormwater management, the site was designed with dual drainage concept and runoff from the proposed development is to be conveyed by major and minor systems to downstream stormwater management facilities. Hydrological analysis of the proposed dual drainage system was conducted using DDSWM and the hydraulic analysis of the proposed sewer system was conducted using XPSWMM. A surface water runoff model (Class B) was developed to consolidate the DDSWM and XPSWMM models. LID BMPs designed for the Phase 1A area (LID Demonstration Area) were also incorporated into the consolidated model.

Site Conditions: The site is a former Canadian Forces Base and the majority surface infrastructures are roads and parking lots. The proposed development would pose moderate potential for alteration of the hydrologic system; therefore, a surface runoff model (Class B) was deemed the appropriate approach to assess the development impact.

Stormwater Management: The design of the proposed Ph1A development area incorporated multiple LID BMPs across the site. Proposed LID BMPs include soakaway pits, enhanced swales, and bioswales in road right-of-way. A surface runoff Model (Class B) was used to evaluate the effectiveness of the widespread and distributed LID BMPs.

Stream Geomorphology and Erosional Impacts: There are two significant watercourses downstream of the proposed development. Runoff from the development site currently drains to both watercourses. However, runoff from Phase 1A will be directed away from the two creeks and routed to a new stormwater management facility which will discharge directly to the Ottawa River. Studies were conducted to evaluate the fluvial geomorphological stability of the creeks. The Western Creek was determined to be geomorphically stable, with most reaches lacking obvious signs of ongoing erosion. However, the Eastern Creek has several sub-reaches that show signs of channel instability. Engineering works, such as culverts, have the potential to destabilize the channel in both creeks; therefore, it is crucial that any future stormwater detention pond designs minimize perturbation of the channel. Due to the high likelihood of downstream impacts to channel stability, a surface runoff model (Class B) was selected as the appropriate modelling approach to assess the flow input to the creeks.

Proximity to Surface Water Dependant Natural Features: Sensitive surface water features are not identified in the development area; therefore, this factor was not applicable in the consideration of the model evaluation

Proximity to Groundwater-Dependant Natural Features: Sensitive groundwater features were not identified in the development area; therefore, this factor was not applicable in the consideration of the model evaluation.

Depth to Water Table: A hydrogeological report was completed to assess existing hydrogeological conditions in the development area and to determine the expected potential impacts on groundwater and groundwater users. Average groundwater depth was approximately 3.4 m. However, due to the proposed site raise and soil amendment plans, the ultimate development condition is considered to be highly capable of accepting infiltration/recharge. The surface runoff model (Class B) was considered appropriate for the water table setting on site due to its limited impact to surface water conditions.

Soil and Surficial Geology: Stratigraphy on the east side of the development area consists of asphalt surface treatment underlain by granular sand and gravel which is, in turn, underlain by silt or clay layer followed by bedrock. Stratigraphy on the west side of the area consists of a thin layer of topsoil underlain by silty clay and sand and gravel layers followed by possible bedrock. Overall, the stratigraphy of the site can be considered to be of a thin layer of highly permeable soil at the surface underlain with lower permeable soils. The development design included soil amendment to promote infiltration. The surface runoff model (Class B) developed to reflect the designed infiltration capacity of the amended soil was considered to be appropriate in the assessment of infiltration-based LID BMPs.

Conclusions: The Wateridge Village development impact analysis is an example of a medium-scale modelling assessment. The development will have limited impact to and by the groundwater system and is not near any surface water/groundwater sensitive features. The development area has moderate drainage system complexity and the surface runoff model (Class B) was considered to be appropriate for the impact assessment. A completed model selection table for this project is presented as Table A5.10.

Table A5.10 - Example Model Evaluation Exercise - Wateridge Village Subdivision LID Design – Phase 1A

SITE FACTOR	RATIONALE	DETAILED CONSIDERATIONS	NOTES	INDICATED CLASS OF MODELLING EFFORT	(PROPOSED) CLASS OF MODELLING EFFORT (A/B/C/D)	JUSTIFICATION REQUIRED? (Y/N)
Scale of Proposed Development	*Level of effort required will reflect the physical scale of the proposed development. Larger developments will likely have more significant impacts than a relatively small infill or a retrofit and require more detailed models that consider a larger spatial extent and the impacts on groundwater and surface water.*	Small (0-20 hectares)	Minor impacts to the local hydrologic system expected	A		No
		Medium (20-250 hectares)	Should consider the local groundwater and surface water systems	B/C	**B**	
		Large (250+ hectares)	Must consider the local to regional scale water balance	D		
Pre-development Site Conditions	*Retrofits, redevelopments, or infill-developments in urbanized areas would have a low potential for measurably affecting the water balance and would generally require a limited level of analysis. Developments in fully naturalized sites would likely have the greatest relative change and would require more analysis. Existing stormwater infrastructure will need to be included in the modelling exercise.*	Full Naturalized	Significant potential for alteration of the hydrologic system	D		No
		Agricultural	Moderate to significant potential for alteration of the hydrologic system	B/C		
		Peri-Urban	Moderate to significant potential for alteration of the hydrologic system	B/C	**B**	
		Urban	Low potential for negative impacts to the hydrologic system	A		
Stormwater Management System Design	*The number and distribution of the LID BMPs is one consideration. A large number of widely distributed measures is more likely to affect the overall water balance and would need more in-depth analysis. The complexity of the stormwater management features is another consideration. Simple runoff models could be used to analyze standard measures like stormwater detention ponds, for example. The design and assessment of LID BMPs is more complex and requires more sophisticated models. Proposed stormwater sewer system and non-LID stormwater management measures should be included in the modelling.*	None/Evacuation	No stormwater management measures planned (*approach may not be acceptable to regulators or stakeholders*)	A		No
		Detention	Traditional stormwater management practices (*approach may not be acceptable to regulators or stakeholders*)	A/B		
		Focussed, localized infiltration and storage	Management plan considered some LID BMPs, mostly large scale, isolated components	B/C		
		Widespread, distributed infiltration and storage	Complex management plan, with many, distributed LID BMPs	B/C/D	**B**	
Stream Geomorphology and Erosional Impacts	*Changing the volumes and recurrence of stormwater flows can lead to increased erosion and changes in the geomorphology of reaches within and downstream of the development. Proposed developments in areas where streams are particularly sensitive to geomorphological change will likely generate greater concern from adjacent land owners, conservation authorities, and municipal or county agencies.*	Low likelihood of downstream impacts to channel stability	Sediment transport yields and stream channel stability is unlikely to be affected by planned alterations	A	**B**	No
		High likelihood of downstream impacts to channel stability	Changes to the runoff or land cover characteristics of the site have a high potential to either destabilize local stream systems or increase sediment yields	B/D		
Proximity to Surface water Dependant Natural Features	*Sensitive surface water features, such as runoff-dependent wetlands, headwater streams on low permeability materials, and some cold water streams, would require more in-depth analysis as they are sensitive to changes in the water balance resulting from the cumulative effects of development.*	Wetlands	Potential for offsite impacts through alteration of the site runoff characteristics (*unless feature is demonstrated to be disconnected from the surface water system*)	A/B/D	**N/A**	No
		Sensitive downstream habitat	Potential for offsite impacts through alteration of the site runoff characteristics	B/C/D		

SITE FACTOR	RATIONALE	DETAILED CONSIDERATIONS	NOTES	INDICATED CLASS OF MODELLING EFFORT	(PROPOSED) CLASS OF MODELLING EFFORT (A/B/C/D)	JUSTIFICATION REQUIRED? (Y/N)
Proximity to Groundwater-Dependant Natural Features	*Sensitive surface water features, such as groundwater-dependent wetlands, headwater streams that are groundwater fed, and cold water streams, would require more in-depth analysis as they are sensitive to changes in the water balance resulting from the cumulative effects of development. Features in areas designated as wellhead protection areas, highly vulnerable aquifers, high-volume recharge areas, and ecologically-significant recharge area would also require more in-depth analysis*	Wetlands	Potential for offsite impacts through alteration of the local groundwater flow system (*unless feature is demonstrated to be disconnected from the groundwater system*)	C/D	**N/A**	No
		Coldwater Streams	Potential for offsite impact to natural features through alteration of the local groundwater flow system	C/D		
		Streams with measured baseflow contribution (BFI > 0.5)		C/D		
		Ecologically Significant Groundwater Recharge Areas (ESGRAs)		C/D		
		Significant Groundwater Recharge Areas (SGRAs)/High Volume Recharge Areas (HVRAs)	Potential for impacts to the regional groundwater flow system	B/C/D		
		Wellhead Protection Areas (WHPAs) & Vulnerable Aquifers (HVAs)	Potential for impacts to municipal/regional water supply sources	B/C/D		
Depth to Water Table	*Analyzing the pre- and post-development water balance is areas with shallow depth to the water-table requires complex models to simulate the non-linear feedback between processes controlling Dunnian runoff, ET, and groundwater recharge.*	Shallow (Seasonal depth to water table < 4m)	Suggests high vulnerability to local changes in drainage and recharge, correct functioning of LID BMPs must be evaluated	B/C/D		No
		Deep (Seasonal depth to water table > 4m)	Suggests low vulnerability to local changes in recharge, potentially high capacity to accept additional infiltration/recharge	A/B	**B**	
Soils and Surficial Geology	*Areas with poor drainage and/or low-permeability soils, such as silts and clays, at surface clay can impair the effectiveness of infiltration-based LID BMPs. Analytical or numerical groundwater models would be needed to predict water table response to infiltration and examine how these features perform and to assess the need for underdrains.* *(* indicates the need for detailed field investigations)*	Thick (>5-8m), highly permeable soils (gravel to medium sand) at surface	High capacity to accept additional infiltration/recharge	A/B		Yes (See Text)
		Thin (<5m), highly permeable soils at surface underlain with lower permeable soils	Moderate capacity to accept additional infiltration/recharge, may require further investigation	B/C/D		
		Moderately permeable (fine sands to sandy silts) soils at surface	Low capacity to accept additional infiltration/recharge	B*/C/D		
		Fine grained (silt, clays, silt/clay tills, and organics) at surface	Very low capacity to accept additional infiltration/recharge	B*/C/D	**B***	

A5.3 Model Development and Application

Selecting an appropriate model (or models) which can address the various hydrological conditions at a proposed site is only the first step. The modelling exercise must be scoped; the model constructed, verified, calibrated and validated; and the final design must be evaluated and documented. The following section provides a brief outline of the basic steps undertaken when applying a model to design stormwater systems or investigate an existing design. The proponent is also advised to consult the documentation for the model code selected and various texts on model development, calibration, and application (discussed in Section A5.2.10).

Some municipalities and conservation authorities provide technical guidelines for stormwater management submissions. These guidelines may include design criteria and methodologies, best management practices, and submission requirements. Available local guidelines should be followed to ensure the project objectives align with the requirements of the regulatory authority. Before undertaking any modelling study, it is advisable to pre-consult with the regulator to ensure the planned technical approach is aligned with the regulator's expectations.

A5.3.1 Detailed Model Selection

While the Model Selection Framework provides guidance towards the selection of a technical approach, the study proponent will need to select a specific model code to apply for each project. No specific guidance is provided here, as the final choice of model code remains up to the professional judgment of modelling team. The only general requirement is that the selected model must be able to adequately represent the physical processes at work within the study area. Furthermore, if a hydrologic process isn't represented explicitly it may not be possible to alter the process to represent future conditions. The team should consider the following when selecting a final model and developing a modelling approach:

Spatial Extent and Resolution. The modelling approach must be able to assess the hydrologic processes at a scale and level of detail suitable for the proposed site.

Runoff Generation and Routing. It must be shown that the modelling approach uses an appropriate runoff generation and routing method. Ideally it should account for Hortonian (infiltration excess and Dunnian (saturation-excess) processes, runoff from impervious areas to pervious, and re-infiltration of run-on from other areas.

Snow Accumulation and Snowmelt. Snowmelt processes are always important in Ontario and should be adequately considered where necessary.

Evapotranspiration. Potential Evapotranspiration rates vary depending on soil type, vegetation, and climate while Actual ET depends on the available soil moisture. The selection of the ET simulation method will play a large role in determining data requirements and ultimate accuracy of the model predictions.

Infiltration/Soil Moisture. The model should represent processes that occur at the soil surface and within the soil zone. These focus on the partitioning of infiltration and runoff and can be represented in a range of ways and levels of complexity (e.g., SCS curve numbers, Green and Ampt relation, or -1-D and 3-D Richards equation). As with ET processes, the method selected will play a large role in determining data requirements and ultimate accuracy of the model predictions.

Recharge. Recharge is of prime importance in modelling the groundwater system and in particular during the design of LID BMPs. The model should be able to represent movement and storage in the unsaturated zone in areas of deep water table.

Groundwater/Surface Water Interactions. Groundwater plays in important role in sustaining low flows in many streams and rivers: if required, the model used must be able to effectively represent streams and wetlands and be able to transfer water from the groundwater system to the surface water system.

River Hydraulics and Routing. The type of streamflow routing, and relationship between flows and stage, will depend on the nature of the water course.

Continuous Simulations. If continuous simulations are required, the model must be able to perform at a suitable temporal resolution. Continuous simulations should represent a climate period long enough to include wet years and dry years. Ideally, the climate dataset should be synthesized from existing climate data but may need to be synthetically generated in data poor areas.

A5.3.2 Data Collection

Data collection represents the first task in model development. Data must be obtained at a suitable temporal and spatial resolution to support the parameterization, calibration, and validation of the final model. Section A5.3 provides a detailed discussion of the data needs for different model classes and the sources of data available for model development in Ontario. Previous studies conducted in the general area can provide insight into reasonable values for model parameters and identify technical issues that may need to be considered.

After the selection of a specific modelling code and initial attempts at implementation, new data gaps and sources of uncertainty within the site characterization may arise. This might require the collection of additional field data on-site to ensure an accurate parameterization of the selected model to match site conditions.

A5.3.3 Establishing Modelling Objectives

Specifying the objectives of a study represents an important step in any modelling exercise. Correctly scoping the study at an early stage is critical to ensuring that the model is developed with the capacity to explain and represent the hydrologic regime at the study site and predict future conditions. This step involves clearly defining how the model will be employed, as a design and/or analysis tool.

Study boundaries should be defined that encompass the study site, key monitoring locations, and sensitive ecological features that are proximal to study site (Sections 5.3.5 and 5.3.6). Additionally, the appropriate temporal and spatial scales to describe the hydrologic regime at the study site should be clearly defined. Key sensitive features, special policy areas and targets, both water quality and quantity, should be identified at this stage. Likely, a portion of this work would have been completed as part of applying the model selection framework.

Existing or baseline conditions should be established. This work may draw upon previously completed Subwatershed Studies or Environmental Implementation Reports. Baseline conditions should be used to set performance targets to control offsite runoff as well as onsite infiltration and recharge. For retrofits, redevelopments, or infill-developments there may be opportunities to restore pre-development hydrologic function. In these cases, baseline conditions could include performance targets based on estimated pre-development conditions or model simulations of historical conditions.

At this stage in the study, clear lines of communication should be established with review agencies and project stakeholders to ensure the modelling objectives meet the study requirements. Specific performance targets may be dictated by local regulations, and regulators may have specific site concerns that must be addressed. Scoping the modelling objectives can often be an iterative process, but a collaborative and open approach will help guarantee project success.

A5.3.4 Model Construction

Model construction describes the process of preparing the input data in the correct format, creating the model input files, and undertaking initial simulations. Model construction forms the first step in the calibration and validation of the model. Model construction relies heavily on the availability of good quality data and field observations with which to characterize the study area. A well-supported field program and data foundation (Section A5.3.2) can improve the quality of the initial parameterization and final calibration of the model. Model parameters are revised to improve the model's match to the local hydrologic and hydrogeologic conditions through the model verification and calibration steps discussed below.

The steps required to parameterize a hydrologic, groundwater, or integrated model can vary significantly between model codes. Lumped catchment models (see Section 5.1.2) or similar types of codes often require few parameters. The preparation of inputs for these models is usually more straightforward, however, many of these parameters cannot be directly estimated from site characteristics and require calibration. Data preparation for distributed, physically-based models is typically more complex; however, many parameters can be estimated for site or catchment properties. Model manuals and previous modelling studies represent key resources during construction and parameterization.

To the greatest extent possible, model parameters should be derived from site specific field observations. The topographic features onsite should be represented at the finest resolution possible and can be derived from digital elevation models or site surveys. Infiltration and recharge parameters, soil zone parameters, and hydraulic conductivities should ideally be obtained from onsite soils analysis or borehole drilling. Regional land coverage mapping should be revised for consistency with the existing site conditions, if required.

If developing a continuous model, long-term climate data inputs should be prepared to drive the model simulations. Many agencies require long-term runs of 30-years or greater when developing site water budget elements. When evaluating the performance of a stormwater system or a specific LID feature, long-term runs allow performance to be evaluated under dry, average, and wet conditions.

Some regulating agencies may require that the preliminary model calibration to existing conditions (discussed in subsequent sections) be documented and submitted for review and approval prior to proceeding to the application of the model in a predictive manner. A good time to meet with project stakeholders is after model construction is complete and calibration is underway.

A5.3.5 Model Verification

Model *verification, calibration,* and *validation* are necessary and critical steps in any model application. ***Model Verification*** involves examining the model to ensure that it represents required hydrologic processes accurately and that there are no inherent numerical problems with obtaining a solution. In some cases, this can be done by examining the model's source code; however, in most cases it is sufficient to vary the model inputs within reasonable ranges and examine changes to the predicted values to ensure that the model is responsive to the changes and the predicted values are reasonable. These s*ensitivity and uncertainty analysis* are often undertaken as part of the model calibration and verification process, although it is recommended as a best practice to conduct separate verification processes during the model evaluation process and, where required, in conjunction with scientific peer-review. Although uncertainty and sensitivity analysis are closely related, uncertainty is parameter specific, and sensitivity is algorithm specific with respect to model "variables".

Uncertainty analysis investigates the effects of lack of knowledge and other potential sources of error in the model to evaluate the "uncertainty" associated with model parameter values. When developing any hydrologic or groundwater model, there is a certain degree of uncertainty associated with the wide range of information needed to define natural systems and the sparseness of reliable data. Other sources of uncertainty include: (1) model-related errors, such as uncertainty resulting from inadequate or incomplete representation of the system processes: and, (2) data-related errors, such as uncertainty resulting from errors in input data, even if the model is used correctly. These types of uncertainty can be reduced by careful application of internal review and other quality assurance/quality control procedures and external peer review, where required. Where possible, model results should be accompanied with a statement of uncertainty, possibly as error bounds on the projected results. Models cannot be expected to be more accurate than the uncertainty (confidence interval) in the input and observed data, and as a minimum, possible sources of model uncertainty should be included in any discussion of the model results.

Sensitivity analysis examines the degree to which the model results are affected by changes in a selected input parameter. The aim of the sensitivity analysis is to estimate the rate of change in the output of the model with respect to changes in the model inputs and/or model parameters. Such knowledge is important for (1) evaluating the applicability of the model, (2) determining parameters for which it is important to have more accurate values, and (3) understanding the behavior of the system being modeled. Because different models contain different types and ranges of uncertainty, sensitivity analysis during the early stages of model development is useful for identifying the relative importance of model parameters and where to focus efforts on obtaining the optimal parameter values. During a trial-and-error calibration process, the modeller will likely develop an understanding of how the model outputs are affected by changes to parameter values; however, a formal sensitivity analysis is useful for conveying this information to others. When conducting a formal sensitivity analysis, the input parameters are typically varied over a reasonable range of values which straddle the range of the calibrated values.

Confidence in a model's ability to support a decision is generally increased when information is available to assess the uncertainty in the model outputs. Uncertainty and sensitivity analysis allows a model user, peer reviewers, and the regulators to be more informed about the level of confidence that can be placed in model results.

A5.3.6 Model Calibration

Model Calibration consists of a process in which model coefficients or parameters are adjusted within physically defensible ranges until the resulting predictions give the best possible fit to the observed data. This requires that field conditions at a site be properly characterized and that observation data are available. Lack of proper site characterization may result in a model that is calibrated to a set of conditions that are not representative of actual field conditions. Identifying reasonable ranges of parameter values is another key precursor to the calibration effort. Initial estimates for key calibration parameters can be obtained from previous studies, book values, or model default values.

Calibration is often a hierarchical process. For hydrological models this usually begins by calibration of the model to snow accumulation and snowmelt processes and then to runoff, ET, and streamflow. A hydrologic calibration typically involves a successive examination of the four characteristics of the watershed hydrology: (1) annual water balance, (2) seasonal and monthly flow volumes, (3) daily flow volumes, (4) baseflow, and (5) storm events. Simulated and observed values for each characteristic are examined and critical parameters are adjusted to improve or attain acceptable levels of agreement. Adjustments to the instream hydraulics simulation must be completed before instream sediment and water quality transport processes are simulated and calibrated because runoff is the transport mechanism by which nonpoint pollution occurs and erosion depends on in-stream flows.

For groundwater models, initial calibration is usually done under steady-state conditions to determine long-term average recharge rates and hydraulic conductivity values for the aquifers and aquitards. By matching average groundwater levels and baseflow to streams. Transient calibration is done next to determine appropriate storage coefficient values by matching the observed time-dependent response in observation wells. Calibration of solute transport models for groundwater should only begin after the flow system has been characterized to a high level of accuracy and the loadings have been determined based on local recharge rates.

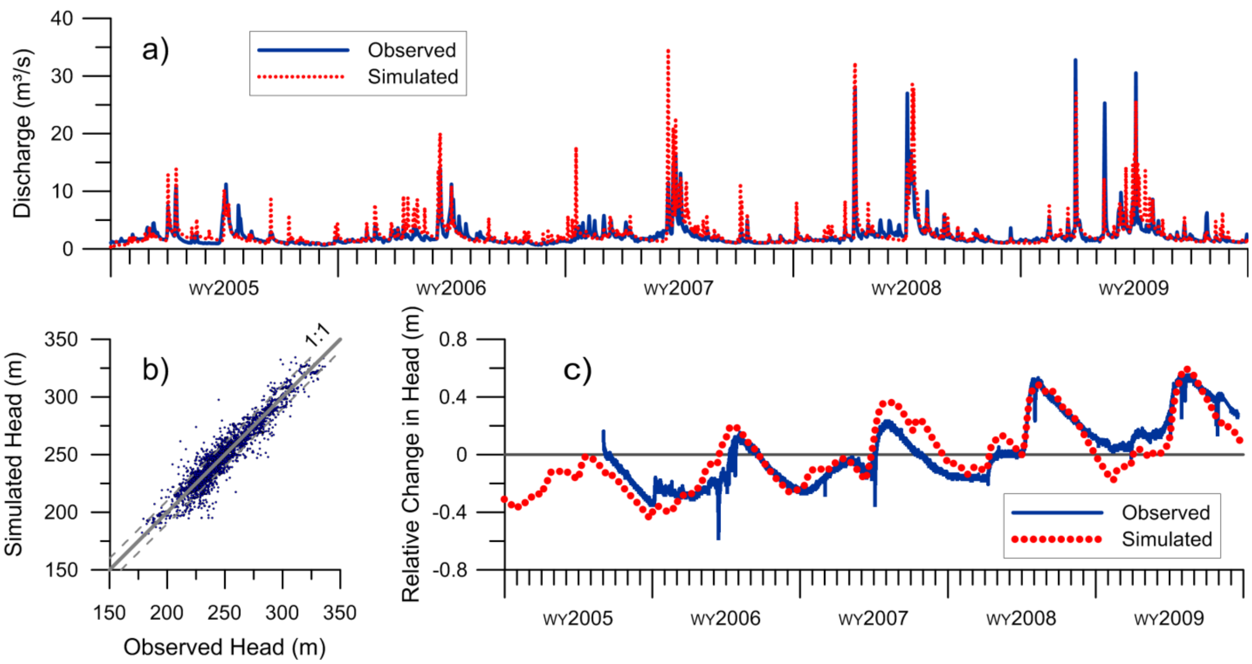
Calibration can be undertaken through ***trial-and-error*** (i.e., manual) or ***automated methods*** (such as PEST (WMC, 2016) or OSTRICH (Matott, 2016) or Monte-Carlo techniques). Some modelling packages may include calibration tools which can automate part or all of the process. **Table A5.11** provides a summary of the typical datasets available by model class which can be employed during calibration.

Table A5.11 - Available calibration datasets by model class

Class	Description	Calibration Datasets
A	Water Balance Frameworks	Streamflow observations Pan evaporation, lysimeter, or eddy covariance measurements
B	Surface Water Runoff (Hydrologic) Models	Streamflow and spotflow observations Pan evaporation, lysimeter, or eddy covariance measurements Snow pack depth and Snow Water Equivalent (SWE) measurements Soil moisture measurements Sediment loadings Water quality measurements
C	Groundwater System Models	Static groundwater levels Transient or continuous groundwater levels Spotflow/low streamflow observations Estimates of daily or monthly baseflow volumes Seepage measurements
D	Loosely-coupled, coupled, and integrated groundwater/surface water models	All of the above

During calibration, model parameters are varied to bring simulated model outputs into line with field observations. Comparisons between observed data used during calibration and simulated hydrologic model outputs can be presented with hydrographs of simulated and observed flows. Other types of graphs that can be used to demonstrate the quality of the model calibration include flow duration curves, daily or monthly scatter plots, and annual or monthly histograms. Maps comparing observed and simulated groundwater levels, hydrographs comparing observed and simulated transient response at observation wells, scatterplots comparing observed and simulated values, and maps and graphs of residuals (differences between simulated and observed values) are typical outputs for demonstrating the calibration of groundwater models. Figure A5.31 provides several examples of streamflow and groundwater levels plots.

Figure A5.31 - Typical model calibration plots. a) Simulated and observed streamflow, b) Scatter plot of simulated versus observed groundwater heads, c) Simulated and observed heads at a transient monitoring well (Marchildon *et al*., 2015)



In addition to comparison of simulated and observed flows, the water balance components determined by the calibrated hydrologic models should be reviewed for consistency with expected values for the study watershed. This effort involves displaying model results for individual land uses and soil classes for the following water balance components (if available):

- Precipitation
- Total Runoff (including overland flow, Interflow, and baseflow
- Total Evapotranspiration (PET and AET)
- Infiltration
- Groundwater Recharge

Although observed values may not be available for each of the water balance components listed above, the average annual values must be consistent with expected values for the region, as modified for the individual land use and soil classes simulated. This is a separate consistency, or reality, check with data independent of the modelling (except for precipitation) to ensure that land use and soil classes and overall water balance reflect local conditions.

While qualitative approaches, such as visual comparison, are often employed during calibration, there a number of statistical checks which can be used to define an objective measure of a model's performance. By comparing the simulated outputs against the measured observed dataset, the goodness-of-fit or accuracy of the model can be tested. Table A5.12 presents a number of commonly applied performance measures used in hydrologic and hydrogeologic modelling. Common performance measures for hydrologic models include daily or monthly coefficients of determination, percentage bias, and Nash-Sutcliffe Efficiencies. For some performance measures, the time-series data can be log-transformed where matching low flow and low-water response is a key objective of the modelling exercise. For example, the log Nash-Sutcliffe Efficiency is a commonly applied performance measure in Ontario. Mean error, mean absolute error, and root mean squared error are typical calibration statistics for groundwater models (Anderson and Woessner, 2002).

Table A5.12 - Common performance measures applied during modelling calibration and validation

Name	Equation*	Ideal Value
Mean Error	$ME = \frac{1}{n}\sum(Q_o - Q_s)$	0
Mean Absolute Error	$MAE = \frac{1}{n}\sum\lvert Q_o - Q_s\rvert$	0
Root Mean Squared Error	$RMSE = \sqrt{\frac{1}{n}\sum(Q_o - Q_s)^2}$	0
Normalized Root Mean Squared Error	$NRMSE = \frac{RMSE}{\max(Q_o) - \min(Q_o)}$	0
Root Mean Squared Normalized Error	$RMSNE = \sqrt{\frac{1}{n}\sum\left(\frac{Q_o - Q_s}{Q_o}\right)^2}$	0
Coefficient of Determination	$r^2 = \left(\frac{\sum(Q_o - \overline{Q_o})(Q_s - \overline{Q_s})}{\sqrt{\sum(Q_o - \overline{Q_o})^2}\sqrt{\sum(Q_s - \overline{Q_s})^2}}\right)^2$	1
Percent Bias	$\mathrm{PBIAS} = \frac{\sum(Q_s - Q_o)}{\sum Q_o} \times 100$	0
Nash-Sutcliffe Efficiency	$\mathrm{NSE} = 1 - \frac{\sum(Q_o - Q_s)^2}{\sum(Q_o - \overline{Q_o})^2}$	1
Volumetric Efficiency	$VE = 1 - \frac{\sum\lvert Q_s - Q_o\rvert}{\sum Q_o}$	1

* Where Q_O is the observed flow or level, Q_S is the simulated/forecasted flow or level, and n the number of observations.

The ideal values provided in Table **A5.12** represent a perfect match between the observed and simulated datasets. In reality, this rarely occurs. Model performance may be limited by the model inputs, oversimplified representation of the hydrologic system, or the quality of the calibration datasets. Each modeller and model reviewer will need to use professional judgment in evaluating the calibration results. There are no universally accepted "goodness-of-fit" criteria that apply in all cases. However, it is important that the modeller make every attempt to minimize the difference between model simulations and measured field observations. While ideally, the difference between simulated and actual field conditions (residual) should be less than 10% of the variability in the field data across the model domain; this may not be achievable based on the available calibration data. A discussion of the quality of the model calibration should be provided with the model results.

It is generally not advisable to apply an uncalibrated hydrologic model. However, for initial or basic assessments, it is possible to obtain useful results from models that are not fully calibrated. The application of uncalibrated models can be very useful in guiding data collection activities or as a screening tool in evaluating the relative effectiveness of remedial action alternatives.

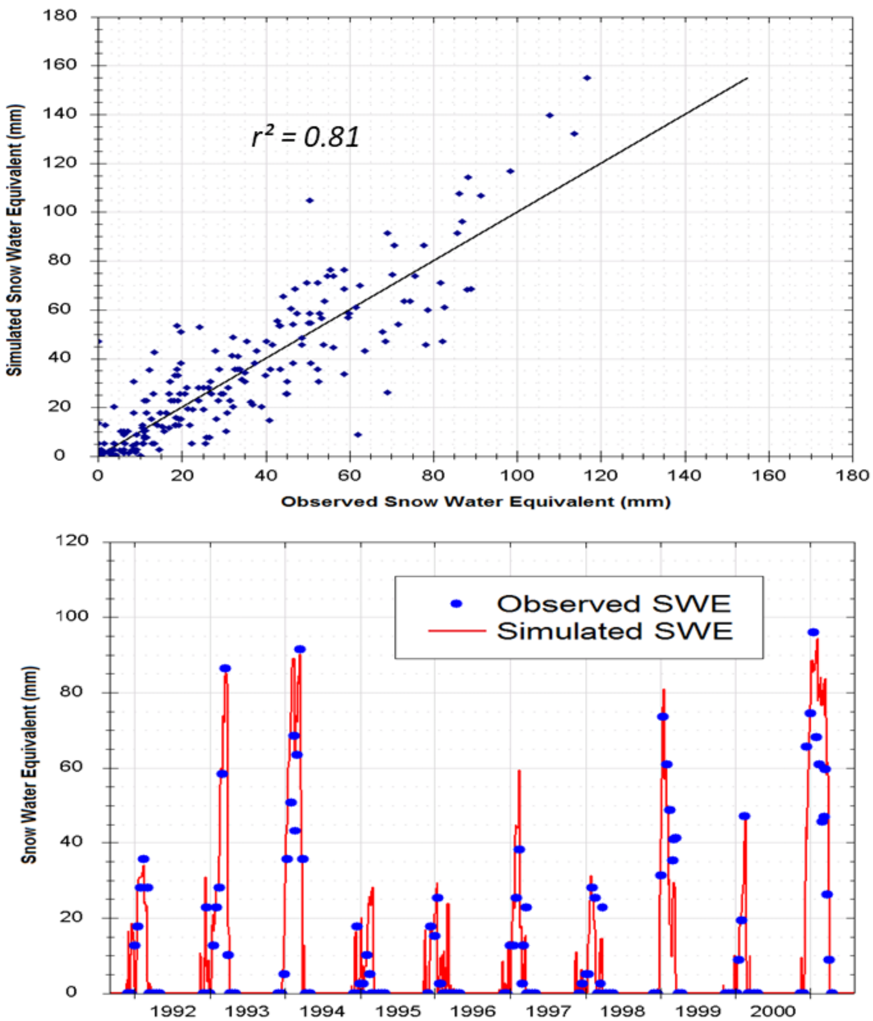
A number of specific considerations related to model calibration are discussed more fully below.

A5.3.6.1 Snowpack Calibration

Snow accumulation and snowmelt is an important component of streamflow generation in Ontario. Accurate simulation of snow depths and snowmelt processes is needed to successfully model the complete hydrologic regime. Snow calibration is part of the overall hydrologic calibration, and should be performed during the initial phase of the hydrologic calibration because the snowpack will impact not only winter runoff volumes, but also spring and early summer streamflow.

Simulation of snow accumulation and snowmelt processes suffers from two main sources of uncertainty: meteorologic input data and parameter estimation. The additional meteorologic time series data required for snow simulation (e.g., air temperature, solar radiation, wind, and dewpoint temperature) are not often available in the immediate vicinity of the watershed, and consequently must be estimated or extrapolated from distant weather stations. Some snowpack models use a degree-day approach and parameterization is fairly straight-forward. Others may use an energy-balance approach where the parameters may be less familiar to the practicing hydrologist and observed values may not be available. This may contribute to a higher level of uncertainty related to model parameterization. Where observed snow depth or water equivalent measurements are available, comparisons with simulated values should be made. Common performance measures include mean error, root mean squared error, coefficient of determination, and percent bias (Table A5.12).

Figure A5.32 - Simulated snowpack water equivalencies versus field observations; (top) scatter plot, (bottom) time series (Earthfx, 2016)



A5.3.6.2 Sediment Erosion Calibration

If required, sediment calibration should follow hydrologic calibration and must precede water quality calibration. Calibration of the parameters involved in the simulation of sediment erosion and transport involves more uncertainty than hydrologic calibration, as predictive capabilities of many sediment models are limited to order of magnitude estimates. During calibration, major sediment parameters are modified to increase agreement between simulated and recorded monthly sediment loss and storm event sediment removal. However, observed monthly sediment loss is often not available, and the sediment calibration parameters are not as distinctly separated between those that affect monthly sediment and those that control storm sediment loss. In fact, annual sediment losses are often the result of only a few major storms during the year. Two graphs showing simulated snowpack water equivalencies versus field observations; (top) scatter plot, (bottom) time series

Rarely is there sufficient observed local data to accurately calibrate all model parameters. Consequently, model users focus the calibration on sites with observed data and review simulations in all parts of the watershed to ensure that the model results are consistent with field observations, historical reports, and expected behavior from past experience. Observed storm concentrations of suspended solids should be compared with model results where available, and the sediment loading rates by land use/soil class should be compared with the expected targets and ranges. The objective is to represent the overall sediment behavior, with knowledge of the morphological characteristics of the stream (i.e., aggrading or degrading behavior), using sediment loading rates that are consistent with available values and providing a reasonable match with instream sediment data. Performance measures for sediment models are highly dependent on the form of the available data, but generally include daily, monthly, or annual mean error, root mean squared error, and coefficient of determination (Table A5.12).

A5.3.6.3 Calibration of Water Quality Parameters

The essence of watershed water quality calibration is to obtain an acceptable agreement of observed and simulated concentrations (i.e., within defined criteria or targets), while maintaining the instream water quality parameters within physically realistic bounds, and the nonpoint loading rates within the expected ranges from the literature. For water quality constituents, model calibration/validation is often based primarily on visual and graphical presentations as the frequency of observed data is often inadequate for accurate statistical measures. Calibration procedures and parameters for simulation of nonpoint source pollutants will vary depending on whether constituents are modeled as sediment-associated or flow-associated. This refers to whether the loads are calculated as a function of sediment loadings or as a function of the overland flow rate. Due to their affinity for sediment, contaminants such metals, toxic organics, and phosphorous are usually modeled as sediment-associated, whereas BOD, nitrates, ammonia, and bacteria are often modeled as flow-associated.

Stream transport and assimilation water quality calibration procedures are highly dependent on the specific constituents and processes represented, and in many ways, water quality calibration is equal parts art and science. As discussed above, the goal is to obtain acceptable agreement of observed and simulated concentrations (i.e. within defined criteria or targets), while maintaining the instream water quality parameters within physically realistic bounds, and the nonpoint loading rates within the expected ranges from the literature. The specific model parameters to be adjusted depend on the model options selected and constituents being modeled, (e.g., BOD decay rates, reaeration rates, settling rates, algal growth rates, temperature correction factors, coliform die-off rates, adsorption/desorption coefficients, etc.). Because the model predictions will change depending upon the selection of the values of biochemical coefficients, consistent coefficient values should be used for different simulation runs. That is, the coefficient values should be transferable for the model predictions to compare with independent sets of field observations.

In study areas where pollutant contributions are also associated with subsurface flows, contaminant concentration values are assigned for both interflow and active groundwater. The key parameters are simply the user-defined concentrations in interflow and groundwater/baseflow for each contaminant. It should be recognized that solute transport in the unsaturated zone and saturated groundwater can be an extremely complex process. Separate groundwater solute-transport models may be needed where loading-based models are inadequate.

The following steps provide a basic description of the steps typically undertaken during water quality calibration:

- Estimate all model parameters, including land use-specific accumulation and depletion/removal rates, wash-off rates, and sub-surface concentrations.
- Tabulate, analyze, and compare simulated nonpoint source loadings with expected ranges of nonpoint source loadings from each land use and adjust loading parameters when necessary.
- Calibrate to in-stream water temperature.
- Compare simulated and observed in-stream concentrations at each of the calibration stations.
- Compare annual nonpoint source loading rates with expected values presented in available literature.
- Analyze the results of comparisons in Steps 3, 4, and 5 to determine appropriate instream and/or nonpoint source parameter adjustments.

A5.2.6.4 Groundwater Model Calibration

As was noted earlier, the calibration process for groundwater models typically involves calibrating first to steady-state conditions and then to transient conditions. With steady-state simulations, a long-term equilibrium state is assumed and hydraulic head (groundwater levels) do not change with time. This allows the modeller to focus the calibration on the hydraulic conductivity values for the aquifers and aquitards and average recharge values. Transient simulations involve the change in hydraulic head with time. These changes can be local, such as the observed response to an aquifer test or other known rate of pumping, or a larger, longer-term response (e.g., season changes in groundwater levels). Transient simulations allow the modeller to focus on the storage properties of the aquifers. Often, however, the local variability in observed response requires the modeller to readjust all parameters because the transient responses tend to be more sensitive to local variation in parameter values. In some highly-transient settings, assuming a long-term average condition is not realistic and models may need to be calibrated without first simulating steady-state flow.

At a minimum, model calibration should include comparisons between model-simulated conditions and field conditions for the following data (where available):

- Hydraulic head data;
- Groundwater-flow direction and general flow patterns;
- Hydraulic-head gradient; and
- Water mass balance.

A plot showing residuals at monitoring wells (calibration targets) is shown in Figure A5.31. A plot in this format is useful to show the "goodness-of-fit" at individual wells. These data may also be plotted on a map to determine whether there are spatial trends in calibration residuals. If the model is run in transient model, simulated groundwater level can be directly compared with field observations as shown on Figure A5.31. Common performance measures for groundwater models include mean error, absolute mean error, and root mean squared error (Table A5.12).

Solute transport from a point source is extremely dependent on the rates and directions of groundwater flow. Calibration of solute transport models for groundwater should only begin after the flow system has been characterized to a high level of accuracy. Solute transport is also dependent on the rate of contaminant loading which, in turn, often depends on the rate of groundwater recharge. Transport processes such as the rates of hydrodynamic dispersion, and the rates of chemical processes such as adsorption, bio-degradation, gaseous diffusion, and geochemical processes at the soil grain/water interface, also affect the ultimate fate of contaminants. Because groundwater is assumed to move at a relatively constant rate, many transport models assume steady-state flow conditions with transient transport. This, however, neglects season and inter-year variations in rates of loading and rates and direction of groundwater flow which can be important at the site scale.

Solute transport models are calibrated by adjusting the transport parameters to match observed:

- Contaminant concentrations (if appropriate);

- Contaminant migration rates (if appropriate);
- Migration directions (if appropriate); and
- Degradation rates (if appropriate).

These observations are likely to be available at contaminated sites (e.g., landfills and industrial waste facilities) but are not likely to be widely available at land development sites. Some monitoring may take place downgradient of infiltration facilities and these data could be used to for model calibration.
(Users seeking further discussion regarding the development, calibration, and application of groundwater models are encouraged to review the Australian groundwater modelling guidelines (Barnett et al, 2012) which provides a thorough and in-depth discussion of these topics. Additionally, there are a number of technical standards are available from the American Society for Testing and Materials (ASTM) related to the selection, documentation, and calibration of groundwater models.)

A5.2.6.5 Calibration of Integrated Models

Integrated models have input data requirements that encompass those of the separate hydrologic and groundwater flow models. The models vary in complexity in how the unsaturated zone and overland flow are simulated and the data requirements for those processes vary accordingly. Calibration of the model is done to the same sets of observation data. A common practice with coupled models is to pre-calibrate each of the submodels separately to narrow the range of parameter values and then perform further refinement with the models linked.

Other secondary information can help to evaluate the model calibration. For example, the integrated model should be able to predict where the water table intersects land surface across the study area. Comparing this against maps of groundwater-fed wetlands is a good check on the model. Similarly, model predictions of where streamflow gains and losses are occurring can also be compared against visual observations of upwelling and vegetation change. Other anecdotal information and traditional knowledge, such as when streams or wells went dry in certain years, or when flooding occurred, can also be checked against the model response.

A5.2.6.6 Considerations: Non-uniqueness, Identifiability, and Over-Fitting

A major challenge during the calibration of any environmental model is ***non-uniqueness***. Commonly, there are more unknown parameters that known data or data sets with which to undertake calibration. This can result in multiple combinations of parameters that produce equally good calibration results. There may be no single set of ***identifiable*** model parameters. In hydrologic modelling, this is commonly known as the ***equifinality*** problem and can lead to models with a high degree of uncertainty.

There are several techniques to minimize the uncertainty created by non-uniqueness. First, not every combination of model parameters may be physically realistic. Critical review by the modeller can eliminate sets of parameters which produce matching results but are hydrologically incorrect. Second, independent calibration or estimation of parameters should be undertaken where ever possible. For example, snowpack processes can be calibrated to field observations independent from the runoff model. Parameters governing evapotranspiration, infiltration, and to some extent runoff can be independently estimated if the data are available. Third, model validation can reduce uncertainty and demonstrate that the parameterization represents a global optimum if sufficient data are available.

The modeller should also avoid the temptation of using the multiple parameters in a typical hydrologic model to perfectly fit limited observation data. This process, referred to as ***over-fitting*** (or over-calibration), results in a model that appears to be well calibrated but has been based on a dataset that is either incomplete or not supported by field data. Model validation can help indicate when over-fitting has occurred.

A5.3.7 Model Validation

Model Validation is a comparison of model results with numerical data independently derived from observations, in order to evaluate its performance under a different set of conditions. Model validation is often case specific and no universally applicable model validation process exists. A rigorous model validation exercise may not be feasible in areas with limited datasets.

A common method of validation is the ***split-sample approach*** where the observed record is split into separate periods for calibration and validation (Andréassian *et al.*, 2009). Multiple sub-periods can be employed to increase the rigour of the method. If multiple observation locations are available (i.e., two or more stream gauges), the pool of available spatial observations can also be split into calibration and validation groups. Splitting the observation data into multiple groups tests for over-fitting and ensures the model explains the hydrologic system rather than the noise in the observed record.

A5.3.8 Application to Assessment of Stormwater Design

After the model has been constructed and calibrated to an appropriate level, the tool can be applied to analyze the study objectives (Section A5.3.3). Models can be used in two major ways during a stormwater modelling exercise, either to conduct detailed design of the stormwater system and/or to validate the performance of the proposed design. Often, these two tasks are conducted iteratively towards a final design that meets the required performance criteria.

During detailed design, various criteria may be evaluated depending on the proposed development or retrofit including flood protection, water quality, erosion control, and water balance requirements. A treatment train approach using source, conveyance, and end-of-pipe facilities, in combination with low impact development practices, should be considered to meet the design criteria. An assessment of the effectiveness of the proposed design should be undertaken with the model, and the design modified until the simulated system meets the require objectives. Achieving the design criteria for all categories is dependent on minimizing the impact of urbanization on the existing water balance (TRCA, 2012).

Post-development changes in hydrologic regime, the groundwater system, and water quality should also be assessed iteratively during design. In some cases, a model may be developed solely to demonstrate that the proposed design meets the required objectives and performance criteria. The final design should encourage stormwater to infiltrate or be lost to evapotranspiration through the use of LID BMPs. LID BMPs can reduce offsite peak flows and volumes of runoff while maintaining water quality and are critical to sustaining surface and groundwater inputs to natural features that rely on that surface and groundwater regime. As part of the final assessment of the stormwater design, a water balance analysis, comparing existing to post-development conditions, should be conducted to determine how the proposed site changes will affect the overall site water budget.

A5.3.9 Reporting and Documentation

Some municipalities and conservation authorities provide technical guidelines for stormwater management submissions which outline specific requirements for documenting a modelling study. It is advisable to pre-consult with the regulating authority prior to preparing a final modelling report to ensure the format and level of detail are commensurate with the regulator's expectations. Regardless, the goal of the documentation and reporting phase is to ensure that the science underlying the model is defensible and transparent. When models are presented with transparency, they can be used effectively in a regulatory decision-making process (Gaber *et al.,* 2009). Model transparency is achieved when modelling process are documented with clarity and completeness at an appropriate level of detail. This enables communication between modellers, decision makers and the public.

A modelling analysis should be documented in sufficient detail to inform the reviewer of the model analysis about the appropriateness of the model for the stated objectives. This allows the decision-makers to readily interpret and understand recommendations derived from the modelling process. Modelling reports should clearly state the problem (or set of problems) of interest and describe, in detail, how outputs meet identified needs and requirements and can inform regulatory decisions. Documentation enables project stakeholders to understand the process by which a model was selected, its intended application, and the usefulness of the outputs and modelling conclusions. Key points of discussion include (but are not limited to):

- A description of the purpose and scope of the model application.
- Identification of the model selected to perform the task, its applicability and limitations.

- A discussion of the modelling approach.
- Documentation of the data used in the model and sources of data, whether derived from published sources or measured or calculated from field or laboratory tests. The quality of data and limitations on their use should be discussed with respect to their intended use.
- A description of the model construction, verification, calibration, and validation processes.
- A discussion of model limitations.
- A description of the post-development design scenarios being simulated and any other changes made to the baseline model.
- A discussion of model parameter sensitivity and uncertainty addressed to anyone that will use model results.
- A presentation of the simulation results and their interpretation, recommendations and conclusions.

A modelling report should discuss the model verification (Section A5.3.5), model calibration (Section A5.3.6) and model validation (Section A5.3.7) steps undertaken during the study. Clear statements regarding the performance and suitability of the model should be made in-text, with supporting figure, tables, and maps. Where possible, performance measures should be employed to objectively quantify the models performance. Possible errors or uncertainly within the model should be summarized. The following list summarizes the categories of error that can affect the quality of model calibration and acceptability of model results:

1. Errors intrinsic to data acquisition;
2. Errors due to natural spatial and temporal variability;
3. Transcription errors, errors in computerization (digitizing) and storage of data;
4. Data processing errors;
5. Modelling and conceptual errors; and,
6. Output and visualization errors.

If a monitoring program is to be established onsite during development, the modelling report should link areas of uncertainty within the model to specific monitoring objectives. Recommendations may include possible monitoring locations, the parameters to be measured, and the frequency of monitoring.

A5.3.10 Further Reading

The preceding chapter has provided a basic overview of a very complex and challenging topic. The following references are provided for further information regarding model development and calibration.

Rainfall-runoff modelling: the primer Beven, K.J., 2012. Rainfall-runoff modelling: the primer 2nd ed. John Wiley & Sons.
<u>Guidance on the development, evaluation, and application of environmental models</u> Gaber, N., Foley, G., Pascual, P., Stiber, N., Sunderland, E., Cope, B. and Saleem, Z., 2009. Guidance on the development, evaluation, and application of environmental models. Report, Council for Regulatory Environmental Modeling, p.81.
<u>BMP Modeling Concepts and Simulation</u> Huber, W.C., Cannon, L. and Stouder, M., 2006. BMP modeling concepts and simulation. Prepared for the United States Environmental Protection Agency, 166p.
Handbook of hydrology Maidment, D.R., 1992. Handbook of Hydrology. McGraw-Hill Inc.
<u>Water Budget Overview</u> onservation Ontario, 2010. Integrated Watershed Management – Navigating Ontario's Future, A Water Budget Overview for Ontario, 36 p.
<u>Australian groundwater modelling guidelines</u> Barnett, B., Townley, L.R., Post, V., Evans, R.E., Hunt, R.J., Peeters, L., Richardson, S., Werner, A.D., Knapton, A. and Boronkay, A., 2012. Australian groundwater modelling guidelines. *National Water Commission, Canberra*.
Applied groundwater modeling – Simulation of flow and advective transport nderson, M.P. and Woessner, W.M., 2002, Applied groundwater modeling – Simulation of flow and advective transport, Academic Press, San Diego, CA, 381 p.
<u>Integrated Surface and Groundwater Model Review and Technical Guide</u> AquaResource Inc., 2011. Integrated Surface and Groundwater Model Review and Technical Guide: prepared for the Ontario Ministry of Natural Resources, 116 p.

A5.4 Model Data Availability

Data requirements for water budget analysis vary with the complexity of the model and the number of hydrologic processes represented. The simplest water budget models require information on climate (average annual or monthly precipitation and PET values) and soils (e.g., average moisture storage capacity). More complex hydrologic models require complete climate data time series and detailed information and mapping of soil types and properties, land use and cover, vegetative cover, topography, and stream course information. Data sources for specific model types are discussed below. Additional information can be found in AquaResource (2011b) and AquaResource (2013).

The completeness, quality, and accuracy of environmental datasets can vary significantly. While many data collected by government agencies are subject to rigorous QA/QC and published data collection standards (e.g. ECCC climate and streamflow data), modelling projects often involve the amalgamation of data from disparate third-party sources with varying degrees of provenance and quality. With all environmental data, it is incumbent upon the end user to ensure that the data used are fit for the intended purpose.

A5.4.1 Climate Data

Precipitation, in the form of rainfall or snowfall, is the fundamental input to all water budget analyses. Annual precipitation varies significantly throughout the Province of Ontario, ranging from 600 mm/year in the northwest to greater than 1,200 mm/year in areas downwind from the Great Lakes. Precipitation patterns vary with location and season; and aside from lake effect snow, the greatest localized variation is due to summer convective storms.

Historical daily climate data is available from Environment and Climate Change Canada (ECCC). Climate normals describe the 30-year average or extreme climate conditions at a particular location and can be obtained from http://climate.weather.gc.ca/climate_normals/index_e.html. Stations must have at least 15 years of record to be included within this dataset. Useful climate normals include temperature, precipitation, snow depth, wind, humidity, cloud cover, and degree days. Monthly climate data summaries for all stations in Ontario can be obtained at http://climate.weather.gc.ca/prods_servs/cdn_climate_summary_e.html and include temperature, precipitation, snow depth, hours of sunshine, and degree days.

Time series of daily temperature and precipitation data can be downloaded by station from http://climate.weather.gc.ca/advanceSearch/searchHistoricData_e.html#stnNameTab. Hourly data are available from some stations. The data are available as csv or xml files but need review, analysis, and processing to create a complete data set in the correct format for input to the water budget model selected. Dealing with missing data is a common problem associated with processing climate data. Standard rain gauges will not measure snowfall as tipping gauges will not operate in under winter conditions unless equipped with heaters. A snow gauge is used at some stations to capture snow and measure its water content. If snowfall data are not available, temperature–based correction methods can be used to determine during which days or events total precipitation can be assumed to be all snow, all rain or mixed.

Daily and monthly climate summaries for many Canadian weather stations are also available through the US National Climatic Data Center (www.gis.ncdc.noaa.gov) maintained by the National Oceanic and Atmospheric Administration. The site features an interactive map and offers easy to use search and mapping tools for sites in Ontario.

Climate data may also be available from other agencies within the Province. Rainfall data are available at some Provincial Groundwater Monitoring Network (PGMN) locations. Additionally, many conservation authorities maintain independent climate networks and make this data publicly available through their websites. The Ontario Ministry of Transportation and many municipalities also collect climate data; however, these data must be requested directly from the responsible organization. Caution should be used when applying these data as they may be subject to limited QA/QC. Often these stations are sited at locations near other monitoring stations such as stream gauges or near major infrastructure (e.g. water treatment plants, highways, regional headwaters.) These monitoring locations may not be ideal as tree cover or adjacent buildings may limit the stations ability to accurately measure baseline conditions. As with all environmental data, it is recommended the end user ensure that the data are fit for purpose.

Solar radiation (types of measurements can vary; e.g., global solar radiation, sky radiation, reflected solar radiation, net radiation) and pan evaporation are used in hydrologic models to compute evapotranspiration and/or snowmelt but are only collected at select stations. Both Environment and Climate Change Canada's pan evaporation and solar radiation collection programs were discontinued in 2007-2008 due to budget constraints. These historic data can be requested directly from Environment and Climate Change Canada for a fee by calling 1-900-565-1111 (charges apply). Solar radiation data are collected by some conservation authorities and research entities (e.g., the University of Waterloo, University of Toronto, and York University).

Data at the nearest station are useful for water budget studies covering a limited area. For larger areas, the spatial distribution of rainfall between the gauges is important. Techniques for interpolating data range from in complexity from simple methods such as nearest neighbour (Thiessen polygons) to inverse distance methods and geostatistical-based kriging. Corrections for temperature and rainfall lapse rates (i.e., the variation of rates with elevation) may need to be made in areas with high relief unless the water budget model applies the corrections internally.

The Next Generation Weather Radar (NEXRAD) system currently comprises 160 sites throughout the US. Several stations are close enough to Ontario to be useful for hydrologic modelling. The data can provide extremely useful information about the spatial distribution of rainfall for a given study area. The National Centers for Environmental Information (NCEI) archives the data and provides free tools for data visualization. Information on data products, such as one-hour, three hour, and storm total precipitation can be obtained from https://www.ncdc.noaa.gov/data-access/radar-data/nexrad-products. Again, a significant amount of processing is needed to convert the raw NEXRAD data to inputs suitable for the water budget models.

Snow courses are monitored at many locations around the province by conservation authorities, Ontario Power Generation, and Parks Canada. A snow course is a permanent site that represents snowpack conditions in a given area. Snow monitoring involves the use of a calibrated sampler; (West Montrose/Federal Sampler) a hollow tube equipped with a cutting edge which is rotated into the snow pack to cut a core of snow down to ground level. Generally, the courses are about 300 m long with 5 to 10 snow core measurements taken at regular intervals. Each core is measured for depth and then weighed to determine its water equivalent. The average of each of these snow core readings over the locations at each site is recorded as the average depth and water equivalent. Snow course data can be used to parameterize the snowpack submodel within hydrologic models that incorporate cold weather processes. There is no central repository of snow course data maintained within the province, but most conservation authorities will be able to provide some data, typically on a bi-weekly interval.

A5.4.2 Design Storms and Intensity-Duration Curves

Generally, design storms and IDF curves required for the assessment of a development are dictated by local municipal, regional, or conservation authority standards. For development areas with scarce rainfall data or the available data is deemed inapplicable for the site, precipitation monitoring and/or frequency analysis can be conducted to define the design storms. Emphasis is usually given to design storms of low (25mm Rainfall) and high extremes (Regulatory Event).

The Ontario Ministry of Transportation (MTO) provides a web-based application for the purpose of retrieving Intensity-Duration-Frequency (IDF) curves (http://www.mto.gov.on.ca/IDF_Curves). The application provides estimates of the 2, 5, 10, 25, 50, and 100-year return periods for the 5, 10, 15, 30 (min), 1, 2, 6, 12, and 24 (hr) rainfall durations at all locations in Ontario.

A5.4.3 Streamflow and Water Elevation Data

In general terms, there is a good network of high-quality stream gauges in Ontario, operated by the Water Survey Division of ECCC and most conservation authorities, which can be used for model calibration. Archived daily hydrometric data can be obtained from the WSC web site (www.ec.gc.ca/rhc-wsc) in Access or SQL-Lite database format. Hourly or 15-minute instantaneous streamflow observations are available for most WSC stations from 1969 and onwards (ftp.cciw.ca/incoming/Water Survey of Canada/HISTORICAL WSC ONTARIO TIME SERIES DATA/). Some conservation authorities also operate stream gauges and provide real-time data on their websites, historical data must be requested directly from the responsible organization.

Unfortunately, not every watershed has a gauge or, if it does, it may not have record covering the period of interest. One successful approach has been to extend the models to incorporate as many gauges as possible to provide multiple calibration targets and overlapping periods of record. An alternative is the donor catchment approach where additional gauges outside of the area of interest would be included in the model calibration efforts. This technique works well if the donor catchment is in reasonable proximity and has reasonably similar land cover, soils, and topography.

Lake or wetland stage data are much more limited. Some larger lakes are gauged by WSC and reservoirs operated by the conservation authorities have continuous records. Cottage associations may also have volunteers collecting water level information. Wetland stage data are rare, although a number of CAs, (e.g., Conservation Halton) have instrumented selected wetlands. High resolution digital elevation model (DEM) data based on LIDAR may provide a one-time set of elevations.

A5.4.4 Topographic Data

Distributed hydrologic models need good quality, detailed topographic information to simulate overland flow when using diffuse wave methods (with models such as HydroGeoSphere and MIKE-SHE) or to calculate cascading overland flow paths (within models such as PRMS and GSFLOW). Digital elevation models (DEMs) are available in various resolutions from the Ontario Ministry of Northern Development, Mines, Natural Resources and Forestry (MNDMNRF). Provincial Digital Elevation Model Version 3.0 (2013) is available through the Land Information Ontario website (www.ontario.ca/page/land-information-ontario). Many conservation authorities and municipalities also maintain their own elevation datasets. Methods for resampling the data to the model grid and converting the data to model input formats will be needed. This can be undertaken in most common GIS packages and with some modelling software platforms.

A5.4.5 Stream Network, Lake, Pond, and Wetland Mapping Products

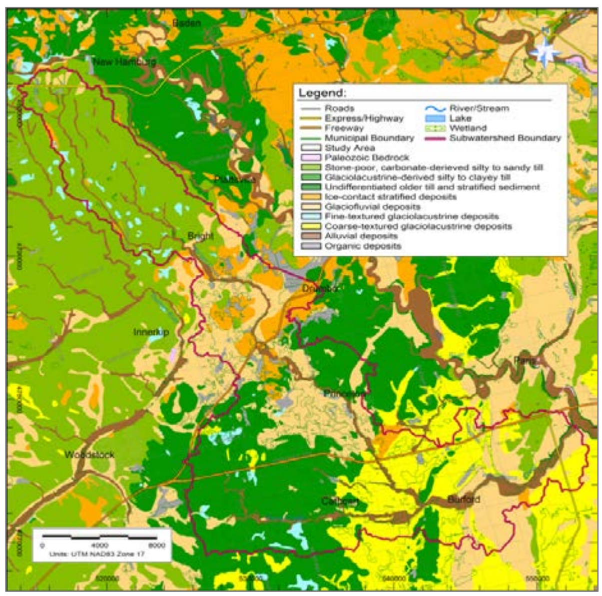
The Water Resources Information Program (WRIP) operating with MNDMNRF has recently published enhanced watercourse mapping for the province. This data product, which includes flow direction, is packaged as Ontario Integrated Hydrology Data (available through the Land Information Ontario website www.ontario.ca/page/land-information-ontario). Curated water body and wetland mapping products are also available for public download through the Land Information Ontario website.

A5.4.6 Soils or Surficial Geology Data

Soil properties have a significant influence on hydrological processes because they control the amount of water that can infiltrate and be transmitted to the water table as well as the amount of water lost to evaporation and transpiration by plants (i.e., actual evapotranspiration).

The Ontario Geological Survey produces surficial geology mapping (http://www.mndm.gov.on.ca/en/mines-and-minerals/applications/ogsearth/surficial-geology) that can be used to aid in model development and parameterization. Agricultural soils mapping produced by the Ontario Ministry of Agriculture and Food, Ontario Ministry of Rural Affairs (2003) can also aid in the characterization of the soils at surface (available through the Land Information Ontario website).

Figure A5.33 - Surficial geology mapping (OGS, 2010) Whitemans Creek subwatershed (Earthfx, 2016)

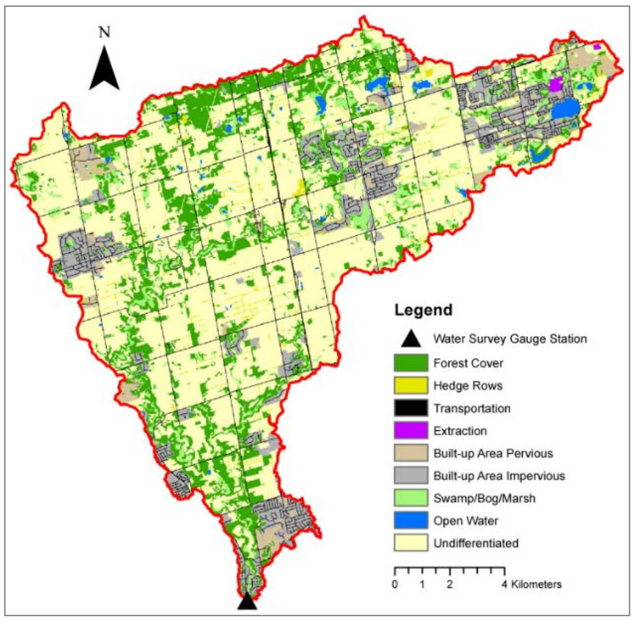


The mapped textural class of the upper soil horizons is provided along with a description of the drainage properties of the mapped unit. This mapping also provides hydrologic soil groups required for the SCS Curve Number runoff method of estimating Hortonian runoff. It is recommended that the information provided by the regional mapping be ground-truthed to provide more accurate site specific information of sediments and extent.

A5.4.7 Land Coverage Data

Several land coverage mapping products are available through the Land Information Ontario website (www.ontario.ca/page/land-information-ontario). Land coverage mapping can aid in the parameterization of hydrologic models. Modern land use and coverage (see Figure A5.34) for most of southern Ontario is included in the Southern Ontario Land Resource Information System (SOLRIS v2) mapping compiled by MNDMNRF (2015). SOLRIS is a landscape-level inventory of natural, rural and urban areas and follows a standardized approach for ecosystem description, inventory and interpretation known as the Ecological Land Classification (ELC) for southern Ontario. The SOLRIS inventory is a compilation of data from numerous sources including: provincial base data (woodland/wetland perimeters, hydrology, built up areas, Ontario road network), satellite imagery, and digital elevation models. Computer modelling, visual interpretation with high resolution aerial photography, and field validation were used to create a seamless inventory for Southern Ontario. SOLRIS data sets cover all of Ecoregions 6E and 7E and report changes in two time periods: 2000-2006 and 2006-2011.

Figure A5.34 - Land coverage mapping of the East Humber River subwatershed derived from SOLRIS (v1.2) (Thompson, 2013)



Detailed mapping and classification of the land cover of northern Ontario was recently completed by MNDMNRF (2014). The Far North Land Cover (FNLC) project produced raster mapping which covers northern Ontario at a 30 m x 30 m cell resolution. Similar to the SOLRIS data product, the mapping was largely derived from Landsat imagery; however, it uses a classification scheme relevant to the ecology and hydrology of the Boreal Shield ecosystem of northern Ontario. The mapping describes 13 classes that fall under 5 major wetland types - open water, bogs, fens, swamps, and marshes - that are further classified by vegetation. Upland or terrestrial areas are also classified by vegetative cover, with disturbed or anthropogenically-modified areas receiving a unique series of classification codes. A major advantage of the FNLC mapping is that the classification scheme implicitly incorporates hydrologic function. For example, in northern Ontario bogs and swamps can represent areas of peat accumulation, and are often in poor contact with the groundwater system.

Some municipalities and conservation authorities have also generated land and vegetation coverage mapping. These products are usually available with a higher resolution and better QA/QC than data products generated by the Province. Some datasets are publicly available, for example, the City of Toronto provides a detailed digital mapping product of the canopy and impervious cover found within the City.

A5.4.8 Groundwater Model Data Requirements

Groundwater models also vary in complexity, not so much in the processes represented, but in the complexity and heterogeneity of the aquifers and aquitards. The number of layers needed to represent the units, the size of the grid cells, and the number of property zones, depends on the local conditions. Methods used to represent surface water features tend to be similar between models but the methods used to represent flow in the unsaturated zone vary considerably within and between the available models.

Groundwater models require the development of a good conceptual model prior to implementing the numerical model. A groundwater flow model is a simplified representation of the complex physical, hydrologic and hydrogeological processes that affect the rate and direction of groundwater flow. The conceptual model helps to identify the critical physical characteristics of the study area that must be represented, including:

- stratigraphy (i.e., the bedrock and overburden stratigraphic layers, stratigraphic correlations, unit top and bottom elevations, lateral extent of the formations and their thickness);
- hydrostratigraphy (i.e., descriptions of the aquifers and aquitards in the study area, their top and bottom surface elevations, and their lateral extent, thickness, and degree of continuity);
- aquifer and aquitard properties (i.e., estimated hydraulic conductivity, anisotropy, saturated thickness, transmissivity, specific storage, and specific yield);
- groundwater flow systems (i.e., types of systems – shallow, deep; interconnection or hydraulic separation; unconfined, semi-confined, confined conditions; temporal/seasonal changes; recharge and discharge locations)
- inputs to the hydrologic system (i.e., rates of groundwater recharge and discharge) and the underlying processes that affect these rates (e.g., precipitation, evapotranspiration, overland runoff, infiltration, and baseflow);
- properties of the surface-water system and factors controlling groundwater/surface water interaction; and,
- anthropogenic inputs and outputs from the groundwater system (pumping rates and return flows).

The numerical groundwater flow model is developed based on a synthesis of the geologic and hydrologic information available in the study area. Calibration of the model is done by adjusting estimated values of aquifer and aquitard properties and recharge rates, all generally having high degrees of uncertainty and wide ranges of possible values, until model outputs, typically simulated heads, match the observed values. Values of groundwater discharge to streams can be compared to estimated values determined through baseflow separation as a secondary check on model calibration.

Continuous groundwater level data is generally sparse across Ontario. The re-established Provincial Groundwater Monitoring Network (PGMN) is a key source of data (https://www.ontario.ca/data/provincial-groundwater-monitoring-network). This can be supplemented with observation wells installed in the vicinity of municipal supply wells, pits and quarries, and waste disposal sites. Static water level data from the MECP water well information system (WWIS) can provide a one-time measurement of the water level at the time of drilling (www.ontario.ca/page/well-records). The spatial coverage of the data is good and can provide useful information regarding general groundwater flow patterns but not transient behaviour.

A5.4.9 Modelling Data Requirements and Sources Summary Table

Datasets that are available through the Land Information Ontario (LIO) data warehouse are marked with an asterisk (*) in the following tables. These tables provide a generic representation of data requirements for many modelling programs. Individual models differ in their parameter and input requirements.

Table A5.13 - Climate inputs and calibration time series data employed in surface water/hydrologic models

Category	Input	Interval	Data Source / Comment
Climate Inputs	Precipitation	Daily/Synoptic	Environment and Climate Change Canada and some conservation authorities (CAs)
		Hourly	
		15 Minute	
		NEXRAD radar-based precipitation data	U.S. National Oceanic and Atmospheric Administration
		Design Storms, Local IDF curves	MTO, local municipalities
	Air Temperature	Minimum/Maximum Daily	Environment and Climate Change Canada and some CAs
		Hourly	
	Solar Radiation	Hourly	Environment and Climate Change Canada (historical hnly); some CAs, universities and research institutions
	Pan Evaporation	Hourly	
	Other	Wind Speed	Environment and Climate Change Canada and some CAs
		Humidity	
		ET stations	
Calibration Datasets	Streamflow	Available from the Water Survey of Canada and some CAs	Available from the Water Survey of Canada and some CAs
		Hourly	Available from the Water Survey of Canada and some CAs
		Spot Flows	Available from some CAs
	Snow Depth and Snow Water Equivalent Observations	Hourly, Snow course observations typically bi-weekly	Available from some Environment and Climate Change Canada Climate stations and CAs

Table A5.14 - Typical input and calibration data requirements for groundwater models

Input Data Requirements for Groundwater Models		
Geological Mapping	OGS Map Sheets	Surficial Geology
		Bedrock Surface Topography
		Bedrock Geology (subcrop), Karst Mapping
Borehole Data	MECP WWIS Well Records	QA/QC issues, mostly shallow, difficult to interpret, good spatial coverage
	OGS and High Quality Borehole logs	Limited availability
Aquifer Properties	Previous studies	Tier 2/3 and Municipal Groundwater Supply studies
	Aquifer tests	At municipal wells and contaminant sites. Limited coverage
	Specific Capacity	Data from MECP WWIS, difficult to interpret, good spatial coverage
Unsaturated Zone	Soil Properties	Can be inferred from soil type
	On Site Percolation Tests	Via permeameter or infiltrometer following published procedures
Calibration Data for Groundwater Models		
Groundwater Level Data	MECP Static Water Level Data	Single measurements at time of construction, QA/QC issues, good spatial coverage
	MECP PGMN well network	Limited number of wells, may be affected by local water use
	Other	Municipal and quarry monitoring
Baseflow	Estimated from streamflow data	Streamflow data available from WSC and some CAs. Baseflow separation techniques can be used to infer groundwater contributions to streamflow

Table A5.15 - Input datasets employed to parameterize surface water/hydrologic models

Category	Input	Parameters	Data Source / Comment
Stream Channel	Cross-sections	Paired Station-Elevation Data, Roughness	Field survey, LiDAR data, or topography mapping, CA datasets
	Stream Network	Cascade Delineation, Hydraulic Routing	Water Resources Information Program (WRIP) Enhanced Watercourse mapping* (MNDMNRF), CA datasets
	Digital Elevation Model	Digital Elevation Model	Provincial Digital Elevation Model*, LiDAR, Canadian Digital Surface Model
Catchment Characteristics	Topography	Catchment area	Derived from DEM, Ontario Base Maps (OBM)*, LiDAR, survey data
		Slope	
		Catchment Shape Parameter(s) (e.g., routing length, time to peak)	
	Soil Conditions	Pervious surface infiltration parameter(s) [e.g., SCS Curve Numbers, infiltration parameters, etc.]	Surficial/Quaternary Geology (OGS), Agricultural Soils Mapping* (OMAFRA), SOLRIS*, conservation authorities and Municipal Land Use Data (if available), site infiltration measurements and soil characterization
	Drainage Infrastructure	Storm sewer System (Pipes and outfalls, etc.)	Municipal records (GIS and paper records), infrastructure databases
		Tile and Municipal Drains	Tile Drainage and Constructed Drain Mapping* (OMAFRA)
LID BMPs	Surface Characteristics	Dimensions Outflow Rates	Design specifications
	Subsurface Characteristics	Dimensions Infiltration rate LID feature into surrounding soils.	MECP WWIS Well Records, Surficial/Quaternary Geology (OGS), Design specifications, site borehole logs and investigations, site infiltration measurements

+See Section 5.3.8 for a method to convert hydraulic conductivity values to infiltration rates.

APPENDIX 6 – MODELLING APPROACHES FOR ASSESSING CLIMATE CHANGE AND AN EXAMPLE OF CLIMATE CHANGE SENSITIVITY OF THE LAKE SIMCOE BASIN

A6.1 Overview of Modelling Approaches for Assessing Climate Change

Chapter 5 of this manual discusses the use of models to aid in predicting and assessing the performance of stormwater management plans in complex settings. The focus of the models is on the site scale but should also take in to account the hydrologic setting of the surrounding watershed.

The same modelling approaches, with some important modifications, can be used to assess the performance of stormwater management plans and designs under future climate conditions. This section presents strategies for representing future climate within the framework of the types of models discussed in Chapter 5 in order to determine the impact of climate change on a wide-variety of environmental parameters including local water balance; runoff volumes and streamflow groundwater recharge; seasonal or long-term water quantity; and water quality trends.

A6.1.1 General Circulation Models

Climate change predictions are made with General Circulation Models that simulate atmospheric and ocean circulation across the world and the interaction with the land masses and sea ice. The models are built on large grids with cells ranging from 250 to 400 km. Results of long-term simulations are often presented in terms of annual, seasonal, and monthly change in climate variables such as temperature, precipitation, solar radiation, and wind speed.
As of 2010, there were 21 GCM models, developed by different government and/or academic research groups in different countries. For example, the Canadian Centre for Climate Modelling and Analysis (CCCMA) a division of the Climate Research Branch of Environment and Climate Change Canada and Climate Change, has developed CGCM4/CanCM4, a fourth generation atmospheric GCM. The GCM models differ in their grid scales and in assumptions regarding clouds, interaction mechanisms, and sub-grid scale processes.

In addition to the different GCM models, each GCM has different sets of predictions based on different greenhouse gas (GHG) emission scenarios. The scenarios are based on different assumptions regarding factors such as future demographic, socioeconomic, cultural, and technological change. In the IPCC Fifth Assessment Report, a subset of scenarios, the Representative Concentration Pathways (RCPs), was used for the new climate model simulations carried out under the framework of the Coupled Model Intercomparison Project Phase 5 (CMIP5) of the World Climate Research Programme. In all RCPs, atmospheric CO_2

concentrations are higher in 2100 relative to present day as a result of a further increase of cumulative emissions of CO_2 to the atmosphere during the 21st century (IPCC, 2013).

While the various GCM model assumptions, construction details, and emission scenarios differ, the IPCC considers each model prediction to be equally valid with each possible model outcome given the same probability. They recommended that climate change impact assessment studies take a statistical approach and use as many scenarios of climate change as possible to cover the widest range of possible outcomes. The overall objective is to conduct assessments of future climate change, account for uncertainties in the predictions, and develop adaptation strategies that would be resilient to a wide range of possible outcomes.

A6.1.2 Downscaling of Global Climate Models for use in Hydrologic Analysis

GCMs cannot predict behaviour at a scale smaller than the grid size (typically ranging from 250 to 400 km). As well, current GCMs cannot account for spatial variability at a fine scale (e.g., local land use, topography, and surface water features). Even features as large as the Great Lakes are not represented in most GCMs. The GCMS are more representative of large-scale, average climate characteristics and potential changes.

> Downscaling of Global Climate Models (GCMs) is what is known as a 'top-down approach' whereby a limited selection of individual projections are used to predict potential climate impacts. A deep understanding of downscaling techniques is required, and the use of this procedure should be justified.

Different methods are available for downscaling GCM outputs for use in local-scale models. EBNFLO and AquaResource (2010) discuss several methods (including: the change-field method; synthetic and analogue data sets; statistical downscaling; weather generators; and regional climate models) and recommend that a range of downscaling methods be applied for each hydrologic analysis. Further information on downscaling GCMs can be found in EBNFLO and AquaResource (2010) – See the Resource Directory.

Climate Change Water Balance Analysis
Precipitation and temperature time series data from downscaled climate change models can be used to model future water balance scenarios. This is especially useful on the watershed or subwatershed-level but can also be used at the site-level to determine event-based, seasonal or annual contributions to runoff, infiltration and evapotranspiration. This type of analysis can be used to assess whether adaptation measures such as LID BMPs are able to provide resiliency (i.e. mitigating negative hydrologic impacts associated with climate change scenarios). The Ontario Climate Data Portal (see the Resource Directory) is an online resource that provides access to downloadable data for climate scenarios across Ontario using geospatial maps, including typical climate change indicators (e.g. temperature, precipitation) at temporal scales from annual, seasonal, monthly to daily and hourly. These time series can be applied to existing and development phase land use water balance models.

Data sets downscaled from a wide selection of GCM model results have been assembled by several Ontario agencies and made available to the public. For example, Ontario Ministry of Northern Development, Mines, Natural Resources and Forestry has established a website where future climate data sets can be downloaded for use in hydrologic models (See the Resource Directory). As well, dynamically downscaled climate projections are available for the Province from the Ontario Climate Data Portal (see the Resource Directory).

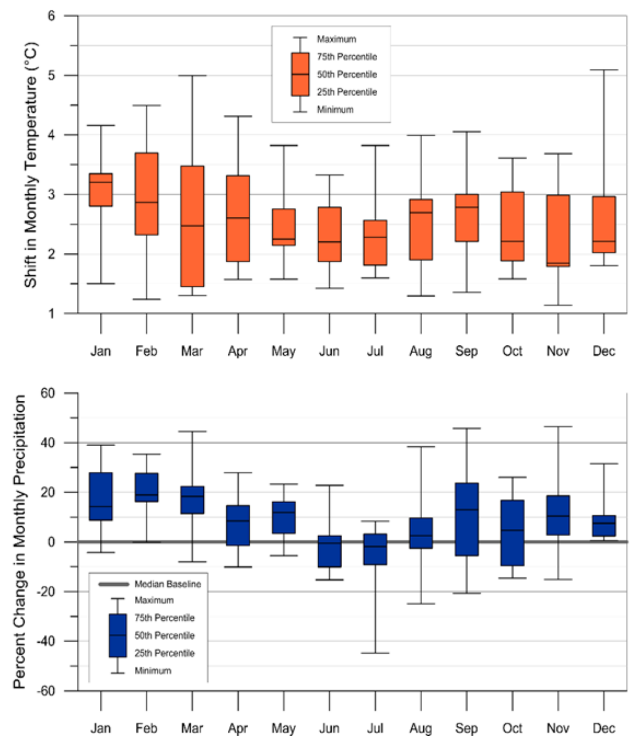
GCM model results have been used, for example, to aid in developing modified IDF curves for use in stormwater design (e.g., AMEC, 2012 or Simonovic and Peck, 2009). The use of modified IDF curves is discussed in Section 6.9.

Hydrologic models developed for assessing the impacts of land development on water budgets and watershed processes methods can be applied to assess their behaviour under future climate. The input climate data time-series (precipitation, temperature, solar radiation, humidity and wind speed), usually obtained from observations, can be replaced with data modified based on the downscaled results of GCM models (see the Resource Directory). By comparing model results for baseline (observed climate) and under future climate scenarios, the behaviour under a wide range of possible future climate conditions can be evaluated.

Change Field Method
The change field method is the most established method for GCM downscaling, and involves calculating mean monthly changes in future climate parameters (e.g., temperature and precipitation) based on output from the GCM models. Comparing these climate parameters to existing mean data sets is the first step in the process. These monthly factors are used to adjust

a long-time series of observed climate at a station to create a synthetic future data set. A range of different GCM outputs, each with its set of monthly average percentage change, can be used to create an ensemble of different climate input time series.

Figure A6.1: (top) shift in monthly temperatures and (bottom) scaling of monthly precipitation values for the simulated 2041-2070 time-frame at Orillia Brain



Example: In a study of subwatersheds on the Oro Moraine, climate data sets with the applied change fields were obtained for the Orillia Brain AES climate station (AES: 6115811) from the Ontario Ministry of Northern Development, Mines, Natural Resources and Forestry website. The period spanning 1961-1990 was used to represent baseline climate conditions. To create climate input data sets representing 2041-2070, predicted changes in the mean monthly values (e.g., a +2.5 °C increase in average daily temperature for January) were used to shift the observed 1961-1990 daily minimum and maximum temperatures for each respective month. In a similar manner, monthly scale factors (e.g., a 10% increase in total precipitation for January) were used to scale the observed 1961-1990 daily precipitation values for each respective month. Figure A6.1a shows the range in monthly shifts in the Orillia Brain temperature data for the simulated 2041-2070-time frame for all GCM/emission scenarios; Figure A6.1b shows the range in monthly percentage increase in the Orillia Brain precipitation data for the simulated 2041-2070-time frame for all GCM/emission scenarios.

The change field method has been widely adopted due to its ease of use. The primary advantage is the ability to generate change fields for a wide variety of GCM/emission scenario combinations and thereby investigate a wide-range of predicted responses and develop an improved understanding of uncertainty associated with local-scale responses to future climate change.

One of the key limitations of the change field method for hydrologic impact assessment, however, is that potential impacts of climate change on inter-annual or day-to-day variability of climate parameters are not represented. The change field method shifts or scales the daily values, but the variability in timing and intensity inherent in the dataset remains the same. This can lead to an underestimation of future floods, droughts, groundwater recharge and snow-melt timing (Bates et al., 2008). These limitations should be kept in mind when reviewing the findings of this study. Other downscaling methods are discussed in in EBNFLO and AquaResource (2010).

Scatterplot and Percentile Method
It is generally not practical to assess a watershed using all results of all possible GCM/emission scenarios. EBNFLO and AquaResource (2010) discuss two methods for selecting a subset of scenarios to use in generating hydrologic model input data sets:

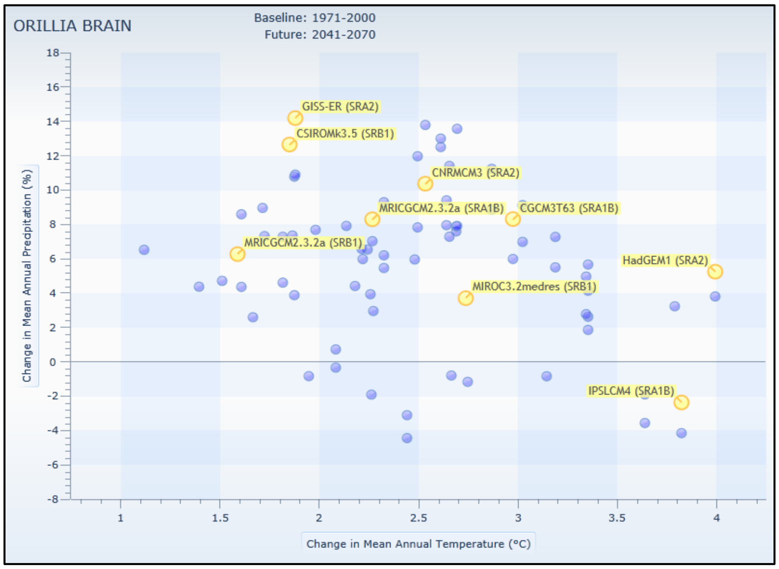
1. Scatterplot method; and
2. Percentile method.

In the scatterplot method, a relevant summary statistic for each GCM, such as the percentage change in annual precipitation, is plotted against a second relevant statistic, such as the percentage change in annual temperature. The GCMs representing the four extreme points are selected as a means of bracketing the range of possible outcomes, although other GCMs can be added to supplement these points.

In the percentile method, the summary statistics are each ranked in ascending order and the GCMs representing the 5th, 25th, 50th, 75th, and 95th percentile are selected yielding 5 GCMs per statistic. Some GCMs may be selected twice.

Example:
In the Oro Moraine example, GCM results, as sampled at the Orillia Brain AES climate station (AES: 6115811), were ranked in ascending order, first based on their mean annual temperature change and then based on mean annual precipitation change. Five GCMs were selected for temperature change and five for precipitation change, based on the rankings. Because one of the scenarios (MRICGCM2.3.2a – SRB1) was included in both rankings, only nine unique GCM/emission scenarios were considered (yellow circles in Figure A6.2).

In **Figure A6.2: Scatterplot of climate scenarios, sampled at Orillia Brain and GCM scenario selection (yellow) based on percentile method**



summary, there are several methods available for downscaling results from GCMs, of which, the change field method is the most direct. Datasets derived using these methods are available for use in hydrologic models from provincial websites (see the Resource Directory).

To avoid having to run the full range of GCM results through a model, the scatterplot and percentile method offer a means of bracketing the likely range in model outcomes. The hydrologic models using the modified climate data time series can be run to simulate a particular land development scenario or stormwater management design and evaluate the performance under a range of future climate conditions.

A full case-study example detailing the Climate Change Sensitivity of the Lake Simcoe Basin is provided below.

A6.1.3 Example of Climate Change Sensitivity of the Lake Simcoe Basin

Several climate change studies have been undertaken in the Lake Simcoe basin utilizing different methodologies. MacRitchie and Stainsby (2011) applied climate change projections from 10 General Circulation Models to a simple water balance model (available at http://wwwbrr.cr.usgs.gov/projects/SW_MoWS/Thornthwaite.html) to estimate the future effects of climate change on water quality and quantity. The study predicted increased surface water runoff in the winter months and decreased water availability in the summer. Additionally, the authors anticipated an increase in the frequency of low water levels and drought events during the summer along with an increased risk of flooding in winter.

Chu (2011) assessed the vulnerability of wetlands, streams and rivers within the Lake Simcoe watershed to climate change. Future changes to physical habitats were assessed by pairing biological indicators (e.g., fish habitat) to GCM scenario parameters (e.g., temperature and precipitation). Results indicated that 89% of the wetlands within the watershed will be vulnerable to drying and shrinkage due to increases in air temperatures and decreases in precipitation.

The effects of changing land use and climate on the hydrology and carbon budget of the Lake Simcoe Watershed was studied by Oni et al. (2012). GCM data were applied to a subbasin-scale hydrologic model Hydrologiska Byråns Vattenbalansavdelning (HBV) to predict dissolved organic carbon fluxes to Lake Simcoe under future conditions. The hydrologic model suggested increased variability in the predicted runoff in spring and winter seasons relative to historical baseline conditions. Further use of the linked hydrologic-carbon model (HBV-INCA) (Integrated Catchment Model or INCA) was made by Crossman et al. (2013) to analyze the Black River subwatershed in greater detail. The model predicted higher winter flows, reduced summer flows and an earlier snowmelt in the subwatershed. Based on the predicted changes to the hydrologic regime, and increased overall temperatures, the study concluded that total phosphorus loading to Lake Simcoe was likely to increase throughout the 21st century which will have a negative effect on the Lake's ecological and trophic status.

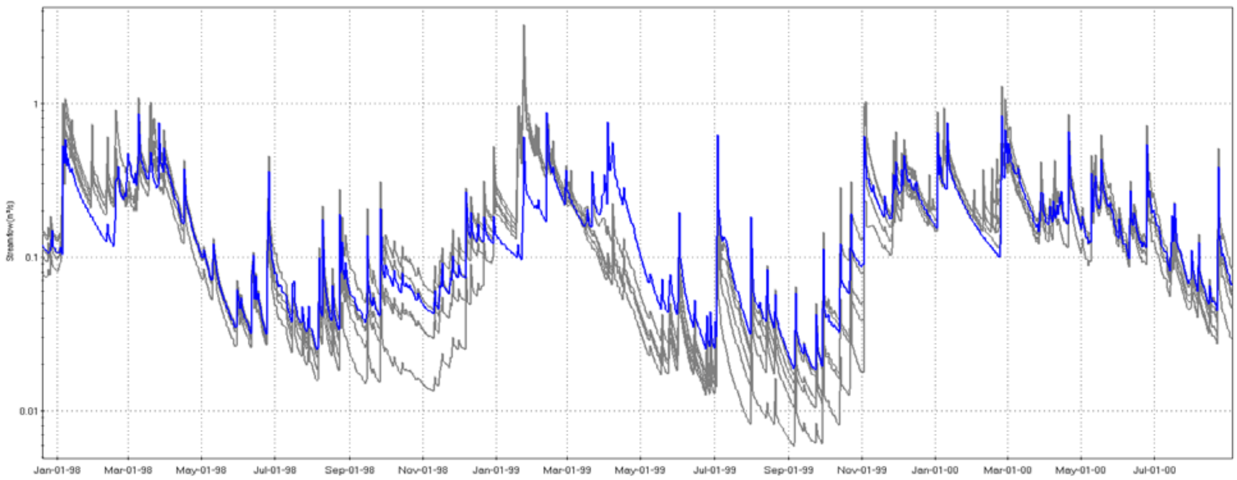
An integrated groundwater/surface water model was applied in the Lake Simcoe basin, using climate change projections from multiple GCMs, to evaluate the effects of climate change on groundwater and surface water flow at the subwatershed scale. The model, developed by Earthfx Incorporated (2013), covered the Oro Moraine area which included the North Oro, South Oro, and Hawkestone Creeks subwatersheds on the northwest side of Lake Simcoe (Figure A6.3). The model focused on representing the shallow groundwater flow system, headwater streams, and wetlands that form on the flanks of the Oro Moraine. The geology is complex and consists of alternating tills and sand deposits which have been dissected by glacial tunnel channels.

The change field method of downscaling the GCM data, as described in Section A6.1.2, was applied in this study (Wexler, et al., 2014). Monthly data for the 20-year period (2041-2070) were obtained from a range of GCMs and used to modify an actual observed (baseline) 30-year (1961-1990) climate time series. The use of multiple GCMs ensured that a representative range of climate predictions were investigated and that results bracketed the likely outcomes. Results of the climate change and drought analyses were presented as changes in simulated streamflow, groundwater discharge to streams, changes in spatial distributions of soil moisture and groundwater recharge, and changes in wetland stage and hydroperiod.

Figure A6.3: Oro Moraine with study subcatchments

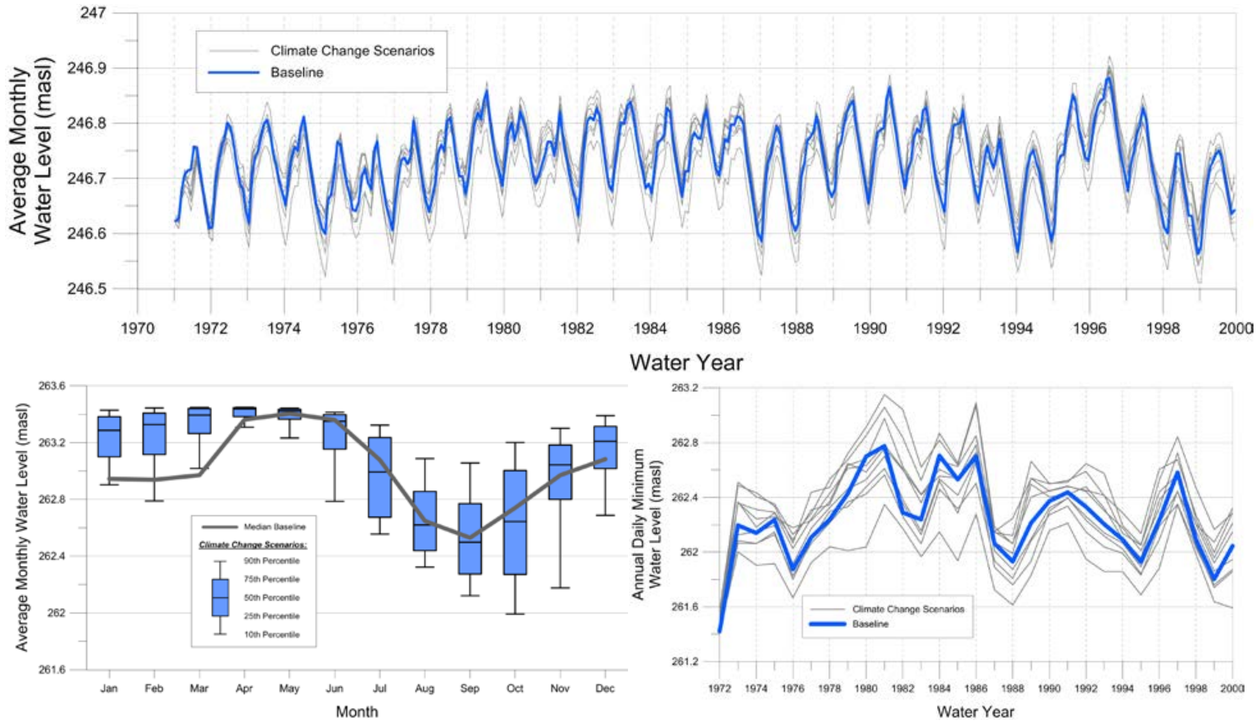
Results showed that the hydrologic response under future climate change was sensitive to the underlying geology. Groundwater-fed streams, particularly headwater reaches sustained by local groundwater recharge, were significantly affected by the reduced recharge during the late spring and summer months as shown in Figure A6.4. Streams that were better connected to the Oro Moraine through deeper regional groundwater flow paths were much less sensitive. While the three subwatersheds were superficially very similar in terms of land use and surficial geology, the modelling results showed that sensitive streams were predominantly located in the South Oro watershed, while the main branch of Hawkstone Creek and most of the North Oro Creek reaches were less sensitive because of their better connection through the subsurface to the high recharge, high storage Oro Moraine. Comparisons were made between the results from integrated model and a stand-alone hydrologic model and demonstrated that consideration of the underlying geology and groundwater feedback mechanisms yielded a more accurate representation of the likely climate change impacts. One noted limitation in the change field method is that is does not account for possible variation in storm frequency or intensity.

Figure A6.4: Historic streamflow (blue) in Shellswell Creek (South Oro) and predicted flows (grey) using precipitation and temperature data from downscaled from a range of Global Circulation Models (Wexler et al, 2014)



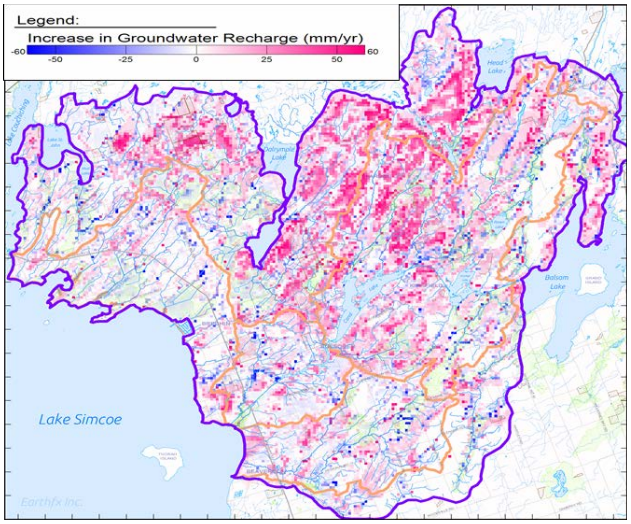
Earthfx (2014) developed a similar integrated groundwater/surface water model for the Ramara Creeks, Whites Creek, and Talbot River subwatersheds on the northeast side of Lake Simcoe. The northern part of the area lies within the Carden Plain alvar (a low-relief weathered bedrock surface with open fractures) while the rest of the study area is covered by till or clay plains. As in the Oro Moraine study, an assessment of groundwater and surface water flow under a changed climate was conducted using the change-field method to downscale results from a range of GCMs representing the 2041-2070 time frame. Results of the climate change analyses were presented as changes in stream flow, groundwater discharge to streams, the spatial distributions of soil moisture and groundwater recharge as well as local changes in wetland stage and hydroperiod (Figure A6.5).

Figure A6.5: Monthly average groundwater level (upper), minimum annual water level (lower left), and monthly water level statics for 9 GSFLOW simulations of future climate conditions in the shallow bedrock aquifer (Earthfx, 2014)



Groundwater recharge was predicted to increase with climate change across most of the study area (as shown by the red areas on Figure A6.6). Warmer and wetter fall and winter seasons allow more water to enter the groundwater system. Furthermore, the timing of the spring freshet is predicted to shift, with more recharge occurring earlier in the spring. The warmer winters predicted by the climate change models result in less accumulated snow and less water stored in the snowpack into late-spring. This, in turn, increases the sensitivity of low-flow response during the longer, hotter summers.

Figure A6.6: Predicted change in groundwater recharge under 2041-2070 climate conditions (Earthfx, 2014)



A comparison of the Oro Moraine and Carden Plain settings indicated that while both sites had high recharge features, the subwatersheds on the Oro Moraine were more resilient to drought and climate change because of the higher groundwater storage capacity.

In summary, various techniques can be applied to downscale climate change results and use the data to modify inputs to hydrologic models ranging in complexity from simple water budgets to integrated surface water/groundwater models. Despite the differences in techniques, some common observations and meaningful results regarding the likely behaviour of the watersheds under future climate were generated. The same techniques can be applied at a smaller scale (individual subwatershed or catchment) to assess changes in the local water budget and how the stormwater management features will behave under future climate conditions.

APPENDIX 7 – ACKNOWLEDGEMENTS

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Municipal Engineers Association (MEA) - Represented by the City of London
Water Environment Association of Ontario (WEAO)
Institute for Catastrophic Loss Reduction (ICLR)
Green Infrastructure Ontario Coalition
Landscape Ontario
Building Industry and Land Development Association (BILD) and the Ontario Home Builders' Association (OHBA)
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City of Calgary
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City of Toronto
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