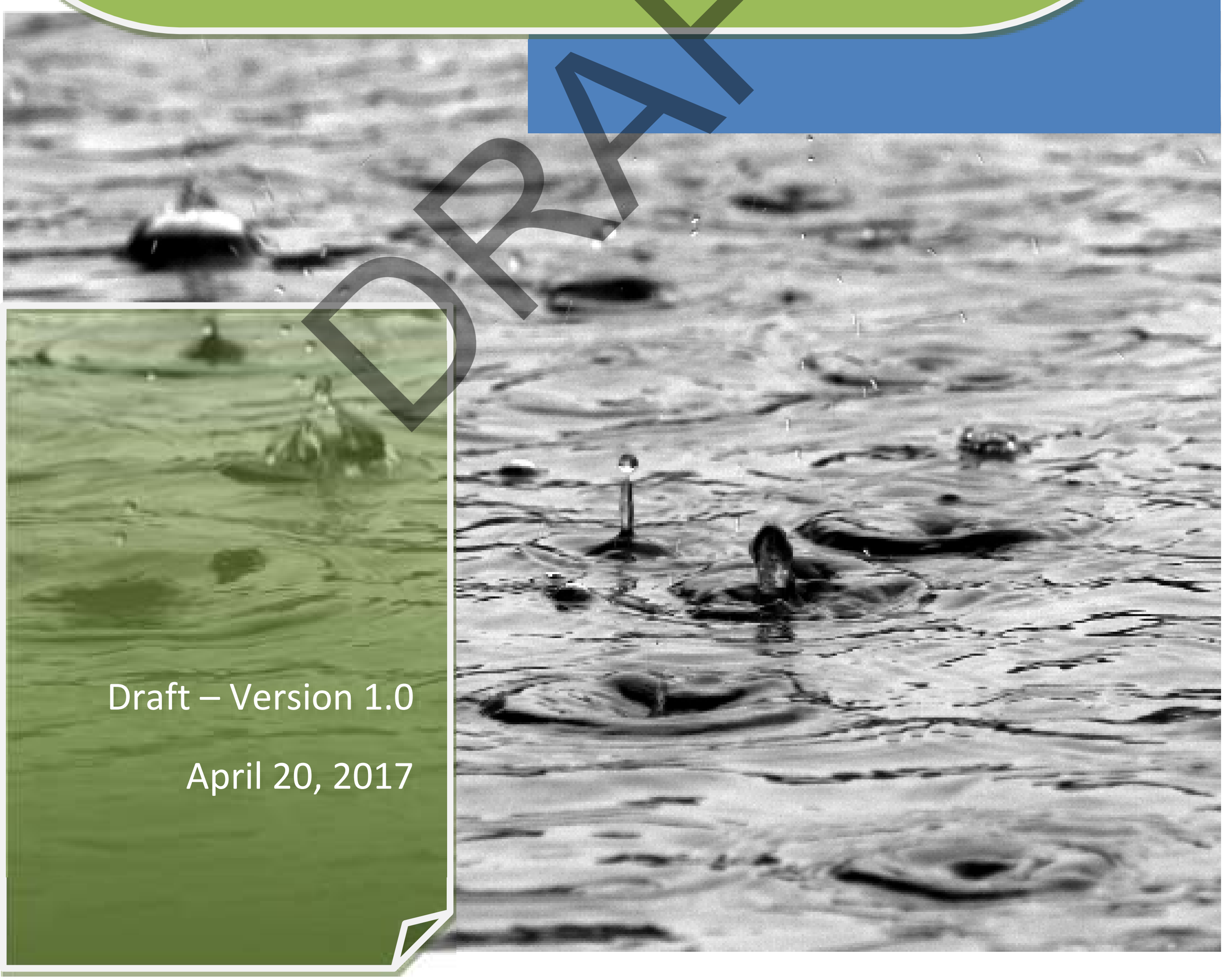
April 2017

Ministry of the Environment & Climate Change

DRAFT
Low Impact Development (LID) Stormwater Management Guidance Manual



Draft – Version 1.0

April 20, 2017

DISCLAIMER

The following document has been prepared based on expert input, stakeholder consultation and professional judgement; and represents a draft document intended for distribution, review and comment by the Stakeholder Review Group (SRG), the Ministry of the Environment and Climate Change (MOECC) staff as well as other provincial agencies and organizations.

This draft document has not endorsed by the Ministry of the Environment and Climate Change (MOECC) and has been prepared for consideration only.

PREFACE

During the past three decades, with improvements in watershed management and our understanding of the watersheds themselves, there has been an evolution in stormwater management in Ontario. Planners, engineers, landscape architects and designers now must address a broad suite of technical issues including the maintenance 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 forecasted impacts of climate change.

The most recent approaches and techniques used in stormwater management (SWM) reflect our collective understanding and evolution and have lead to a change in the way in which the public and policy makers regard Ontario's water resources, the natural and human environments. This change, embodied within the principles of Green Infrastructure (GI) and Low Impact Development (LID), has led to considerable alterations in the planning, design and construction of Ontario communities and the infrastructure necessary to sustain them.

LID is an innovative state of the art approach to managing stormwater by first and foremost treating runoff (precipitation) at its source, as a resource to be managed and protected rather than a waste. In this regard, the emphasis is to maintain the existing pre-development water balance 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. 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 now outdated land use and infrastructure planning driven solely by rapid conveyance and public safety objectives using only grey infrastructure (i.e. subsurface pipes) in combination with end-of-pipe controls.

However, it is no longer enough to simply apply LID and GI SWM approaches as part of land planning to simply mitigate impacts. To truly protect Ontario's water resources, the natural and human environments and preserve the ecological services already provided by our existing natural systems, these practices must be integrated into everyday urban forms, into the very fabric of the community. In this way, a complete and healthy community is formed whereby the very features which support the human inhabitants (roads, parks, grassed areas, sidewalks) become the very elements that protect the existing hydrologic features and function, create habitat, and make a community more livable.

This Low Impact Development (LID) Stormwater Management Guidance Manual should be used in conjunction with 2003 Stormwater Management Planning and Design Manual (SWMPDM). This manual, and its companion document, the 2003 SWMPDM, collectively provide the guidance and SWM criteria, necessary to implement a holistic treatment train approach to stormwater management in Ontario using the full spectrum of source, conveyance and end-of-pipe controls.

Echoing the 2003 SWMPDM, it is not the intent of the Ministry to limit innovation with this manual. Significant effort has been made to write the manual in a manner that does not inadvertently restrict creative solutions. The Ministry encourages the development and application of innovative designs and technologies, where supported by literature, supporting research or other, when developed by a qualified person. Where the designer can show that alternate approaches can produce the desired results or even better, such designs should be considered. However, the designer is responsible for the designs which are made with respect to stormwater management for any given site.

ACKNOWLEDGEMENTS

The following agencies, organizations, municipalities participated on Stakeholder Review Group (SRG) and generously provided their time and input into the preparation of this manual:

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Other stakeholders participated in the workshops and provided input into the development of this manual.

The prime consultants for the project were Aquafor Beech Ltd. (Chris Denich (PM), Peter Hebert, Dave Maunder and Will Cowlin) and Earthfx Inc. (E.J. Wexler and Pete Thompson).

Technical expertise and review services were provided by Emmons and Oliver Resources (Jay Michels) and J.F. Sabourin and Associates Inc. (Jean-Francois Sabourin and Heather Wilson).

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Appendix

Appendix 1 – Glossary of Terms
Appendix 2 – List of Abbreviations and Acronyms
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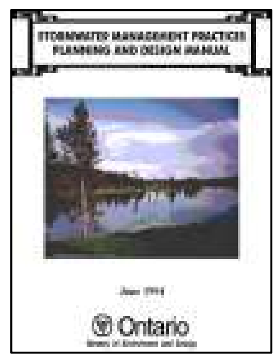
1 Introduction

1.1 History of the MOECC Manuals

The “state-of-the-art” in stormwater management has been evolving rapidly. In Ontario, this evolution has taken the form of several provincial reports, guides and manuals. The following section provides an overview of the evolution of SWM in Ontario and the history of the MOECC stormwater manuals.

- 1991 - the Ministry of the Environment published a report entitled Interim *Stormwater Quality Control Guidelines for New Development*. The report documented experience with structural and non-structural Stormwater Management Practices (SWMPs) and concluded that they should be implemented in conjunction with new urban development and redevelopment. The report pubclished more than more than two decades ago included recommendations for the control of stormwater volume using source controls and vegetative practices, noting that:
    - o Source controls which reduce the amount of impervious area or restrict the discharge of stormwater to sewers should be used first to achieve specified volume controls; and
    - o Stormwater quality ponds should be considered as the last line of defence and applied only after all opportunities for infiltration of stormwater have been exhausted.



- 1994 - The Ministry of the Environment initiated the development of a *Stormwater Management Practices Planning and Design Manual*. The 1994 manual had a significant focus on water quality. The manual inctroduced four (4) levels of stormwater quality protection focusing on suspended sediment reductions and included a recommendation for the infiltration of 5mm of runoff for the preservation of baseflow within local watercourses.

- 2003 – Stormwater Management Planning and Design Manual (SWMPDM) which is a companion document to this manual, provides a more integrated approach, as compared to its 1994 predecessor, that incorporates water quantity and erosion considerations. The SWMPDM provides technical and procedural guidance for the planning, design, and review of stormwater management practices. The focus of the manual was broadened to incorporate the current multi-objective approach to stormwater facility planning to address targets related to hazards, water quality, fish habitat and recreation. Fundamental SWM objectives which are included in the 2003 SWMPDM include:
    - o Groundwater and baseflow characteristics are preserved;
    - o Water quality will be protected;
    - o Watercourse will not undergo undesirable and costly geomorphic change;
    - o There will not be any increase in flood damage potential; and ultimately and

- That an appropriate diversity of aquatic life and opportunities for human uses will be maintained.

A central theme of the SWMPDM is the application of a "treatment train", a term that is used to describe the combination of controls – source, conveyance and end-of-pipe controls - usually required in an overall stormwater management strategy to ensure that aforementioned objectives are achieved. The SWMPDM states that:

> *"the recommended strategy for stormwater management is to provide an integrated* ***treatment train approach*** *to water management that is premised on providing control at the lot level and in conveyance (to the extent feasible) followed by end-of-pipe controls. This combination of controls is the only means of* ***meeting the multiple criteria for water balance, water quality, erosion control and water quantity****."*

- 2015 - In February, the MOECC released an interpretation bulletin to clarify the ministry's expectations regarding SWM. Specifically, the bulletin clarified that the ministry's existing policies and guidance and emphasized an approach to SWM 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), often as part of a treatment train approach. The bulletin also reinforced the ministry's desire to implement LIDs as part of a holistic SWM approach and that LID BMPs are relevant to all forms of development, including new development, redevelopment, infill, and retrofit development.

1.1.1 Present Day and This Manual

Since the publication of the 2003 SWMPDM, advancements have been made in the approaches used to manage stormwater and the technologies available to the stormwater practitioner. 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 required within Ontario's stormwater systems. To encourage stormwater solutions that treat stormwater as a resource and that mimic the natural that hydrologic pathways of infiltration and evapotranspiration, the Province has developed a suit of policies, incentives and legislation that promote the implementation of LID BMPs. These include the Lake Simcoe Protection Plan (2009), the Water Opportunities Act (2010), the Policy Review of Municipal Stormwater Management in Light of Climate Change (2010), Ontario's Great Lakes Strategy (2014) and the Showcasing Water Innovation grant program.

This Low Impact Development Stormwater Guidance Manual was developed to complement the 2003 Stormwater Management Planning and Design Manual, with a focus on source and conveyance controls. Similar to the 2003 manual, this document should be used as a tool for understanding the design criteria and performance requirements of stormwater management projects and not as a rulebook or design manual for stormwater management solutions. The 2003 manual is still to be used as a tool for the end of pipe stormwater management criteria and design recommendations while the LID SWMGM provides volume control requirements. **Figure 1.1** illustrates the relationship between the 2003 SWMPDM and this manual and the SWM criteria to be applied as part of the required treatment train approach.

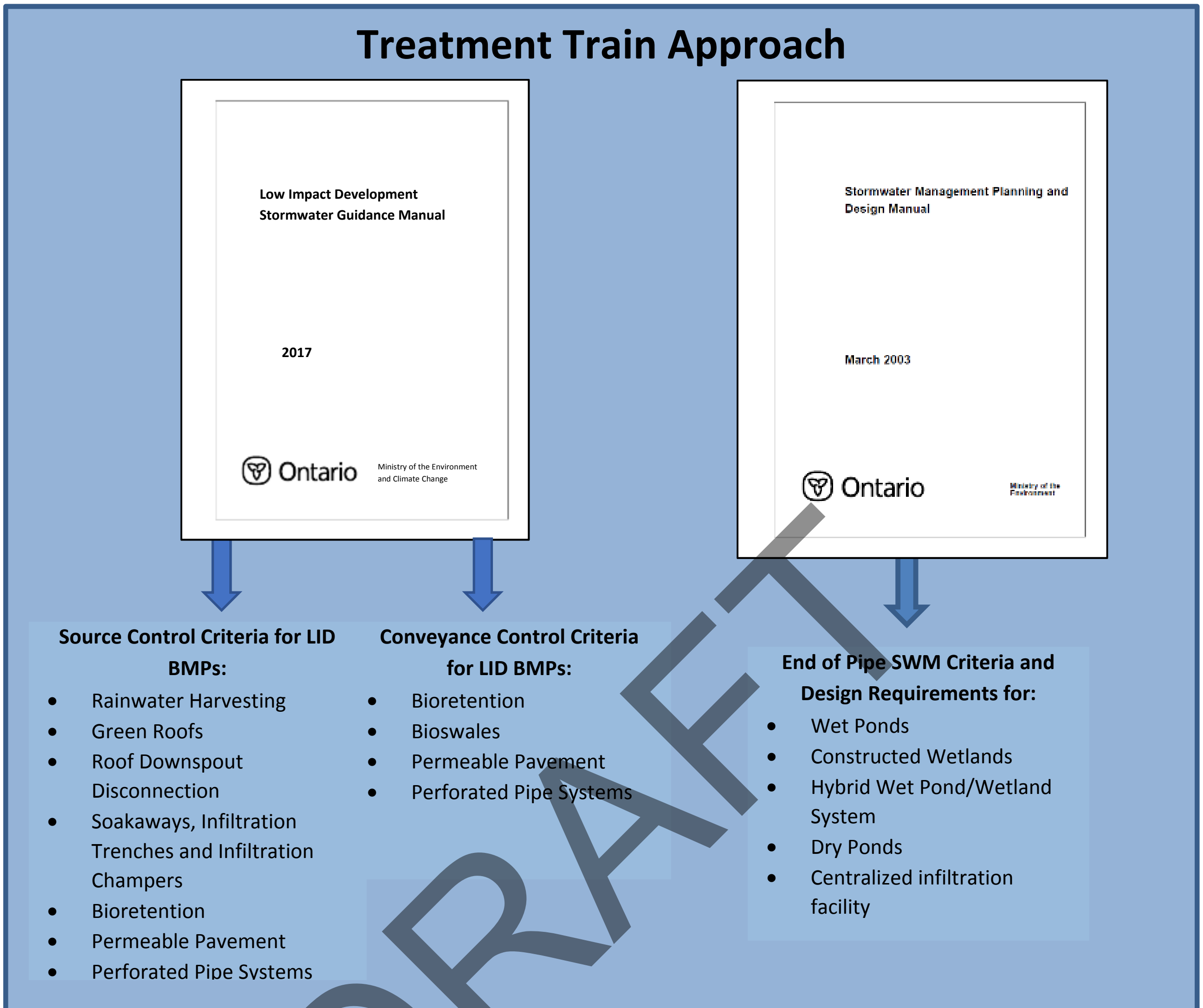


Figure 1.1: Role of the Provincial SWM Manuals in Achieving the Treatment Train Approach

Regarding the intended use of this document, it is worth emphasizing points made in the preface.

> *During the past three decades, with improvements in watershed management and our understanding of the watersheds themselves, there has been an evolution in stormwater management in Ontario. Planners, engineers, landscape architects and designers now must address a broad suite of technical issues including the maintenance 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 forecasted impacts of climate change.*
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in the planning, design and construction of Ontario communities and the infrastructure necessary to sustain them.

LID is an innovative state of the art approach to managing stormwater by first and foremost treating runoff (precipitation) at its source, as a resource to be managed and protected rather than a waste. In this regard, the emphasis is to maintain the existing pre-development water balance 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. 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 now outdated land use and infrastructure planning driven solely by rapid conveyance and public safety objectives using only grey infrastructure (i.e. subsurface pipes) in combination with end-of-pipe controls.

However, it is no longer enough to simply apply LID and GI SWM approaches as part of land planning to simply mitigate impacts. To truly protect Ontario's water resources, the natural and human environments and preserve the ecological services already provided by our existing natural systems, these practices must be integrated into everyday urban forms, into the very fabric of the community. In this way, a complete and healthy community is formed whereby the very features which support the human inhabitants (roads, parks, grassed areas, sidewalks) become the very elements that protect the existing hydrologic features and function, create habitat, and make a community more livable.

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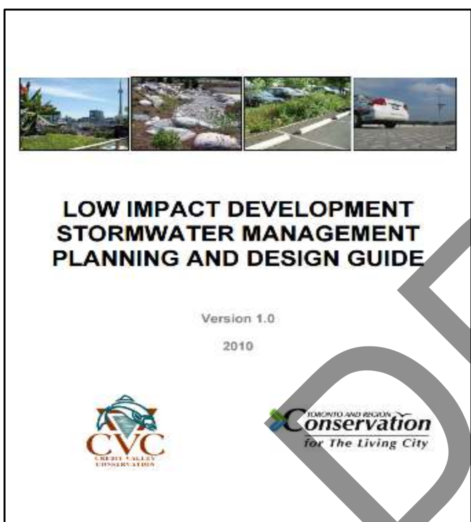
1.2 Supporting Resources

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. While this manual provides design criteria for volume control, a framework for the selection of modelling approaches, a climate change assessment methodology, as well as a description of how to reduce the risks associated with groundwater contamination - existing publications developed by the Toronto Region Conservation Authority's (TRCA) Sustainable Technology Evaluation Program (STEP) and by Credit Valley Conservation are valuable resources that are to be used during the following phases of LID implementation:

- Planning & Design;
- Construction; and
- Assumption, Maintenance and Lifecyle Activities.

The following LID resource documents that have been developed and are suitable for use in Ontario are described below. A **Resource Directory** accompanies this manual in **Appendix 3**. The **Resource Directory** includes links where these resources can be downloaded and will be updated as resources are updated and new resources are released.

LID Resources for Planning & Design



The **Low Impact Development Stormwater Planning and Design Guide** was released 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 practices.

The Design Guide was not meant to be a stand-alone document. It is intended to augment the Ontario Ministry of the Environment's 2003 Stormwater Management Planning and Design Manual, which provides design criteria for "conventional" end of pipe stormwater management practices such as wet ponds and constructed wetlands. LID features that are covered in this guide include:

- 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 LID Planning and Design Guide also includes **Fact Sheets** for each LID practice as Appendix A. These fact sheets provide a quick technical reference for general design guidance, applications, construction considerations, common concerns, ability to meet SWM objectives, and site considerations.

Appendix B of the guide is a **Landscape Design Guide for Low Impact Development**. This appendix provides land managers and professional practitioners with an understanding of the guiding principles of LID planting design, implementation and management. This document is an important resource for LID plant selection for all types of LIDs with consideration given to potential site constraints.

Appendix C of the guide is a **Site Evaluation and Soil Testing Protocol**. This appendix outlines the field testing protocol for infiltration-based LID practices.

LID Resources for Planning & Design (Retrofits)

The Grey to Green **Road Right of Way Retrofit Guide** provides guidance for municipal retrofits of road right of ways (ROWs) with innovative LID practices. The guide provides municipal planners, engineers and technical staff with guidance from screening LID options through lifecycle activities. Within the guide the implementation process is broken into 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 **Business and Multi-Residential Guide** 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 Low Impact Development **Residential Retrofits Guide** provides guidance for engaging residents to adopt LIDs on their private properties. This guide presents:

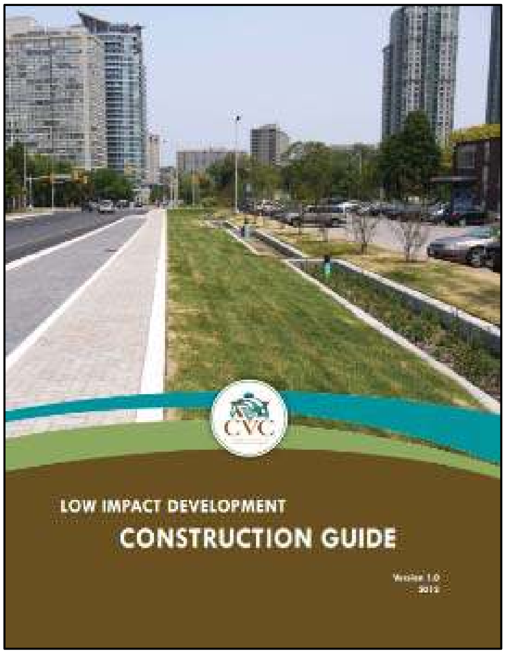
- Residential LID options
- Strategies for targeting neighbourhoods with LIDs
- Municipal retrofit project team requirements
- Methodology for conducting neighbourhood-level market research
- Marketing Plan Options
- Tips for rolling out a marketing plan

The Grey to Green **Public Lands Retrofit Guide** provides guidance for LID retrofits of public realm properties. The guide discusses LID options and implementation strategies for the following property types:

- Parks
- Municipal facilities
- Schools
- 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

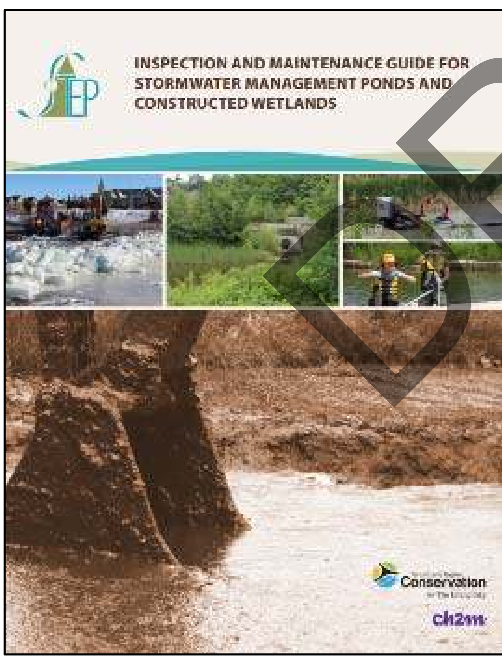


The Low Impact Development **Construction Guide** was released to provide guidance to design consultants, municipal engineers, plan reviewers, and construction project managers regarding common LID construction failures and how to avoid them. The goal of this document is to guide the proper construction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

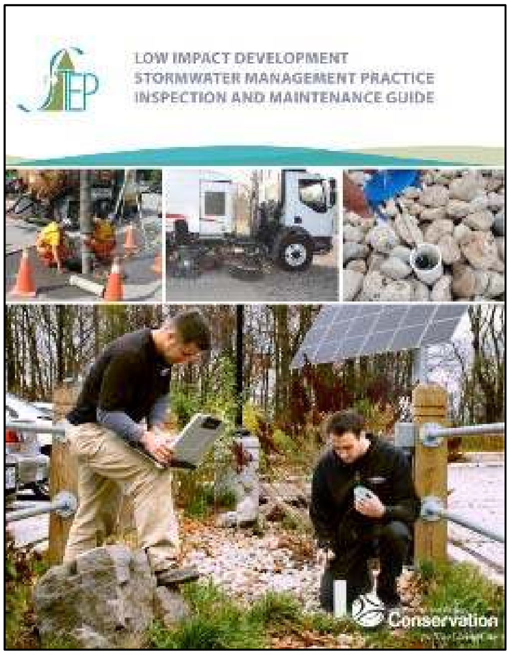
The Construction Guide includes:

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

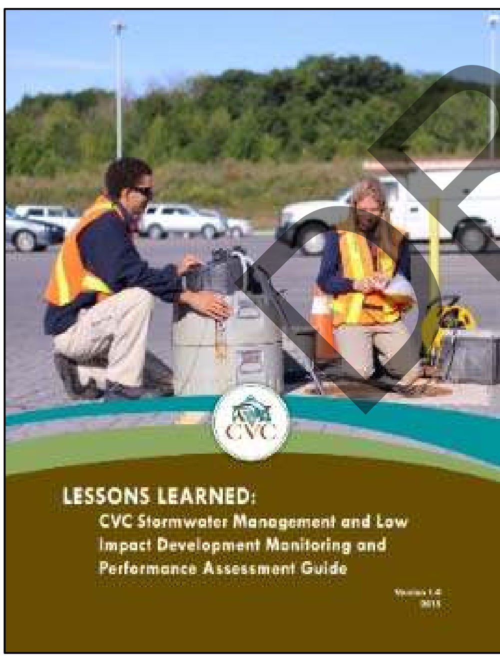
Maintenance, Assumption and Lifecyle Activities



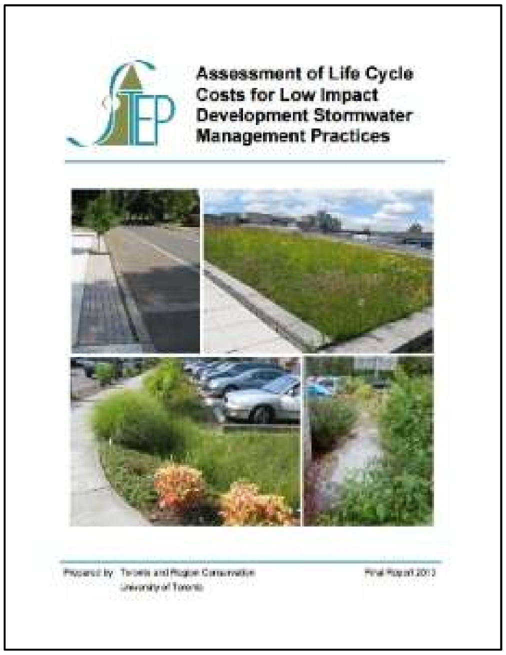
The Inspection and Maintenance Guide for Stormwater Management Ponds and Constructed Wetlands serves as guideline to address fundamental elements that should be considered in routine stormwater management facility inspection and maintenance and sediment removal and disposal decision making processes.



The **Low Impact Development Stormwater Inspection and Maintenance Guide** provides guidance for municipalities and property managers with developing their capacity to integrate LID SWM 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 **Stormwater Management and Low Impact Development Monitoring and Performance Assessment Guide** presents the general steps, experiences, and valuable lessons CVC has learned through designing and implementing monitoring plans and activities since 2008. The guide is intended to be used as a resource for developing and implementing performance monitoring of LID practices.



The **Assessment of Lifecyle Costs for Low Impact Development Stormwater Management Practices** is a publication that evaluates the capital and life cycle costs of Low Impact Development (LID) practices over a 50-year time horizon based on a detailed assessment of local input costs, maintenance requirements, rehabilitation costs and design scenarios relevant to Canadian climates. Along with the report, a costing tool was developed and is available for download.

1.3 Manual Outline

The sections and information provided in this Low Impact Development Stormwater Management Guidance Manual include:

Chapter 1 – Introduction

Provides an introduction to the LID Stormwater Guidance Manual, outlining the history of SWM manuals in Ontario, its relationship with its companion document, the 2003 SWMPDM, and its role in the successful implementation of a treatment train approach to stormwater management in the province of Ontario. Also provided is a list and summary supporting resources for use by practitioners, and an overview of the effect of urbanization, an introduction to LID and a summary of key stormwater related legislation.

Chapter 2 – Environmental Planning Process

Describes the environmental planning process, the relationship between stormwater management (SWM) plans and subwatershed studies, the hierarchy of SWM criteria developed as part of the land-use processes, the role of the Ministry SWM Manuals within the land use planning context and the legislative context governing SWM in Ontario. This section also summarizes the legislation governing stormwater including relevant statutes, regulations, policies, guidelines and Acts.

Chapter 3 – Stormwater Management Design Criteria

Outlines the Runoff Volume Control Target (RVCT) for new development, redevelopment, infill-development, reurbanization, linear infrastructure and SWM retrofits in Ontario.

Chapter 4 – Groundwater Considerations

Outlies the relationship between groundwater systems and watershed health, and the benefits of LID BMPs in relation groundwater resource. It includes a detailed discussion of the risk to groundwater resources from stormwater runoff and infiltration LID BMPs and the methods by which risks can be managed in the context of source protection policies.

Chapter 5 – Criteria for Model Selection

Provides guidance regarding criteria for selecting a technical approach for predicting and assessing the performance of stormwater management plans on a long-term basis including a methodology for the potential selection of model classes to appropriately represent the subject site(s).

Chapter 6 – Climate Change

Provides an overview of climate change, observed global and local climate change parameters, and an overview of Ontario's Adaptation Strategy and Action Plan. The chapter describes the roles and responsibilities of municipalities in climate change adaptation planning, describes the need for assessing the impacts of climate change on development planning and design at the site and municipal scale, modelling approaches and describes a 4-step climate change adaptation process and how LIDs can build climate change resiliency. Existing municipal planning tools that can be used to support climate change adaptation are also detailed.

Chapter 7 – Approvals

Describes the Environmental Compliance Approval (ECA) process and submission requirements relating to stormwater management (sewage) works and Low Impact Development (LID) BMPs in compliance with Ontario Water Resources Act.

Chapter 8 – Erosion and Sediment Control During Construction

This section discusses the importance of providing enhanced erosion and sediment control during construction of sites that include LID BMPs. Current erosion and sediment control guidelines are discussed along with enhanced strategies for preventing malfunction and failure of the facilities.

Chapter 9 – Operation and Maintenance (O&M)

Describes O&M for municipally owned systems, and the process by which O&M activities can be optimized as part of design and construction. The chapter describes the O&M approaches for both municipally owned and privately owned systems, approaches for assigning responsibilities as well as suggested municipal tools, policies and processes to ensure appropriate O&M on privately owned LID BMPs.

Chapter 10 – Monitoring and Performance Verification

This section summarizes assumption and performance verification protocols for LID BMPs. The differences between conventional stormwater management facility monitoring and LID BMP monitoring are discussed along with subwatershed and watershed level programs.

Chapter 11 - References

1.4 Effects of Urbanization

Changes in land use from natural cover, such as clearing forests for cultivation or conversion of rural lands to urban development forms, alters the water balance as pervious surfaces are converted to impervious surfaces, infiltration characteristics of the soils are altered and vegetation is removed or altered. When rural lands are urbanized, porous soils are replaced with impervious materials such as concrete and asphalt which yield high runoff during precipitation events. Consequently, land use change can lead to a significant and sometimes radical alteration in the prevailing watershed hydrology and 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 additional of hydraulic structures such as bridges and culverts. Channel erosion and input from land uses changes also cause increased sediment load is 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 1.4.1** 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.

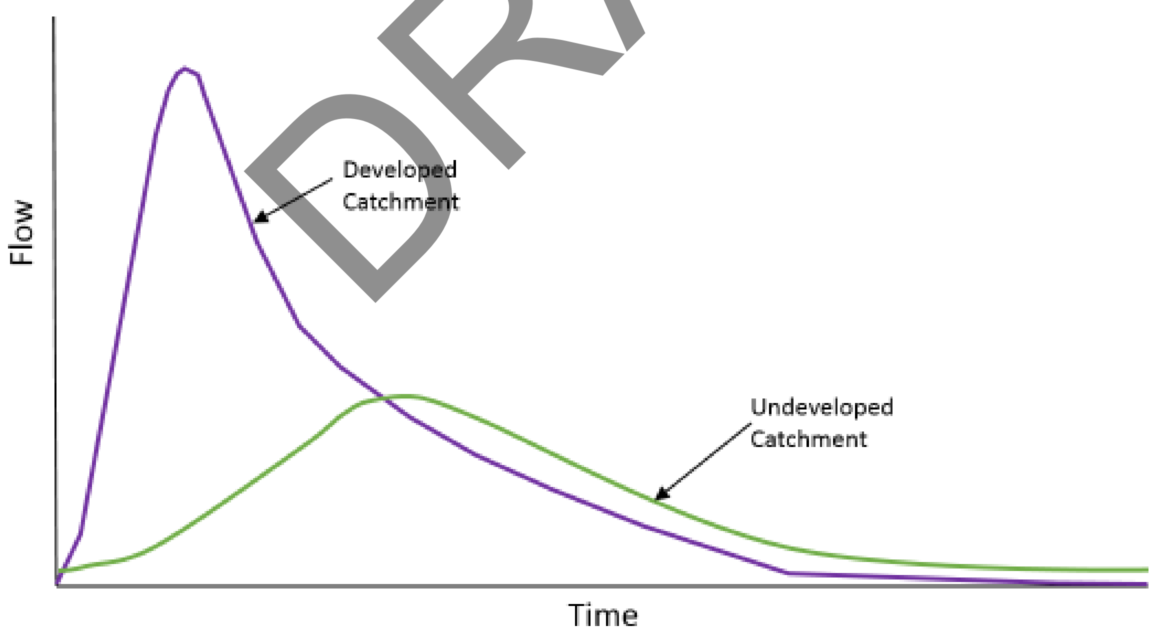


Figure 1.4.1: Flood Hydrographs for undeveloped and developed catchments

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 elevated levels of suspended solids, nutrients, bacteria, heavy metals, oils and grease, and sodium and chloride from the winter application of road salt.

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

5. **Decline is aesthetic value and recreational potential:** Ontario's water bodies are used for a wide range of recreational activities including fishing, paddling, and swimming. 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 keep these valuable resources available for recreational purposes.

Combined with the effects of decreases in infiltration volumes directed to shallow and deep groundwater, which supplies 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 additional 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.

The goal of maintaining and restoring the natural or pre-development hydrologic integrity of watershed and its associated water balance is to avoid alterations to instream erosion rates, water quality degradation, losses in groundwater recharge rates, increased flow, impacts to the natural environment as well as to avoid unfunded infrastructure liabilities. As such, avoiding changes to the natural watershed hydrology and the associated water balance as a result of development must be the primary focus of stormwater practitioners. To effectively mitigate the impacts, stormwater strategies must include a means to reduce runoff volume with the objective of maintaining the pre-development water balance.

1.4.1 Discussion of Conventional SWM

The management of stormwater runoff was conceived as a means to allow land use change, specifically urban development, to occur while mitigating the affects 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 to offset the hydrologic effects of urbanization are insufficient to prevent increased channel erosion, the deterioration of water quality and aquatic habitats[i] [ii].

Although unintended, over most of its stormwater history, Ontario has relied primarily 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 the purpose of attenuating large flood flows. In the 1980's and early 1990's design standards for detention ponds were revised to provide water quality treatment through settling of suspended sediments. More recently (beginning in the late 1990's), ponds began to be designed for the management of increased erosion potential associated with hydromodification and in the mid 2000's for thermal protection of receiving waterbodies. However, there is a fundamental problem with the reliance on detention facilities as the basis for the management of hydrologic changes in watersheds, as they do not address or mitigate impacts to the water balance.

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 wetland occur, these losses are not generally significant in the majority of detention facilities. As such, runoff volumes are not reduced and the pre-development infiltration portion of water balance is not maintained.

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[iii, iv, v, vi, vii, viii]

1.4.2 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 as ***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 waters 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 proportions of precipitation (P) which enter the hydrologic pathways of runoff (R), infiltration (I) and evapotranspiration (ET) is known as a water balance and is represented by the following simplified equation:

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

Or

$$\boldsymbol{P = R + I + ET}$$

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 or supplied to the watercourse through shallow groundwater discharge. The portion of precipitation accounted for in each of these components of the water balance is determined by a number of factors which can be broadly classified as:

1. Climate,
2. Vegetation, and
3. 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.

1.4.3 Water Demand and Use

The per capita water usage from residential homes in Canada is approximately 251 liters per day (Environment and Climate Change Canada, 2011). The total daily water intake volume for all manufacturing industries in Ontario is approximately 4 million cubic meters (Statistics Canada, 2009). Though less than manufacturing and municipal sectors, agricultural water use is also a vital component of water use in Ontario but it varies significantly depending on weather conditions.

As of 2015, Ontario's population was estimated to be 13.8 million. By 2041, Ontario's population is expected to grow by 30.1 percent or almost 4.2 million people to a total of almost 18 million (Ontario Ministry of Finance, 2016). With increased population comes additional people relying on our municipal and private water supply systems for both residential, agricultural and industrial purposes. Although significant improvements have been made in water use efficiency, many ageing municipal water systems will require upgrades to meet increased demand while maintaining the required 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.

1.5 Introduction to GI and LID

Green Infrastructure (GI) is a general overarching term that can encompass a wide array of specific stormwater management practices that are cost-effective, resilient approach to managing wet weather impacts that provide many community benefits. While many definitions of GI exist, for the purposes of this manual, the following definition, which is consistent with the Provincial Policy Statement (PPS) shall apply:

Green infrastructure (GI): means natural and humanmade (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.

Low Impact Development (LID) are humanmade or engineered systems and are a subset of Green Infrastructure used for the management of rainwater and stormwater runoff (**Figure 1.5.1**). 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. For this document, the following definition, adapted from the United States Environmental Protection Agency (U.S. EPA, 2007) and consistent with the Low Impact Development Stormwater Planning and Design Guide and other resources listed in **Section 1.2** shall apply:

Low Impact Development (LID) is a stormwater management strategy that seeks to mitigate the impacts of increased runoff and stormwater pollution by managing runoff as close to its source as possible. LID comprises a set of site design strategies that minimize runoff 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.

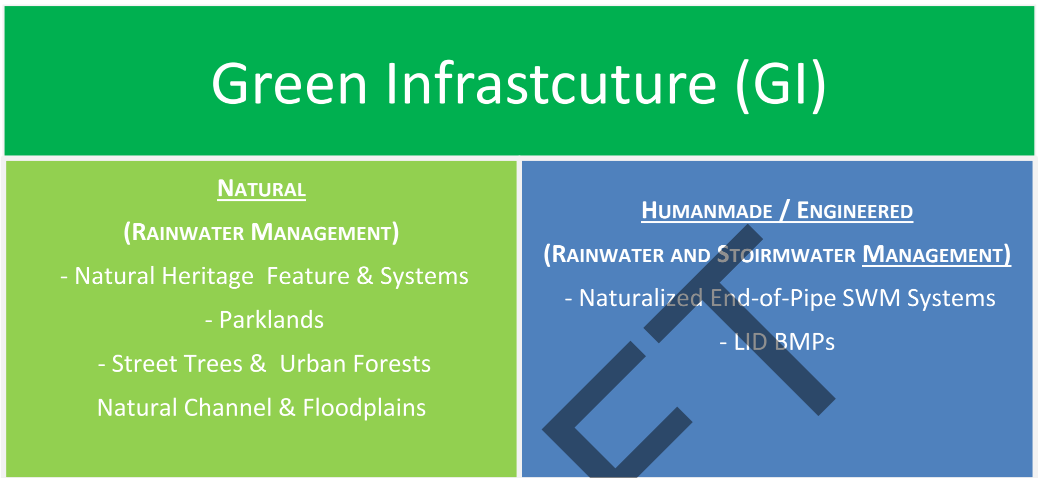


Figure 1.5.1 - Green Infrastructure

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

The 2010 LID Stormwater Planning and Design Guide (see the **Resource Directory**) describes the key principles for Low Impact Development Design as follows:

1. **Use existing natural systems as the integrating framework for planning** (See **Chapter 2**);
- 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.

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;
- 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;
- Maintain natural flow paths by utilizing open drainage (e.g., swales).

4. Create multifunctional landscapes

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

5. Educate and maintain

- Provide adequate training and funding for municipalities 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 SWM BMPs on private property;
- Establish legal agreements to ensure long-term operation and maintenance (See **Chapter 9**).

1.5.1 LID BMPs and Approaches

LID BMPs are considered at the earliest stage of site design, are installed during construction and sustained in the future as infrastructure system. Each LID BMP incrementally reduces the volume of stormwater on its way to the receiver. In doing so, LID BMPs are applied to meet stormwater management targets for water quality and quantity as well as erosion and infiltration / water balance objectives.

1.5.1.1 *Better Site Design*

The implementation of LID BMPs within any development context begins not with the planning, selection or design of the individual LID BMPs themselves, but with the application of the principles of better site design.

There are more than a dozen different better site design techniques which can be applied early in the design process at development sites. While not all of the better site design techniques will apply to every development site, 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 saving

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;
- Stormwater/ absorbent landscaping;
- Reducing impervious cover in site design including:
    - Narrower streets
    - Slimmer sidewalks
    - Smaller cul-de-sacs
    - Shorter driveways
    - Smaller parking lots

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 **Section 1.5.3** 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**).

Low Impact Development (LID) stormwater management BMPs are listed in **Table 1.5.1**, including their general classification as either a source control, conveyance control or both.

Table 1.5.1 – LID BMPs

LID BMP	Source Control	Conveyance Control	Notes
Rain water harvesting	✓		
Green Roofs	✓		
Downspout disconnection	✓		
Soakaways, Infiltration Trenches and Chambers	✓		
Bioretention (a.k.a rain gardens)	✓		
Vegetated Filter Strips	✓		
Permeable Pavements	✓		
Enhanced Grass Swales (a.k.a. vegetated swales)	✓	✓	Suitable for use within the road right-of-way
Dry Swales (a.k.a bioswales)	✓	✓	
Perforated Pipe Systems		✓	
Tree BMPs	✓		
Soil Amendments	✓		

1.5.1.2 *Rainwater Harvesting*

Rainwater harvesting is the process of intercepting, conveying and storing rainwater for future use. Harvesting rainwater for domestic purposes has been practiced in rural Ontario for well over a century. Roof runoff is the 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 onsite usage of potable water for irrigation and associated costs.

Rainwater harvesting systems can range from widely distributed small scale practices such as residential rain barrels to large subsurface units as shown above.

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). 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.

For the planning and design of Rainwear Harvesting systems see Chapter 4.1 of the 2010 LID Stormwater Planning and Design Guide. A link to this document can be found within the **Resource Directory**.

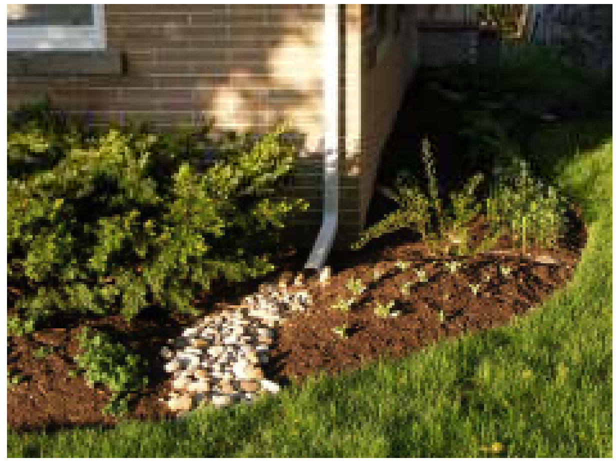
1.5.1.3 *Green Roofs*

Green Roof on the lower podium of a condominium

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 underdrain and overflows points and is conveyed in a typical building drainage system and onto the next LID BMP in the treatment train. 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.

For the planning and design of green roofs see Chapter 4.2 of the 2010 LID Stormwater Planning and Design Guide. A link to this document can be found within the **Resource Directory**.

1.5.1.4 *Downspout disconnection*



Residential downspout disconnection

Downspout disconnection involves directing flow from downspouts to a 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.

For the planning and design of downspout disconnection systems see Chapter 4.3 of the 2010 LID Stormwater Planning and Design Guide. A link to this document can be found within the **Resource Directory**.

1.5.1.5 *Soakaways, Infiltration Trenches and Chambers*

Infiltration chambers can be installed below conventional parking surface without compromising

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 and extend their lifecycle.

This practice is also known as infiltration galleries, french drains and / 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 (as opposed to only aggerates) 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. 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.

For the planning and design of Soakaways, Infiltration Trenches and chambers see Chapter 4.4 of the 2010 LID Stormwater Planning and Design Guide. A link to this document can be found within the **Resource Directory**.

1.5.1.6 *Bioretention (a.k.a rain gardens)*

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 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 practices are easily scalable to any site.

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.

Bioretention can be implemented as either:

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.

For the planning and design of bioretention see Chapter 4.5 of the 2010 LID Stormwater Planning and Design Guide. A link to this document can be found within the **Resource Directory**.

1.5.1.7 *Vegetated Filter Strips*

Vegetated filter strips (a.k.a. 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 SWM 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. Maintaining sheet flow into the filter strip through the use of a level spreading device (e.g., pea gravel diaphragm) is essential.

Vegetated filter strip providing pre-treatment to a bioretention facility

For the planning and design of vegetated filter strips see Chapter 4.6 of the 2010 LID Stormwater Planning and Design Guide. A link to this document can be found within the **Resource Directory**.

1.5.1.8 *Permeable Pavements*

Permeable pavement is a collective term that describes LID BMPs that can be used in place of conventional asphalt or concrete pavement. These alternatives contain pore spaces or joints that allow stormwater to pass through to a stone base for infiltration into underlying native soil or temporarily detained for flood control purposes. Typical types of permeable pavement include:

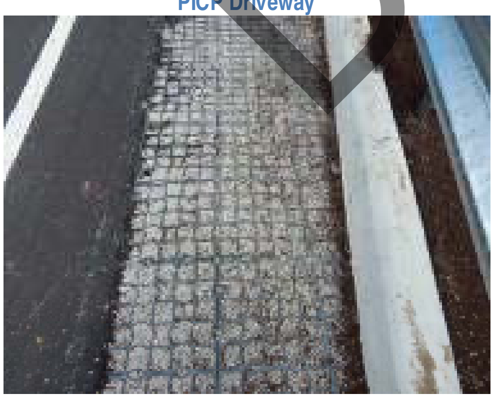
- pervious concrete;
- porous asphalt;
- permeable interlocking concrete pavers (PICP) (i.e., block pavers);
- plastic or concrete grid systems (i.e., grid pavers or grass pavers); and
- rubberized granular surfaces, bricks and pads.

Pervious concrete parking lot

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.

PICP Driveway

Porous Asphalt Roadway



Permeable Plastic Grid System Road Shoulder

PICP Parking Lay-by and Sidewalk

When implemented as within a parking lot, permeable pavement can be implemented as either:

Full permeable pavement parking surface (drive lanes and parking stalls);

Partial permeable pavement parking surface where permeable pavement 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).

For the planning and design of permeable pavements see Chapter 4.7 of the 2010 LID Stormwater Planning and Design Guide. A link to this document can be found within the **Resource Directory**.

1.5.1.9 *Enhanced Grass Swales (a.k.a. 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 (see Section 1.5.1.10 – Dry Swale). 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.

Enhanced Grass Swale

For the planning and design of enhanced grass swales see Chapter 4.8 of the 2010 LID Stormwater Planning and Design Guide. A link to this document can be found within the **Resource Directory**.

1.5.1.10 *Dry Swales (a.k.a 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**.

Bioswales can be planted with grasses for simple maintenance or shrubs and perennials for higher aesthetic appeal.

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 or have more elaborate landscaping. 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.

For the planning and design of dry swales strips see Chapter 4.9 of the 2010 LID Stormwater Planning and Design Guide. A link to this document can be found within the **Resource Directory**.

1.5.1.11 *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 runoff. They are underground stormwater conveyance systems composed of perforated pipes installed in gently sloping granular stone beds lined with geotextile fabric that allows infiltration of runoff into the gravel bed and underlying native soil.

Perforated pipe systems employ many of the same materials and construction practices as conventional storm sewer pipes.

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. They are capable of handling runoff from roofs, walkways, parking lots, and roads.

For the planning and design of perforated pipe systems see Chapter 4.10 of the 2010 LID Stormwater Planning and Design Guide. A link to this document can be found within the **Resource Directory**.

1.5.1.12 *Tree BMPs*

The use of trees to manage stormwater runoff has been shown to be a highly effective approach. Mature tress 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 BMP utilized with a parking lot.

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).

1.5.1.13 *Soil Amendments*

Compost 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.

Soil Amendments in an urban park

For the information on soil amendments visit the STEP website, a link can be found within the **Resource Directory**

1.5.2 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 Best Management Practices (BMPs) in a 'treatment train' approach to provide integrated treatment of runoff from any and all sites.

LID practices used together with conventional stormwater BMPs as part of an overall holistic treatment train approach have been shown to better meet SWM 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. **Figure 1.5.2.1** illustrates the impact of a holistic approach to stormwater management on the four (4) primary and most common stormwater management objectives when LID and conventional BMPs are used.

As discussed previously, LID is a green infrastructure approach to SWM that uses simple, distributed and cost-effective engineered landscaped features and other techniques to infiltrate, store, filter, evaporate and detain rainfall where it falls. The principles of LID are part of the evolution of SWM whereby rainwater is managed as a resource.

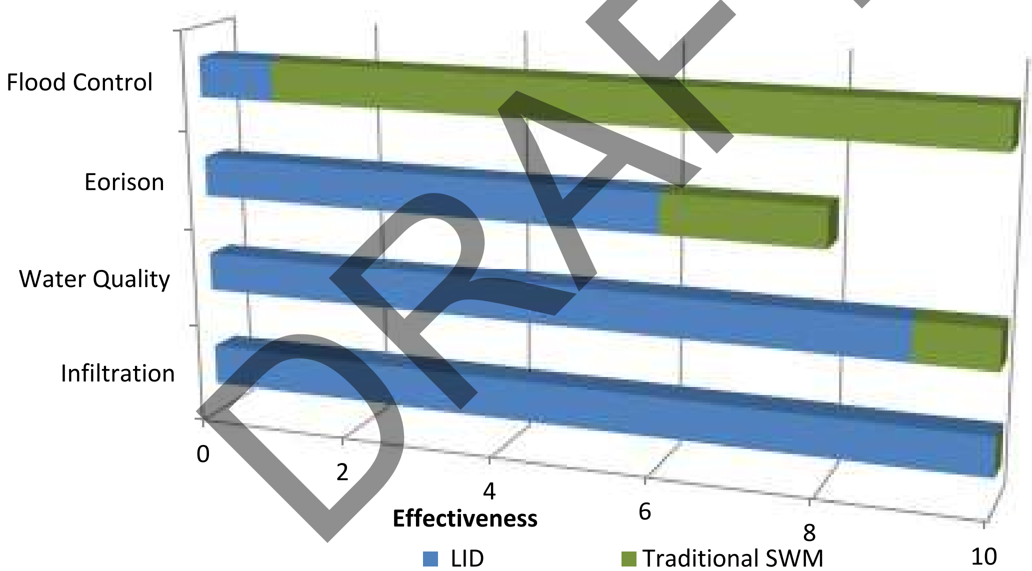


Figure 1.5.2.1: A holistic approach to stormwater management

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;
- 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 run off velocities and discharge rates;
- improving water quality;
- enhancing evapotranspiration;

- maintaining soil moisture regimes to support the viability of vegetation communities;
- maintaining surface and groundwater supplies to support existing wetland, riparian and aquatic habitats;
- reduction in frequency, duration, peak flow, and runoff volume;
- reduction of channel degradation and in-channel erosion;
- minimizing impacts and even preventing urban and riverine 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 mitigation and adaptation

1.5.3 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 and CVC).

When discussing the 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. Simply put, it should not be a surprise to anyone, that 'doing less' will always be the lowest cost alternative.

- 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 (visit the **Resource Directory**).

- Using the 'belt and suspender' approach 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. It should be noted when planned, designed and planned using this manual and the supporting information provided in the **Resource Directory**), that it is not the Ministry's intent to require duplicate infrastructure, however there are some limited exemptions.

- 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).

Additional discussion regarding capital costs, life cycle costs and O&M costs are discussed 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 reduced 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 SWM versus conventional SWM design. On average, the EPA found a construction cost savings ranging from 15 to 60%, with an average of 25% using LID practices as compared to conventional stormwater management. **Table 1.5.3.1** 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 1.5.3.1: Summary of Construction Cost Comparison for Selected LID Case Studies

Project	Project Type	LID Tech.	Construction Costs			Cost Savings
			Conventional SWM	LID	Cost Difference	
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 *	$unknwn *	$91,500	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%
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 practices 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 project in Ontario (**Table 1.5.3.1** 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 1.5.3.2.**

Table 1.5.3.2: Average Incremental Construction Cost to Implement LID BMPs as part of Planned or Routine Road Works

Treatment Measure	Road Resurfacing (% of $ increase)	Road Reconstruction (% 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, visit the **Resource Directory**.

These costs included O&M activities expected both annually and at less frequent intervals. **Figure 1.5.3.1** 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 total suspended solid load reduction, all LID options are more cost effective than conventional asphalt draining to an proprietary stormwater treatment device unit.

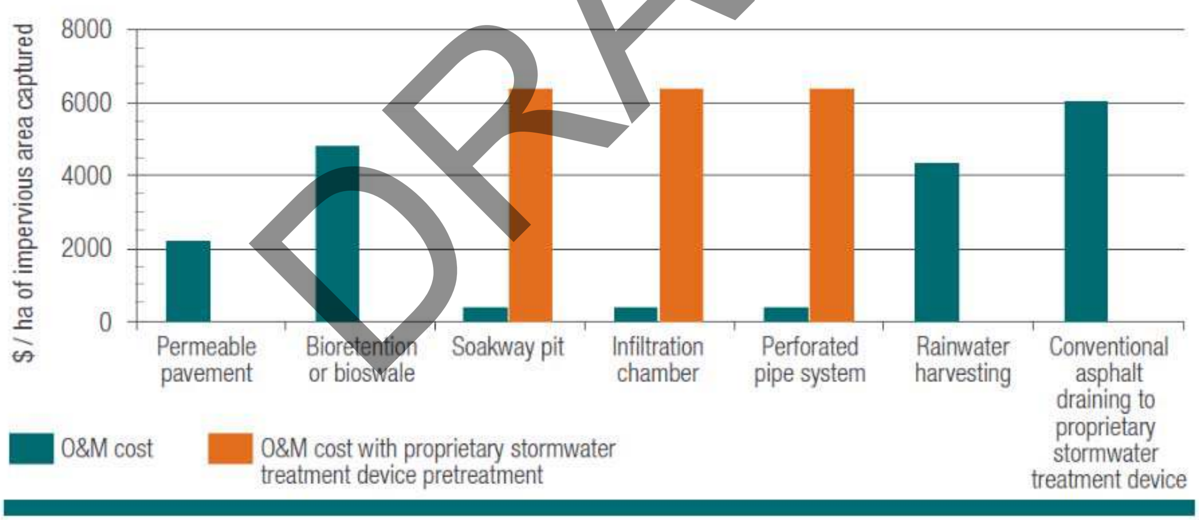


Figure 1.5.3.1: Annual O&M cost per ha of Impervious Area (Source: TRCA/STEP,2013; CVC, n.d.)

O&M Costs

Generally, LID practices have lower-long term life cycle costs, perform better and provide additional community benefits as compared conventional stormwater infrastructure. LID practices generally have a lower initial cost (see **Table 1.5.3.1**) with operation and maintenance costs typically separated by the extent and type of vegetation incorporated into the design.

LID practices vegetated with perennials, shrubs and trees typically require more ongoing maintenance in the early years of establishment, whereas turf area require substantially less. After established the maintenance requirements of most LID practices have little difference from most turf, landscape or natural areas and do not require new or specialized equipment. See **Chapter 9** for additional discussion regarding O&M.

LID practices 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 percent 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. SWM 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 the Environmental Compliance Approval (ECA) permits. 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 become sources of phosphorus 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 flood risk.

LSRCA study found that the costs for pond maintenance can range from $267,000 up to $1.6 million. In comparison, the Toronto Region and 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). **Figure 1.5.3.2** presents the life-cycle maintenance costs of LID BMPs as compared to SWM Ponds.

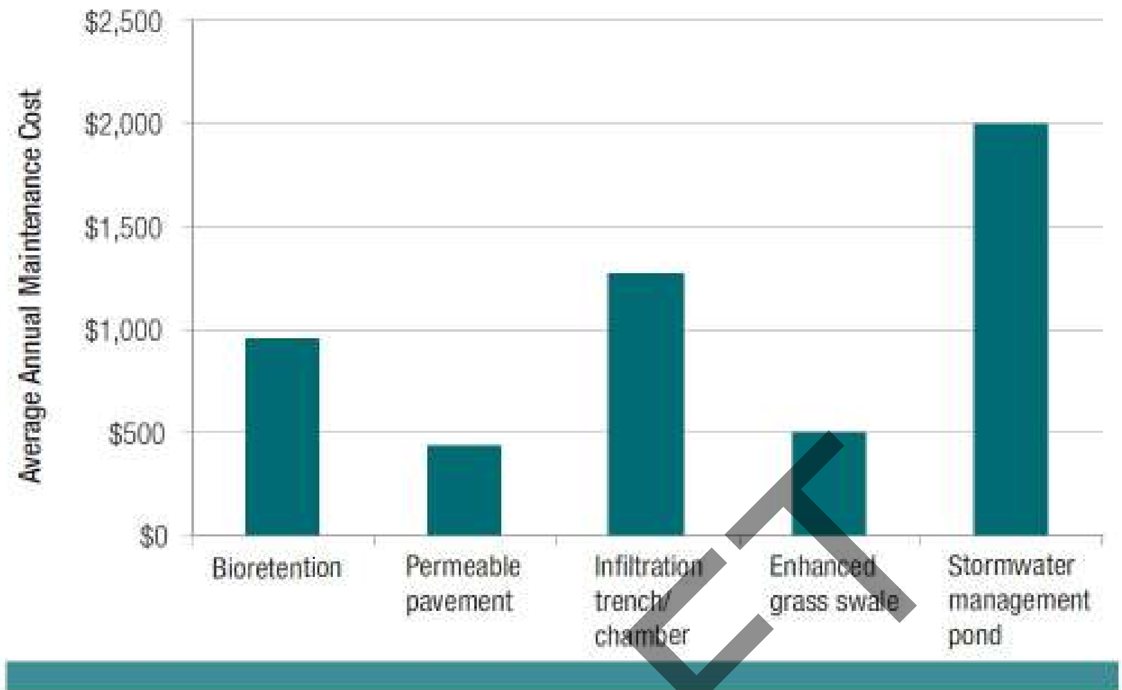


Figure 1.5.3.2: Life-cycle maintenance costs of LID BMPs and conventional stormwater management ponds (Source: TRCA/STEP,2013; CMHC, 2013; CVC, n.d.)

2 Environmental Planning Process

There are several policies, acts, regulations, and plans that have been developed by local provincial and federal authorities that relate directly to the management of stormwater in Ontario. This section of the manual provides a brief summary of the legislation governing stormwater management that need to be considered when planning and designing stormwater systems. Relevant statutes, regulations, police, guidelines and Acts are summarized in the general categories of:

- Federal Level
- Provincial Level
- Municipal Level

2.1 Ontario Land-Use Planning

Ontario's land use planning system gives municipalities the key role in planning decisions. Provincial direction to municipalities is given on sound infrastructure planning, environmental protection, economic development and safe communities. One of the roles of the MOECC in the land use planning system is to provide direction to stormwater practitioners and to support resilient municipal stormwater management systems and adaptation to climate change and other identified stressors, for new and existing developments.

In Ontario, municipalities are responsible for municipal stormwater management (e.g. planning, design, establishment, operation and maintenance). Municipal stormwater management deals with the component of the urban surface run-off that is or would 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. Climate change is an additional factor contributing to the complexity.

2.2 SWM Plans in the Context of Watershed Studies

Subwatershed plans and **watershed plans** are ecosystem based environmental planning approaches undertaken to provide technical, environmentally sound planning decisions within the context of the municipal land use planning process. They are goal-oriented and guide urban development while protecting the natural ecosystem functions. These plans often define policies and management programs intended to preserve and restore key ecological functions. Areas of focus of subwatershed and watershed plans may include but are not limited to:

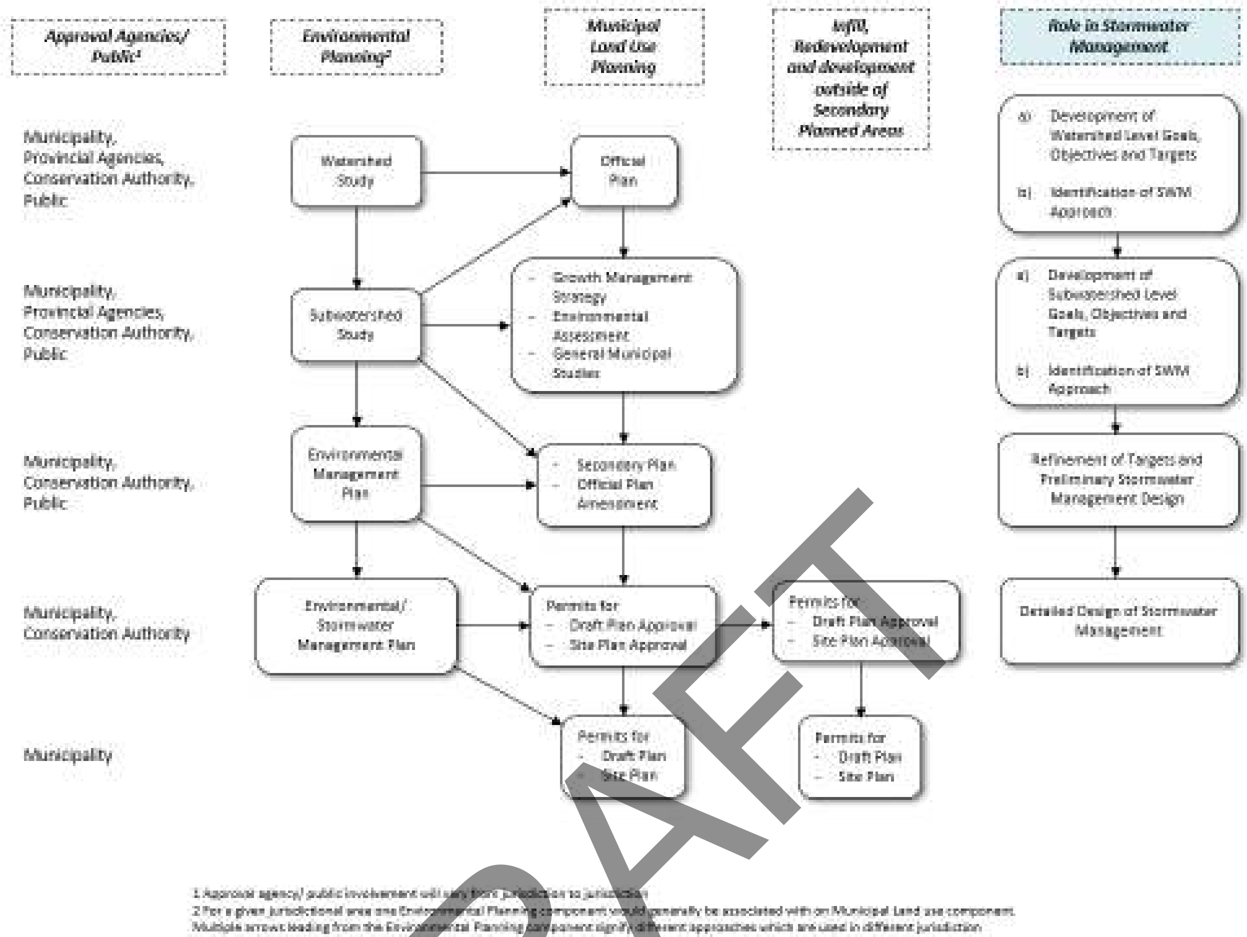
- Refining land use designations and establishing development restrictions;
- Buffer establishment around natural features;
- Water quality preservation or enhancement;
- Salt management planning;
- The preservation or enhancement of ecological features and corridors;
- The definition or refinement of natural hazards such as flooding and erosion;
- The mitigation of natural hazards; and
- The interaction of surface and groundwater regimes.

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 storm water management on objectives related to water balance, stream erosion, water quality, temperature, baseflow, flooding, fisheries habitat and aquatic life. While these plans set multidisciplinary goals, objectives and targets, they do not provide the level of detail required for design.

On a smaller scale, **environmental management plans** and **master environmental servicing plans** are completed at a level corresponding with a tributary subcatchment boundary or Secondary Plan boundary or a portion thereof. Where a subwatershed or watershed plan is available, an environmental management plan will summarize and refine the findings of the previous plans at a higher level of resolution and provide enough detail for preliminary stormwater management design. **Master drainage studies** are also completed at this level of detail but focus more closely on stormwater management infrastructure and less on natural heritage.

Within next level of land use planning are **plans of subdivision** and **site plans**. These are both completed by a proponent of development and submitted to review agencies to demonstrate that the design meets municipal, agency and provincial standards. Where higher level studies such as subwatershed plans, environmental management plans and master environmental servicing plans exist, meeting the requirements outlined in these studies must be demonstrated prior to approval. SWM targets developed as part of higher level studies such as subwatershed plans, environmental management plans and master environmental servicing plans may supersede the SWM targets described within this manual.

Figure 2.2 illustrates the stormwater management planning process within the context of land use planning in Ontario. It should be noted that this Low Impact Development Stormwater Management Guidance Manual provides guidance for all levels of stormwater planning and specifically provides design criteria where more detailed site specific studies have not been conducted or where subwatershed, environmental management plans, master environmental servicing plans and master drainage studies have not considered volume-based approaches such as infiltration-based LID BMPs and stormwater reuse.



2.2.1 Role of the MOECC Manuals & Land Use Planning

Municipal stormwater management includes the conventional stormwater management systems that are managed by municipalities as well as source and conveyance control systems known as LID BMPs. Some LID BMPs are managed by municipalities, such as those located on road rights of way, while others may be located on private properties. The 2003 Stormwater Management Planning and Design Manual promotes a treatment train approach (lot level, conveyance, end of pipe), however the emphasis of the document is guidance on conventional stormwater management systems with a water quality focus on suspended solids. The 2003 Manual is based on work from the 1990s and it does not properly address adaptation to climate change or recent stormwater innovation. This Low Impact Development Stormwater Management Guidance Manual is not intended to replace the 2003 Stormwater Planning and Design Manual, but rather to compliment the 2003 Manual by:

- Defining stormwater volume control requirements is Ontario;
- Presenting criteria to select water budget and water modelling tools for use in Ontario;
- Establishing guidelines and processes for groundwater protection form infiltration based LID BMPs; and
- Presenting a process for which to reflect future Climate scenarios and assess Climate Change risks and vulnerabilities.

2.2.2 SWM Legislative Context and LID Implementation

While the MOECC is the provincial lead on environmental protection, stormwater management is a shared responsibility with municipalities, the developers, property owners (residents, businesses), conservation authorities, provincial ministries, federal departments, NGOs, and others all playing important roles.

At the local level, **regional** and **municipal governments** set stormwater management policies that must be followed by developers and property owners. These policies are municipality specific but often include provisions related to:

- Design criteria including (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 inlet and for conveyance systems;
- Ownership and access requirements (e.g. easements, setbacks, etc.);
- Lot grading and drainage pattern requirements;
- Acceptable devices used; and
- Municipally accepted water quality devices.

Additional to stormwater management specific policies, municipal by-laws may affect the implementation of some LID BMPs and stormwater management practices. These by-laws may include those governing lot grading, drainage and property stands (e.g. may prohibit plantings in areas that can be used for LID practices).

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). A Conservation Authorities' regulatory powers are granted under **Section 28 of the Conservation Authorities Act**. Specifically, the following provisions:

- Section 28(3) - A regulation may provide for permission to be granted subject to conditions and for the cancellation of the permission if conditions are not met
- Section 28(16) - Every person who contravenes a regulation or the terms and conditions of a permission of an authority is guilty of an offence
- Section 28(17) - Upon conviction the court may order the removal of the development or the rehabilitation of the watercourse or wetland. Any and all end-of-pipe and outfall retrofit works as well as any stream restoration works will require consultation and permits under this legislation.

At the **provincial level**, several ministries are responsible for aspects of storm water management (e.g. MOECC, Ministry of Municipal Affairs (MMA), Ministry of Natural Resources and Forestry (MNRF), Ministry of Infrastructure (MOI) and Ministry of Transportation (MTO)). The MOECC recommends that the ministries work together with municipalities and conservation authorities to seek solutions for resilient municipal stormwater management systems that are adaptive to climate change and to collaborate on new and existing municipal tools for source control stormwater management.

Within the provincial legislative framework, the Ontario Water Resources Act (OWRA) and the Environmental Protection Act (EPA) provide a sufficient legislative framework for implementing adaptation to climate change for municipal stormwater management, through approvals, general prohibitions, orders, penalties and regulation making authority for environmental protection. OWRA Section 53 provides a broad, case by case, framework for approval of stormwater management facilities. The OWRA also provides the legislative framework for reporting on stormwater system inventory, condition or performance.

Applications for a stormwater management ECAs are considered by the MOECC on a site-specific basis. Applications may be guided by existing guidelines such as the 2003 Stormwater Management Planning and Design Manual, which provides design guidance for stormwater management facilities such as stormwater ponds. Additional guidance for storm sewers can be found in the Design Guidance for Sewage Works 2008. These documents provide design or technical guidance rather than policy direction (refer to **Chapter 7**).

The Guideline B-1 Water Management (Blue Book) provides overall guidance for water management in Ontario. The application of the Guideline B-1 is determined on a site-specific basis and may require a detailed site assessment. Water quality assessment has not always been included in assessing applications for approval for municipal stormwater management facilities. Instead, MOECC approval for stormwater management facilities are based on the design guidance outlined in the SWM Manual.

Presented in **Table 2.1** and **Table 2.2** are summaries of the policy implications and the relevant federal and provincial stormwater management guideline documents respectively.

Table 2.1 lists the policies and acts applicable to stormwater management planning, design, permitting and best management practices under key federal, provincial, and local legislation. **Table 2.2** lists the guidelines applicable to stormwater management planning and best management practices under federal and provincial levels.

Table 2.1 - Summary of Policies, Acts, Regulations, and Plans Relating to Stormwater Management

Level of Government	Name of Management Tool: Policy/Act/Regulation/ Plan	Type of Tool	Purpose and Relevance to Stormwater Management
Federal	Federal Fisheries Act	Act	Purpose is to ensure the conservation and protection of fish and fish habitat.
	Navigable Waters Protection Act	Act	Prohibits dumping of wastes that may interfere with navigation. Prohibits construction in navigable waters.
	Migratory Birds Convention Act (1994)	Act	Protection of migratory songbirds and their nests from disturbance or destruction.
	Species at Risk Act	Act	Protection of Wildlife species at risk and recovery plans
	Canadian Environmental Protection Act (CEPA) (1999)	Act	The goal of the Canadian Environmental Protection Act (CEPA) is to contribute to sustainable development through pollution prevention and to protect the environment, human life and health from the risks associated with toxic substances.
	Canadian Environmental Assessment Act	Act	The Act requires federal departments, including Environment Canada, agencies, and crown corporations to conduct environmental assessments for proposed projects where the federal government is the proponent.
	Canada Water Act	Act	An Act to provide for the management of the water resources of Canada, including research and the planning and implementation of programs relating to the conservation, development and utilization of water resources. Authorizes agreements with provinces for the delineation of flood plains and hazardous shorelines for flood and erosion control. In 2010–2011 the governments of Canada and Ontario extended the Canada–Ontario Agreement to June 2012, and added six new commitments to maintain momentum on the restoration, protection and conservation of the Great Lakes, while negotiations proceed between the federal governments of Canada and the United States to amend and strengthen the Great Lakes Water Quality Agreement. The Canadian Federal Great Lakes Program, a partnership of federal departments, provides the framework for working toward Canada's commitments under the Great Lakes Water Quality Agreement. Canada's activities are integrated with those of Ontario through the Canada–Ontario Agreement Respecting the Great Lakes Basin Ecosystem, which outlines how the two governments will cooperate and coordinate their efforts to restore, protect and conserve the Great Lakes Basin ecosystem. Highlights of actions in 2010–2011 include a wide range of research, monitoring and restoration projects in Great Lakes Areas of Concern through the Great Lakes Action Plan and the Cooperative Science and Monitoring Initiative; projects to reduce the amount of nutrients, solids and bacteria entering watercourses; and research in support of Canada–U.S. Lakewide Management Plans (LaMP).
Provincial	Water Management Policies, Guidelines and Provincial Water Quality Objectives (PWQO) 1994 Blue Book	Policy	Policies for surface (and groundwater) quality management in Ontario. Surface water objectives for the protection of aquatic life.
	Provincial Policy Statement (PPS - 2005)	Policy	The PPS is issued by the Ministry of Municipal Affairs and Housing under Section 3 of the Planning Act. It requires that decisions affecting planning matters in Official Plans *"shall be consistent with"* the PPS. The PPS provides *"for appropriate development while protecting resources of provincial interest, public health and safety, and the quality of the natural environment"*. The PPS focuses growth within settlement areas and away from significant or sensitive resources. It directs planning authorities to identify and promote opportunities for intensification and redevelopment where this can be accommodated, taking into account existing building stock, including existing or planned infrastructure. The PPS provides a higher degree of protection for employment lands against conversions to residential uses. The new policies also provide for intensifications and brownfields development to ensure the maximum use of sewer, water and energy systems, roads and transit. The Official Plan is the most important tool to implement the PPS. Section 2.2 of the PPS addresses water, stating that planning authorities shall protect, improve or restore the quality and quantity of water, using the watershed as the ecologically meaningful scale for planning. Planning authorities shall ensure that stormwater management practices minimize stormwater volumes and contaminant loads, and maintain or increase the extent of vegetative and pervious surfaces.
	Integrating Water Management Objectives into Municipal Planning Documents (MOECC - 1993)	Policy	Policy manual on the integration of watershed management practices into municipal planning documents.
	Environmental Assessment Act	Act	Provides protection, conservation and management of the environment in Ontario. Retrofits of stormwater facilities may be carried out as a Class EA subject to the selection of the appropriate schedules under the Municipal Engineers Association (2000, as amended in 2007).
	Drainage Act	Act	Provides for the regulation of drainage practices in Ontario.
	Clean Water Act	Act	Policies and plans will be developed to define and to clarify roles and responsibilities, define permissible actions and identify land uses. For SWM, Non-structural BMPs that use infiltration must consider the relevance of site locations with respect to WHPA, the source of runoff and whether groundwater threats have been identified within the relevant Provincial or Regional documents.
	Lakes and Rivers Improvement Act	Act	The Lakes and Rivers Improvement Act gives the Ministry of Natural Resources and Forestry the mandate to manage water-related activities, particularly in the areas outside the jurisdiction of Conservation Authorities.
	Endangered Species Act	Act	Provides for the protection for species at risk and their habitats.
	Ontario Water Resources Act	Act	The Ontario Water Resource Act deals with the powers and obligations of the Ontario Clean Water Agency, as well as an assigned provincial officer, who monitors and investigates any potential problems with regards to water quality or supply. There are also sections on wells, water works, and sewage works (including stormwater management facilities) involving their creation and operation.
	Environmental Protection Act	Act	The purpose of this Act is to provide for the protection and conservation of the natural environment. Act prohibits discharge of contaminants having an adverse effect.
	Endangered Species Act (2007)	Act	Enacts the protection of Endangered, Threatened and Special Concern species (provincial) and their habitats; regulates activities which may affect these species, and provides for development of Recovery Strategies.
	Fish and Wildlife Conservation Act (1997)	Act	*Fish and Wildlife Conservation Act* enables the Ministry of Natural Resources and Forestry (MNRF) to provide sound management of the province's fish and wildlife.
	SWM in light of Climate Change	Policy Review	Review of the need for a new policy, act, or regulation to deal with municipal SWM systems in light of climate change

Level of Government	Name of Management Tool: Policy/Act/Regulation/ Plan	Type of Tool	Purpose and Relevance to Stormwater Management
	Bill 127, Ontario Water Resources Amendment Act (Water Source Protection), 2002	Act	The Bill amends the *Ontario Water Resources Act* in regard to the availability and conservation of Ontario water resources. Specifically, the Bill requires the Director to consider the Ministry of Environment's statement of environmental values when making any decision under the Act. The Bill also requires that municipalities and conservation authorities are notified of applications to take water that, if granted, may affect their water sources or supplies.
	Water Opportunities Act (2010)	Act	The purposes of the Act are: a) to foster innovative water, wastewater and stormwater technologies, services and practices in the private and public sectors; (b) to create opportunities for economic development and clean-technology jobs in Ontario; and, (c) to conserve and sustain water resources for present and future generations. The Minister of the Environment may, to further the purposes of this Act, establish aspirational targets in respect of the conservation of water and any other matter the Minister considers advisable.
	Lake Simcoe Protection Act (2008)	Act	The purpose of this Act is to protect and restore the ecological health of the Lake Simcoe watershed. The Lake Simcoe Protection Plan was developed under this Act.
	Safe Drinking Water Act (2002)	Act	This Act provides for the protection of human health and the prevention of drinking water health hazards through the control and regulation of drinking water systems and drinking water testing.
	Brownfields Statute Law Amendment Act (2001)	Act	This Act facilitates public access to information contained in records of site condition and to other information filed in accordance with this Act and the regulations.
	Oak Ridges Moraine Conservation Act (2001)	Act	This Act provides legislative framework for the Oak Ridges Moraine Conservation Plan.
	The Greenbelt Act (2005)	Act	This Act enables the creation of a Greenbelt Plan to protect about 1.8 million acres of environmentally sensitive and agricultural land in the Golden Horseshoe from urban development and sprawl.
Local	Conservation Authorities Act	Act	Prevention of the loss of life and property due to flooding and erosion; and, the conservation and enhancement of natural resources. Any projects within the regulated area of the respective CA or impacting wetland will require the acquisition of a permit pursuant to Policies for the Administration of the Development Interference with Wetlands and Alterations to Shorelines and Watercourse Regulation.

Table 2.2 - Guidelines applicable to Stormwater Management at Federal and Provincial Levels

Level of Government	Guideline Document	Purpose and Relevance to Stormwater Management
Federal	Canadian Water Quality Guidelines for the Protection of Aquatic Life	The Canadian Water Quality Guidelines consist of a set of recommended "safe limits" for various polluting substances in raw (untreated) drinking water, recreational water, water used for agricultural and industrial purposes, and water supporting aquatic life. They are designed to protect and enhance the quality of water in Canada. The guidelines apply only to inland surface waters and groundwater's and not to estuarine and marine waters.
	Canadian Water Quality Guidelines for the Protection of Agricultural Water Uses	The Canadian Water Quality Guidelines consist of a set of recommended "safe limits" for various polluting substances in raw (untreated) drinking water, recreational water, water used for agricultural and industrial purposes, and water supporting aquatic life. They are designed to protect and enhance the quality of water in Canada. The guidelines apply only to inland surface waters and groundwater and not to estuarine and marine waters.
	Guidelines for Canadian Drinking Water Quality	To provide a national guideline for the protection of drinking water.
	Guidelines for Canadian Recreational Water	To provide a national guideline for the protection of recreational waters used for primary contact recreation such as swimming, windsurfing and water skiing and for secondary contact recreation activities including boating and fishing.
	Canada/Ontario Agreement Respecting Great Lakes Basin Ecosystems.	Since 1971, Canada-Ontario Agreements Respecting the Great Lakes Basin Ecosystem have guided the Parties in their work to improve the environmental quality of the Basin.
Provincial	Stormwater Management Planning and Design Manual (2003)	This document provides practical guidance that can be used as a baseline reference document for the review of stormwater management applications for approval under Section 53 of the Ontario Water Resources Act. It includes: • Providing direction for sizing of the stormwater quality control component of stormwater management facilities in order to achieve water quality objectives which provide protect fisheries habitat; • Incorporating in-stream erosion control and water balance objectives in addition to flood and water quality objectives into the selection and design of Stormwater Management Practices (SWMPs); • Providing information on SWMPs such as sand filters, bioretention filters, wet swales and hybrid wet pond/wetlands; • Providing design examples for SWMPs; • Providing an appendix which deals with integrated planning for stormwater management.
	Technical Guide, River & Stream Systems: Flooding Hazard Limit (MNRF - 2002)	The technical guide has been developed to assist in the understanding of the latest Provincial Policy Statement (PPS – 2005). It describes approaches consistent with the PPS. This guide serves in an advisory role and should be read in conjunction with the PPS and other flood related implementation guides. The 2002 Technical Guide updates the 1986 Flood Plain Management in Ontario Technical Guidelines. The primary purpose of this document is to *"provide a consistent and standardized procedure for the identification and management of riverine erosion hazards in the Province of Ontario."*
	Natural Heritage Reference Manual for the Natural Heritage Policies of the Provincial Policy Statement, 2005.	Provides guidelines for the implementation of the PPS by planning authorities.
	Significant Wildlife Habitat Technical Guide (2000, MNRF)	Significant Wildlife Habitat has been identified as one of the natural heritage feature areas under the Provincial Policy Statement.
	Protection and Management of Aquatic Sediment Quality in Ontario (MOECC) (1993)	The purpose of the sediment quality guideline is to protect the aquatic environment by setting safe levels for metals, nutrients and organic compounds.
	Guidelines for Evaluating Construction Activities Impacting on Water Resources (MOECC) (1995)	These guidelines were developed to protect the receiving environment according to the physical, the chemical and the biological quality of the material being dredged.
	Incorporation of the Reasonable Use concept into MOECC Groundwater Management Activities (1994)	This guideline establishes the basis for the reasonable use of groundwater on property adjacent to sources of contaminants and for determining the levels of contaminants acceptable to the MOE.
	Watershed Management on a Watershed Basis (MOECC - 1993)	Guideline manual on watershed management practices.

Level of Government	Guideline Document	Purpose and Relevance to Stormwater Management
	Redside Dace – Ontario Recovery Strategy (2010)	Up listed as endangered species in 2009 under the Endangered Species Act. This protects both the species and its habitat, prohibiting damage or destruction of the habitat without authorization by the Ministry of Natural Resources and Forestry ((MNRF).
	Draft Guidance for Development Activities in Redside Dace Protected Habitat (February 2011)	Assist in describing redside dace habitat, the protection afforded under, requirements for review and permitting and BMPs to mitigate impacts.
	The Blue Book (1994)	
	Stormwater Management Planning and Design Manual (2003(	The manual provides technical and procedural guidance for the planning, design, and review of stormwater management practices.
	Low Impact Development Stormwater Planning and Design Guide (2011 V1.0)	The guide was developed 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 practices, and thereby help ensure the continued health of the streams, rivers, lakes, fisheries and terrestrial habitats in the CVC and TRCA watersheds. It is also intended to help streamline and focus the design and review process, as well as ensure that the goals, objectives and targets outlined in watershed and subwatershed studies are being met.
	Designer's Guide for Low Impact Development Construction (Draft 2011)	This guide provides guidance on the approaches and criteria to be applied during construction.
	Watershed (CA specific) Stormwater Criteria Documents	Defines the specific SWM criteria for a specific watershed or Conservation Authority jurisdiction.
	Protection and Management of Aquatic Sediment (Guidelines B-1-3)	The guidelines provided in this document were developed for use in evaluating sediments throughout Ontario, and replace the Open Water Disposal Guidelines (published by the Ministry in 1976) currently used for sediment evaluation.
	Evaluation of Construction Activities Impacting Water Resources (Guidelines B-5)	Aid in the assessment of the environmental impact of construction activities.

3 SWM Design Criteria: Runoff Volume Control Target

The following chapter outlines the Runoff Volume Control Target (RVC_T) for new development, redevelopment, infill-development, reurbanization, linear infrastructure and retrofits in Ontario.

> In all cases, the RVC_T for Ontario shall not preclude the proponent from achieving the required stormwater quantity, quality, erosion control and water balance requirements as identified through watershed, subwatershed, master drainage plans completed following the Municipal Class Environmental Assessment Master Planning process, as described by the Municipal Engineers Association (2000, as amended 2007 & 2011), Environmental Impact Statement (EIS), Provincial Policy and Guidelines or other area specific studies which have been duly reviewed and approved by the relevant agencies and / or authorities; nor does it preclude the proponent from the requirement to prepare appropriate pollution prevention plans per the Canadian Environmental Protection Act, and/or Risk Management Plans per the relevant Source Protection Policies pursuant to the Clean Water Act. In all cases, the area specific requirements and /or most stringent policy and/or requirement shall apply.

3.1 The 90th Percentile

The following section provides context and background into the effects of urbanization on watershed impervious area, history of the 90^{th} percentile approach in North America and how the RVC_T has been calculated.

3.1.1 Watershed Impervious Area

With urbanization, surface drainage efficiency is enhanced, resulting in a significant shift in the hydrology and associated water balance toward a regime with high runoff yield and a rapid flow response. Even at low levels of urbanization within a watershed beginning with an increase in impermeable surfaces of just 4%, can result in changes to stream channel characteristics and aquatic communities [ix]. These impacts have been shown to follow a continuum of impacts and environmental degradation as total watershed impervious area resulting from development increase, specifically:

- As total watershed impervious area changed from 5% to 10%, the physical and biological measures within a watershed generally change most rapidly[x]. With more intensive urban development in the watershed, habitat degradation and loss of biological productivity continues, but at a slower rate[xi];
- At approximately 10% total watershed imperviousness channel adjustments of local watercourses (primarily as enlargement) will occur[xii]; fisheries biodiversity and abundance are initially and significantly impacted[xiii];
- At 10% total watershed imperviousness of watersheds with traditional ditch and pipe systems, about 10% of the total rainfall volume becomes runoff that enters receiving waters; this runoff volume is the root cause of aquatic habitat degradation[xiv];
- 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 [xv];

- In addition, at 30% total watershed imperviousness, urban watershed may be unable to sustain abundant self-supporting populations of cold-water fish [xvi];
- At urbanization levels between 25% and 55% (built form) serious irreversible degradation have been predicted and shown to take place[xvii]; and
- At 50% total watershed imperviousness, poor water quality and concentrations of metals in sediments begin to show significant impact to aquatic biological communities[xviii].

To offset the identified impacts, an increased emphasis on maintaining the natural water balance and replicating the predevelopment hydrologic cycle 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% is clearly a tipping point beyond which significant and sometime irreversible impacts are expected to occur.

Acknowledging, as stated previously, that "at 10% total watershed imperviousness of watersheds with traditional ditch and pipe systems, about 10% of the total rainfall volume becomes runoff that enters receiving waters and that this runoff volume is the root cause of aquatic habitat degradation"[xix], a performance target for the management of runoff volume which limits the total runoff volume to 10% (or less) of total rainfall volume has the potential to avoid:

- The most rapid periods of physical and biological alterations as well as terrestrial and aquatic habitat degradation within a watershed;
- Channel enlargement (erosion);
- Impacts to fisheries biodiversity and abundance;
- Increase the flood flow peaks;
- Irreversible environmental degradation; and
- Poor water quality (concentrations of metals in sediments).

As such, an appropriate performance target for managing runoff volume is to limit total runoff volume to 10% (or less) of total rainfall volume. This means that 90% of rainfall volume must be controlled and an appropriate volume must be returned to natural hydrologic pathways of the water balance in proportions in keeping with the conditions prior to development. This requires the control of 90% of the annual average rainfall, commonly determined through the use of the 90th percentile event.

3.1.2 Background of the 90th Percentile

One of the earliest references to the 90th percentile 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[xx]. 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 is most commonly traced back to The Design of Stormwater Filtering Systems by 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. by Schueler (1992) 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. 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.

At its time of publication, 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 by Chang[xxi] 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 (4) locations within the Chesapeake Bay Area, found the one (1) inch rainfall (25mm) provided an average capture percentage of 85% to 91% of the rainfall volume. This analysis provided justification for using the one (1) inch rainfall event and became known as the "**One-inch-rule**", the **"90 Percent Rule"** or the **"90 Percent Capture Rule"**.

Claytor (1996) 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 Percent Capture Rule value suggesting that a rainfall frequency spectrum (RFS) analysis be conducted using local precipitation data using a longer data set. 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 90th percent rule approach, including numerous US jurisdictions and some Canadian and Ontario jurisdictions, including the Lake Simcoe Watershed which as implemented its own 90th percentile control target in September 2016. The technical basis for the 90 Percent Rule is that the stormwater practice is explicitly designed to capture and treat 90% of the annual rainfall from those events that produce runoff.

3.1.3 Rainfall Frequency Spectrums (RFS)

Rainfall Frequency Spectrum (RFS) curves (also known as "rainfall distribution plots") are suggested as 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.[xxii] 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. [xxiii]

The development of a RFS is generally a first step in the creation of stormwater criteria relating to the 90 percent rule. Data used to generate the RFS and ultimately the 90 percent capture depth are based on a regional analysis of the regional rainfall patterns. **Figure 3.1.1** is an example of an RFS derived from daily rainfall data. The example RFS developed from daily rainfall totals (excluding all events less than both 2mm) illustrates the theoretical 90th percentile rain fall 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" [xxiv] 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 benefits 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 22mm. 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". [xxv]

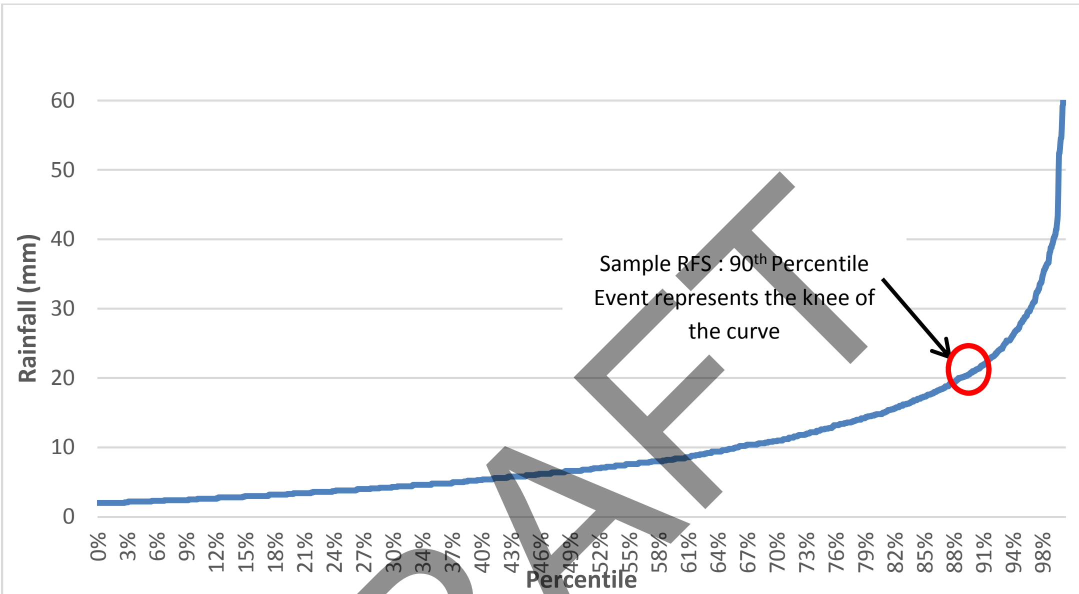


Figure 3.1.1 – Sample RFS which Represents the Knee of the Curve

3.1.4 Determining the RVC_T for Ontario

The volume control target (RVC_T) for Ontario has been based on the 90th percentile rainfall event as determined through the hourly rainfall analysis using a 12-hour minimum interevent time (MIT), disregarding events smaller than 2mm (as these events typically do not produce any measurable runoff due to absorption, interception and evaporation by permeable, impermeable and vegetated surfaces and are at the lower threshold of rain gauge resolution).

To increase the spatial resolution across the province in order to identify and capture geographically significant trends the 95th percentile daily rainfall series (ignoring days with less than 2mm 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. 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 Apr. 1st - Oct. 31st show little variance as compared to all rainfall events (full year) as in all cases 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 deviation in the RVC_T applying a 2mm cut-off. **Figure 3.1.4** illustrated the 90th percentile runoff volume control target (RVC_T) requirements for Ontario using percentile contours (isohyet) mapping which represents regional rainfall variations.

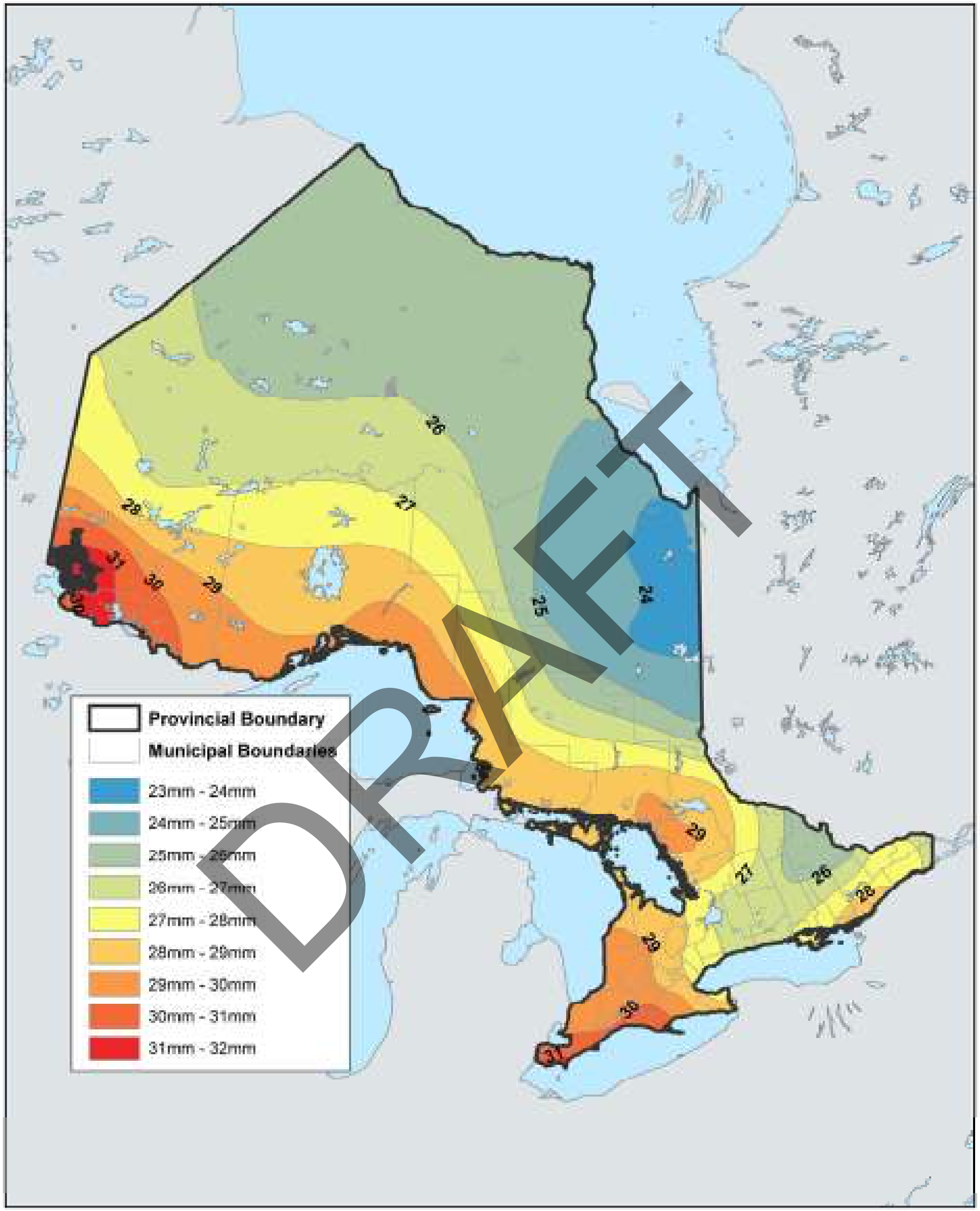


Figure 3.1.4: Regionally Specific 90th Percentile Runoff Volume Control Target (RVC_T) Requirements for Ontario

3.2 Definitions of Development

To assign stormwater criteria that are appropriate for distinct types of development, several definitions must be established. It should be noted that these definitions are only for the purpose of this manual and do not supersede other provincial development designation. For the purpose of this manual the following terminology shall be applied.

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 with a maximum runoff-coefficient of 0.15, whichever is most stringent.

- For Redevelopment, Reurbanization and Intensification the (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 to a maximum runoff-coefficient of 0.30, whichever is most stringent.

- For Linear Development and retrofits the pre-development impervious condition shall correspond to the current conditions present in at the project onset.

Post-development: The expected site condition after proposed site works and construction is complete. This condition should reflect any proposed structures and impervious surfaces.

New Development: The creation of a new lot, a change in land use, or the construction of buildings and structures requiring approval under the Planning Act, but does not include:

a) activities that create or maintain infrastructure authorized under an environmental assessment process; and
b) works subject to the Drainage Act.

Infill Development: New development within an area that is predominately built-out. Infill development can be proposed in residential, commercial and mixed-use areas. Infill development may also include development on brownfield sites.

Redevelopment: The creation of new units, uses or lots on previously developed land in existing communities, including brownfield and greyfield sites. 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.

- Greyfield are previously developed sites that are not contaminated.

Stormwater Retrofits: The voluntary construction of new and/or reconstruction of municipal stormwater infrastructure within an existing urban area, already serviced or inadequately serviced by stormwater infrastructure which provides a net environmental benefit. A stormwater retrofit cannot:

- Be part of a common plan of development (i.e. subdivision, site plan, plan of condominium etc.)
- Be described as new development, redevelopment, intensification and reurbanization; and
- Require approval under the Planning Act.

Intensification: Development of a property, site or area which results in a net increase in density, units or accommodation and can occur in the context of redevelopment and reurbanization. It includes:

a) redevelopment, including the redevelopment of brownfield sites;
b) the development of vacant or underutilized lots within previously developed areas;
c) infill development - new development on formerly vacant land;
d) the conversion or expansion of existing industrial, commercial and institutional buildings for residential use; and
e) 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.

Reurbanization: A process that describes four (4) distinct types of activity, all of which serve to increase the residential or employment density on sites located within the existing urbanized area of a community. The four types of activity captured under the definition of reurbanization include:

a) infill: new development on formerly vacant land;
b) intensification: an expansion in the use of an existing structure or structures that serves to increase the density on a site
c) adaptive re-use: a change in the use of a building or structure, typically from commercial/industrial to residential, that results in greater density; and,
d) redevelopment: the wholesale change or conversion of an area, often involving some form of land assembly and/or demolition, which results in significantly higher density than existed previously (see above)

Linear Projects: Construction or reconstruction of roads, rail lines and transit infrastructure that are not part of a common plan of development or sale.

3.3 Runoff Volume Control Requirements

The following describes the Runoff Volume Control Target (RVC_T) for new development, redevelopment, infill-development, reurbanization and linear infrastructure and retrofits in Ontario.

The RVC_T for Ontario has been developed with the goals of:

- ensuring the application of a consistently derived, geographically specific volume control target across the province;
- providing a repeatable and scientifically based approach for sizing stormwater practices that can be performed efficiently and effectively, which can be administered simply, promote better site design, and be flexible in responding to site specific conditions;
- Facilitating greater consistency and integration of stormwater management among the many cities, watershed organizations and regions within the province;

The RVC_T for Ontario is founded upon the principles of:

- Maintaining the pre-development water balance and returning precipitation volume to the natural pathways of runoff, evapotranspiration and infiltration in proportions which are in keeping with the watershed conditions prior to development. **The goal of maintaining the pre-development water balance shall be to ensure the ecosystem function and natural quality and hydrological characteristics of natural features, including aquatic habitat, baseflow, water quality, temperature, storage levels and capacity, and hydroperiods will be maintained and known impacts or urbanization are avoided**. As such, the appropriate portion of the RVC_T must be returned to natural pathways of the pre-development water balance. Any remaining volume should be controlled per the Mandatory Control Hierarchy (See **Section 3.3.1**).

- Regarding rainwater as a resource which is to be managed as close to the source area as possible (i.e. on-site) using approaches which focus on runoff prevention.

- Fundamentally recognizing that at 10% total watershed imperviousness of watersheds with traditional ditch and pipe systems, about 10% of the total rainfall volume becomes runoff that enters receiving waters; this runoff volume is the root cause of aquatic habitat degradation[xxvi]. As such an appropriate performance target for managing runoff volume is to limit total runoff volume to 10% (or less) of total rainfall volume. This means that 90% of rainfall volume must be controlled and returned to natural hydrologic pathways, through infiltration, evapotranspiration or re-use. Therefore, the RVC_T is based on the management of the geographically specific 90th percentile event (**Figure 3.1.4**).

- That reducing runoff volume at the source is the key to protecting property and infrastructure, habitats, aquatic and terrestrial ecosystems and water quality.

- That a BMP which is sized to capture and treat the runoff generated from the 90th percentile event will also capture and at least partially treat an equivalent volume during larger rainfall events beyond the 90th percentile. Therefore, treating the runoff generated from the 90th percentile rainfall will result in a capture efficiency of greater than 90% of the annual average rainfall volume.

- The means to achieve the RVC_T includes:
  a) **Retention** - where the captured volume shall be ultimately infiltrated, evapotranspired or re-used and the specified volume will not later be discharged to sewer networks (with the exception of internal water re-use activities) or surface waters and does not therefore become runoff.

  and

  b) **Volume Capture and Treatment** - Also referred to as `*treatment and release*`, where the volume capture and treatment directly aims at reducing surface water impairment through treatment of the specified volume, often referred to as a “water quality volume”.

- The application of Landscaped based volume based stormwater controls, such as LID BMPs are a key component of climate change adaption and mitigation strategies.

- Runoff is generated from all surfaces (not exclusively from impervious surfaces).

- Volume based stormwater controls, including LID BMPs, are relevant for all forms of development, but site specific restrictions (or constraints) may limit implementation. As such, flexibility is required to ensure the site-specific characteristics are considered in planning and design.

- In all cases, the RVC_T for Ontario shall not preclude the proponent from achieving the required stormwater quantity, quality, erosion control and water balance requirements as identified through watershed, subwatershed, master drainage plans completed flowing the Municipal Class Environmental Assessment Master Planning process, as described By the Municipal Engineers Association (2000, as amended 2007 & 2011), Environmental Impact Statement (EIS), Provincial Policy and Guidelines or other area specific studies which have been duly reviewed and approved by the relevant agencies and / or authorities; nor does it preclude the proponent from the requirement to prepare appropriate pollution prevention plans per the Canadian Environmental Protection Act, and/or Risk Management Plans per the relevant Source Protection Policies pursuant to the Clean Water Act. In all cases, the most stringent policy and/or requirement shall apply.

3.3.1 Exemptions

Any works that results in site disturbance that result in the creation of impervious surface or fully reconstructs existing impervious surface must meet the RVC_T, except where the following exemption apply and where the exemptions do not contravene municipal by-laws, policies or requirements:

1. For minor building activities (i.e. additions, deck sheds, patios etc.) subject to municipal permits and / or any developments not requiring site plan approval, nor any *Planning Act* approval;

2. Where local or area specific volume control targets have been identified through:
   a) the land planning process (i.e. watershed, subwatershed studies etc.);
   b) Environmental Impact Statement (EIS);
   c) Provincial Policy and Guidelines and / or;

d) Other area specific studies which have been duly reviewed and approved by the relevant agencies and / or authorities.

3. In areas where the specific subwatershed, sewershed or drainage area has adequate SWM control (erosion, flood control, water quality and water balance) consistent with current Ministry requirements (this manual and the 2003 SWMPDM) and where the receiver can be shown through good science to not be experiencing direct impacts or indirect from the contributing SWM runoff.

Additional consideration is given to sites with restrictions (i.e. constraints) where flexible treatment options may be permitted as discussed in **Section 3.3.3.5**. Sites with identified constraints are not exempt from the RVC_T, but rather are given additional flexibility to reduce the volume target to suit the local site conditions.

It is acknowledged that individual municipalities may choose to enact more stringent requirements based on specific needs, policies or environmental goals and is supported by the MOECC.

3.3.2 RVC_T Mandatory Control Hierarchy

To provide flexibility in the implementation of the RVC_T, to ensure it is applied consistently across the province and that a treatment train approach is also utilized, a Mandatory Control Hierarchy has been developed whereby stormwater management practices are preferentially selected which:

- Begin with better site design (see **Section 1.5.1.1**);
- Utilize natural systems and preserve existing natural systems;
- Create multifunctional landscapes that achieve goals and objectives beyond stormwater management to include broader community goals of livability and sustainably as well as environmental protection objectives;
- Contribute to water sustainability across the watershed to reduce the use of resources including potable water; and
- Provides climate change co-benefits. A co-benefit is an action or a technology that is designed to both reduce greenhouse gas (GHG) emissions and reduce vulnerability to climate impacts in the future. When something contributes to both climate change mitigation and adaptation, it is a climate co-benefit (See **Section 6**).

The mandatory control hierarchy for application as part of the RVC_T for Ontario include the following priorities in keeping with the above noted rationale. While mandatory control hierarchy provides inherent flexibility in the types of SWM BMPs which can be used, it shall be a requirement that the practitioner document the selection rationale from priority 1 approaches to priority 3 approaches, explicitly describing the site restriction or restraints which prevent the implementation including all relevant supporting documentation as required. Note: this requirement has been included as a submission requirement for approvals (see **Section 7**).

1. **Control Hierarchy Priority 1 (Retention)** – LID retention technologies 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 re-use collected rainwater for internal or external uses respectively. The target volume is controlled and not later discharged to the municipal sewer networks (with the exception of internal water re-use activities) or surface waters and does not therefore become runoff. **Priority 1** BMPs shall be applied to meet local water balance requirements and are encouraged to be applied to the maximum level possible given the on-site conditions and the local environmental considerations:

Rationale: **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) as compared to approaches which rely on removal efficiencies (i.e. % removal)
- Prevent urban flood and combined sewer overflow (CSO) by increasing the sewer capacity by reduced volume and peak flows, as well as delayed time-to-peak;
- Maintain the pre-development water balance;
- Contribute to stream baseflow and mitigation of thermal impacts to urban streams; and
- Preserve groundwater quantity and levels.

2. **Control Hierarchy Priority 2 (LID Volume Capture and Release)** – LID filtration technologies which utilize filtration to filter runoff using LIDs with appropriate filter media per the LID Stormwater Planning and Design Guide (2010, v1.0 as amended from time to time). 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 Volume Capture and Release may be infiltrated or evapotranspirated). **Priority 2** BMPs shall be applied to the maximum level possible given the on-site conditions and the local environmental considerations:

Rationale: **Priority 2** BMPs:

- Reduce 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. % removal)
- Provide additional water quality benefits result from treatment process of filtration which may also include pollution adsorption and sedimentation;

3. **Control Hierarchy Priority 3 (Other Volume Detention and Release)** – 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 contaminates 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. **Priority 3** BMPs shall be applied such that the RVC_T is satisfied and that other SWM criteria i.e. water quantity control, erosion control etc. are satisfied.

Rationale: **Priority 3** BMPs:

- Additional water quality benefits result from treatment process of filtration (which may also include pollution adsorption and sedimentation), separation of pollutants from runoff or sedimentation;

3.3.3 Post-development Runoff Volume Control Target (RVRT) for Ontario

Any works that results in site disturbance that result in the creation of impervious surface or fully reconstructs existing impervious surface must meet all of the following stormwater performance requirements as described below.

3.3.3.1 New Development Volume Control

For new, nonlinear developments that results in the creation of impervious surface(s) on sites without restrictions, stormwater runoff volumes will be controlled and the post-construction runoff volume shall be controlled on-site, per the mandatory control hierarchy, for the runoff generated from the geographically specific 90th percentile rainfall event (**Figure 3.1.4)** from all surfaces on the entire site. The site shall be required to maintain the pre-development water balance.

3.3.3.2 *Redevelopment, Reurbanization and Intensification Volume Control*

For redevelopment, reurbanization and residential intensification projects that results in the creation of impervious surface (including the expansion of parking surfaces) for sites without restrictions, stormwater runoff volumes will be controlled and the post-construction runoff volume shall be controlled on-site, per the mandatory control hierarchy, for the runoff generated from the geographically specific 90th percentile rainfall event (**Figure 3.1.4)** from all surfaces on the entire site. The site shall be required to maintain the pre-development water balance.

3.3.3.3 Linear Development Volume Control

a) New linear projects without restrictions and subject to the approved Source Protection Plan, that results in the creation of impervious surface(s) and/or fully reconstructs the existing impervious surfaces, shall control per the mandatory control hierarchy the larger of the following:

   i. The runoff generated from the geographically specific 90th percentile rainfall event (**Figure 3.1.4)** from the new and/or fully reconstructed impervious surfaces on the site. The site shall be required to maintain the pre-development water balance.

   Or

   ii. The runoff generated from the geographically specific 90th percentile rainfall event (**Figure 3.1.4)** from the net increase in impervious area(s) on the site. The site shall be required to maintain the pre-development water balance.

<u>Linear Development Volume Control Exemption</u>

Roadway resurfacing (i.e. roadway projects which are primarily mill and overlay and other resurfacing activities) as well as trails and sidewalks, are not considered new linear projects and are exempt from RVC_T but are encouraged to undertake SWM retrofits to the activities Maximum extent possible (MEP) See **Section 3.3.3.4**.

3.3.3.4 Retrofits & Volume Control

For the voluntary construction of new and/or reconstruction municipal or non-municipal stormwater infrastructure within an existing urban area, including as part of road resurfacing project and / or trails and sidewalks construction, are encouraged to achieve volume control to the maximum extent possible (MEP). A project can be considered a retrofit provided the following conditions are met:

1) The subject area is already serviced by or is inadequately serviced by stormwater infrastructure,

2) The stormwater retrofit can be demonstrated to provide a net environmental benefit,
3) The subject project can be implemented and is in compliance with the approved Source Protection Plan
4) The subject site or project is not part of a common plan of development as defined by the municipality (i.e. subdivision, site plan, plan of condominium etc.), cannot be described as new development, redevelopment, intensification and reurbanization and cannot require approval under the Planning Act.

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

Maximum extent possible (MEP) shall be defined as the maximum achievable volume control, beyond the water balance requirement, using all known, available and reasonable, including the methods as described within this manual, given the site restriction.

3.3.3.5 Flexible Treatment Options for Sites with Restrictions

The Runoff Volume Control Target (RVC_T) acknowledges that infiltration **(Control Hierarchy Priority 1)** or Volume Capture and Release **(Control Hierarchy Priority 2)** of the runoff generated from the geographically specific 90^{th} percentile rainfall event may not be feasible for every site as a result of site specific constraints. For all sites, regardless of perceived constraints, the proponent shall attempt to comply with the appropriate volume control alternative as described above. The Runoff Volume Control Target (RVC_T) acknowledges that volume control is achievable on these sites via re-use and evapotranspiration practices even when partial or no infiltration is possible.

Should consultation with the subject municipality, conservation authority, the MOECC as part of the Environmental Compliance Approval (ECA) pre-consultation and/or pre-design investigation by the proponent identify that volume targets are not achievable; the proponent must consider and present to the MOECC the merits of relocating project elements to address varying soil conditions and other constraints.

It is noted that the relocation of project elements within linear development is limited, as such the proponent shall be encouraged to relocate project elements to address varying soil conditions and other constraints where possible.

The constraints which may result in the use of alternatives to the above prescribed volume targets include:

a) Shallow bedrock[†];
b) High groundwater[†] or areas where increased infiltration will result in elevated groundwater levels which can be shown to impact critical utilities or private property;
c) Swelling clays or unstable sub-soils;
d) Contaminated soils (i.e. Brownfields);
e) High Risk Site Activities including spill prone areas;
f) Prohibitions and or restrictions per the approved Source Protection Plans;
g) Flood risk prone areas where wastewater systems have been shown through technical studies to be sensitive to groundwater conditions that contribute to extraneous flow rates that cause property flooding / sewer back-ups and where LID BMPs have been found to be ineffective;
h) 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 MOECC and local agencies is required;

i) Existing urban areas where risk to life or property is identified through an appropriate area specific study;

j) Water reuse feasibility study has been completed to determine non-potable reuse of stormwater for onsite or shared use. Potable reuse may be considered on case specific basis.

† 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.

Two (2) alternatives are identified for sites with restrictions (i.e. constraints). The proponent shall document the flexible treatment options sequence starting with Alternative #1 in a hierarchical approach ending with Alternative #2 and submit all documentation to the MOECC and/or appropriate approval authority as part the standard approval process.

3.3.3.5.1 Alternative #1 – Reduced Runoff Volume Control Target

Proponent attempts to comply with the following conditions:

a) Achieve at least 75% volume control from all impervious surfaces for the runoff generated by the geographically specific 90th percentile rainfall event (**Figure 3.2)**.

b) Options considered and presented shall examine the merits of relocating project elements to address, varying soil conditions and other constraints across the site.

c) Not applicable for sites which directly discharge to a watercourse (See **Section 3.3.3.6**)

3.3.3.5.2 Alternative #2 – Maximum Extent Possible (MEP)

Proponent attempts to comply with the following conditions:

b) Achieve volume control to the maximum extent possible (MEP). In regards to Alternative #2, the Maximum extent possible (MEP) shall be defined as the maximum achievable volume control, using all known, available and reasonable methods, given the site restriction. Excessive costs alone shall not be considered an acceptable constraint, instead practitioners are encouraged to explore and document alternative and innovative alternatives with a reduced implementation cost.

a) Options considered and presented shall examine the merits of relocating project elements to address, varying soil conditions and other constraints across the site.

b) Not applicable for sites which directly discharge to a watercourse. (See **Section 3.3.3.6**)

3.3.3.6 Direct Discharge of Stormwater to Watercourses or Wetlands

Sites which discharge directly to watercourses or wetlands present unique 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 does not provide any alternative off-site or centralized treatment options. The Runoff Volume Control Target (RVC_T) acknowledges that volume control is achievable on these sites via reuse, evapotranspiration and infiltration practices.

It should be noted that surface water dominated or dependant features are acknowledged as potential site restrictions (see **Section 3.2.1.5**) 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. Surface water dominated or dependant features which are identified through approved site specific studies hydrologic or hydrogeologic studies, and/or Environmental Impact Statements (EIS) may be considered for a reduced volume control target. Pre-consultation with the MOECC and local agencies is required.

For sites that discharge via private or municipal conveyance systems directly to a watercourse or wetland the proponent will ensure the site achieves complete volume control of runoff that is generated from the geographically specific 90th percentile rainfall event from all surfaces on the entire site. Alternatives #1, #2, will not be considered.

3.4 Water Quality Expectations

Enhanced-Level 1 water quality protection as defined by the 2003 SWMPDM is the reduction of average long-term removal of suspended sediment by 80% or greater. Per the SWMPDM guide any stormwater management practice that can be demonstrated to approval agencies to meet the required long-term suspended solids removal for the selected levels under the conditions of the site is acceptable for water quality objectives. However, the use of removal rates in regards to pollutant removal is fraught with issues when quantifying or demonstration compliance. At its core, a removal rate is founded on relating the incoming runoff concentration vs. the treated (or outgoing) effluent concentration, and quantifying the difference. However, it is fundamental to this process, that it will be inherently easier to achieve a higher removal rate from runoff with higher concentrations of TSS vs. runoff with relatively low TSS. As such, a high removal rate does not necessarily equate to the protection of the environment. In addition, removal rates do not recognize the benefits to water quality from the reduction in runoff volumes. With the application of the RVC_T, it is necessary to account for and provide acknowledgement of the beneficial effects to water quality from volume reduction provided by LID BMPs, in addition to the benefits resulting from the mechanisms of filtration, adsorption, uptake and re-use. It is therefore more appropriate to examine water quality from a load (mass/unit time i.e. kg/yr) reduction perspective, which accounts for the both flow reduction (volume per unit time i.e. m^3/s) and the concentration (mass per unit volume i.e. mg/L).

As such, consistent with the 2003 SWMPDM, specifically the condition that Enhanced-Level 1 water quality protection is defined as the reduction of average long-term removal of suspended sediment by 80% or greater, all SWM BMPs which can demonstrate the long-term removal of 80% or greater of the annual suspended sediment load, shall be considered equivalent to Enhanced-Level 1 water quality protection.

Furthermore, SWM BMPs which achieve the RVC_T (the control of the regionally specific 90th percentile event) shall be considered to have achieved Enhanced-Level 1 water quality protection for the respective contributing drainage area. Treating the runoff from one hundred percent of the 90th percentile rainfalls event (and an equivalent rainfall depth for all events larger 90th percentile rainfall event) from a respective contributing drainage area will provide a high level of pollutant load reduction, which equates to roughly a 90% reduction in the long-term annual load of suspended sediment.

Where proponents are able to achieve the volume, targets described above, this pollutant load reduction will be acknowledged during the review of a stormwater management plan. The complete control of runoff that is generated from a rainfall depth which is lower than the 90th percentile rainfall event from all surfaces on the entire site through a combination of **Priority 1** and **Priority 2** BMPs will be considered by have achieved the relative portion of the full Enhanced-Level 1 water quality protection. For example:

- For a site where the RVC_T is 25mm, 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 Volume Capture and Release) will be considered by have achieved half of the sites required Enhanced-Level 1 water quality treatment. As such, in order to achieve Enhanced-Level 1 protection the proponent may design other onsite stormwater quality best management practices using **Control Hierarchy Priority 3 (Other Volume Detention and Release**) to treat the remaining runoff volume.

3.5 Water Quantity Expectations

The RVC_T does not change or amend the water quantity (i.e. flood control requirements) as identified through watershed, subwatershed, master drainage plans completed following the Municipal Class Environmental Assessment Master Planning process, as described By the Municipal Engineers Association (2000, as amended 2007 & 2011), Environmental Impact Statement (EIS), Provincial Policy and Guidelines or other area specific studies which have been duly reviewed and approved by the relevant agencies and / or authorities or as defined by the relevant municipality or conservation authority.

However, it is noted that a portion of the detention and/or peak flow requirement may be fulfilled through the satisfaction of the RVC_T and the application of volume control LID BMPs as part of **Control Hierarchy Priority 1 (Retention)** and **Control Hierarchy Priority 2 (LID Volume Capture and Release).**

Practitioners shall be required to demonstrate through calculations and / or hydrologic modelling the storage quantity and/or the peak flow reductions associated with achieving or partially achieving the RVC_T and the application of volume control LID BMPs as part of a development, redevelopment, reurbanization, residential intensification or linear infrastructure project. Acceptance and approval shall be subject to the approval of the respective municipality or agency.

4 Groundwater Considerations

4.1 Groundwater and Watershed Health

Groundwater is a vital component of the 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**.1, rain and snow melt infiltrates into the soil zone 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 recharge rates can vary from place to place based on the soil conditions; rates can also vary seasonally and from year to year, depending on annual rainfall amounts.

Discharge from the groundwater system contributes to streamflow. Baseflow is the flow that persists in between rainfall events. Baseflow can include the slow release of water from lakes and wetlands, but in many Ontario streams, baseflow primarily results from the slow discharge of 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 4.1.1** illustrates the interaction between groundwater and surface water in discharge areas.

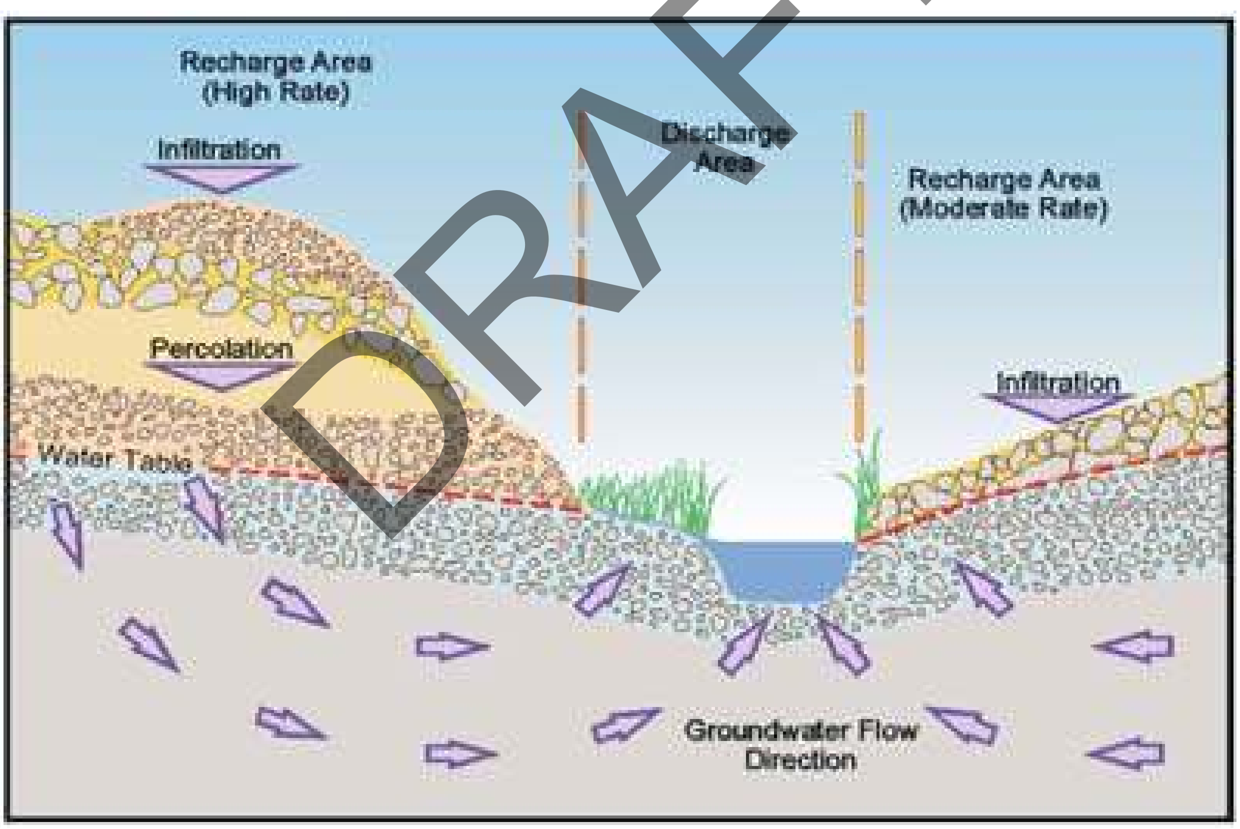


Figure 4.1.1: Groundwater-Surface Water Interaction (Source: MOECC)

In Ontario, most infiltration and groundwater recharge occurs 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 fall in Ontario as evapotranspiration ceases and fall rains set in, gradually declining into the winter months as rain transitions to snow.

Increased urbanization can reduce groundwater recharge in Ontario's watersheds. As new roads, housing, and commercial areas are developed, impervious surfaces and soil compaction significantly reduces infiltration during rainfall events by directing precipitation to the rapid runoff pathways of urban stormwater conveyance systems. This increased runoff has resulted in severely degraded watercourses in urban areas across the province. Reduction in groundwater discharge during summer months has resulted in warmer stream temperatures with higher pollutant loads 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 will likely also have a direct impact on the availability of groundwater resources and watershed health by reducing groundwater contributions to surface water features. The expected warmer wetter winters may increase recharge in January and February, but the longer and hotter summer season will severely affect streamflows in July through September.

4.1 Groundwater Benefits from LIDs

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 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 the water table. This filtration can reduce contaminant for some organic and inorganic contaminants present in stormwater. LID BMPs are crucial to maintaining and improving natural water systems, maintaining the viability of local stormwater infrastructure, and contributing to climate change adaptation and mitigation strategies in urbanizing areas.

4.2 Groundwater Risks from LIDs

As the implementation of infiltration-based LIDs becomes more prevalent, stormwater practitioners have a duty to protect local groundwater resources by implementing a stormwater infiltration policy which is developed based on a sound understanding of identified and future risks. Ultimately, these risks need to be balanced with the benefits of LID implementation to preserve Ontario's groundwater resources, protect 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. As runoff flows across urban landscapes and through conveyance networks, it picks up dissolved and suspended several constituents. **Table 4.2.1** identifies these constituents, the Provincial Water Quality Objectives associated with these constituents, and typical observed concentrations in urban stormwater runoff.

Table 4.2.1: Comparison of Urban Stormwater Runoff Concentrations vs. Provincial Water Quality Objectives (PWQOs)

Parameter	Unit	PWQO	Observed Concentrations
Escherichia coli	CFU/100 mL	-	10,000 to 16 x 10^6
Total Suspended Solids (TSS)	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
Escherichia coli	CFU/100 mL	-	10,000 to 16 x 10^6

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.

Nutrients

- Nitrate is one of the most frequently encountered contaminates 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 form 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.
- 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.
- Sources of organic compounds include runoff from landfills, sewage systems, highway runoff, agricultural runoff and urban stormwater runoff.
- Organic contaminates in urban stormwater runoff include gasoline and oil drippings, tire residuals, exhaust by-products, mechanical lubricants, animal droppings and composing 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, Nickle, 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 4.2.2** 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, 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 LIDs 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 the addition of a perforated underdrain.

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 general, the groundwater contamination potential for common stormwater pollutants using infiltration practices is generally quite low. Under the assumption of infiltrating stormwater into sandy soils with low organic content (worst case scenario for groundwater contamination) and pollutant levels commonly found in urban residential and commercial areas, the contamination potential also presented in **Table 4.2.2**. It should be noted careful consideration must be given to salts and chlorides when infiltrating stormwater.

Table 4.2.2: 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 attenuate by the processes of volatilization and sorption.	Low-Moderate	Low
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 contaminates, 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			

In Ontario, specific groundwater quality concerns are related to the cold climate and winter maintenance of paved surfaces. As noted in **Table 4.2.2**, 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 LIDs, 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 4.2.1** shows chloride loading estimated 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.

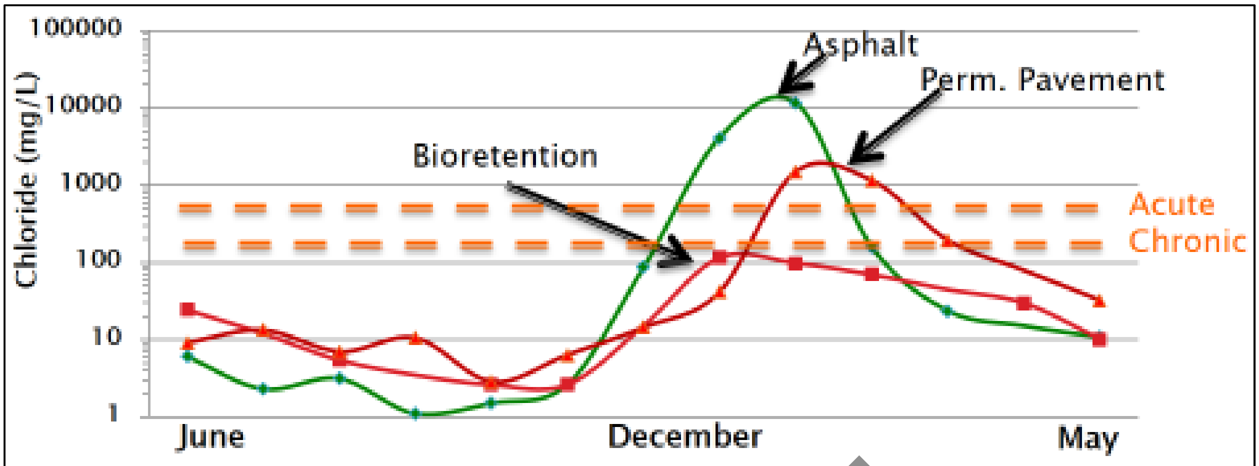


Figure 4.2.1: Groundwater-Surface Water Interaction (Source: Sustainable Technologies Evaluation Program)

Other potential groundwater contaminates are the product of land maintenance, the degradation of vehicles or even natural processes. Pollutants of concern to groundwater resources are identified in **Table 4.2.3.**

Table 4.2.3: Pollutants of Concern for Groundwater Resources

Pollutant	Significant Sources
Nitrate	Agriculture (fertilizer and animal manure), vehicle exhaust, sewage, landfills
Pesticides	Weed and insect control along roadsides
Polycyclic Aromatic Hydrocarbon (PAH) and Halogenated Hydrocarbons	Asphalt, fuel and oil spills and leaks, automotive exhaust
Pathogens	Animal waste and sanitary sewage spills
Metals (zinc, chromium, nickel, and lead)	• Zinc (tire wear, motor oil, grease, and metal deterioration) • Chromium (metal plating, engine wear, break wear and metal deterioration) • Nickel (diesel fuel and gasoline exhaust, lubricating oil, metal plating, bushing wear, brake wear, asphalt paving, metal deterioration) • Lead (tire wear, lubricating oil and grease, bearing wear, metal deterioration)
Chloride	De-icing salts

Source: Adapted from STEP, 2009

In Ontario, threats to drinking water sources are regulated under the Clean Water Act (2006). Through this act, Source Protection Plans have been developed to outline steps that must be taken to reduce the risk posed by drinking water threats. The Province of Ontario has identified 21 prescribed threats under the Clean Water Act. Of these threats, three (3) water quality threats and one (1) water quantity threat relate directly to sites with infiltration-based LID practices.

Water Quality Threats

1) "*The establishment, operation or maintenance of a waste disposal site within the meaning of Part V of the Environmental Protection Act*." This definition includes stormwater management facilities.

2) "*The application of road salt*." 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.

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

Water Quantity Threats

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

4.2.1 High Risk Site Activities

Not all stormwater runoff contains the same levels of pollutants. Roads and parking lots are subject to vehicular traffic as well as winter sanding and salting operations. In contrast, the primary pollutant source on roofs is atmospheric deposition. The identification of site activities that have the potential to generate runoff containing groundwater pollutants is crucial to implementing a technically sound infiltration policy. While municipal zoning is a land use planning tool that can be used to identify possible sources of groundwater contaminants, the review of site activities is a higher resolution risk assessment technique. For example, a moratorium on the infiltration of all water from industrial sites would miss opportunities to infiltrate generally clean runoff originating on rooftops and landscaped areas. A prudent approach to planning infiltration-based LID practices 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. (i.e. Priority 1 and Priority 2 BMPs).

Generally, the more intensive the land use, the greater the potential to contaminate groundwater resources. Industrial land uses typically have the greatest potential to contaminate groundwater resources because of high-risk activities such as hazardous material storage and onsite fueling stations. 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 practices 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 practices, pollution prevention practices in the form of administrative and engineering controls and stormwater management practices that do not infiltrate storm water should be applied in these areas along with Priority 1 and Priority 2 BMPs.

Table 4.2.1.1 further identifies high-risk site activities. High-risk site activities are defined as those with the potential for high levels of contamination such as hydrocarbons, metals, organic and inorganic compounds, sediments and chlorides.

Table 4.2.1.1 - High Risk Site Activities

High Risk Site Activities which preclude the use infiltration-based LID practices within the contributing catchment area		
Acid and Alkali Manufacturing, Processing and Bulk Storage	Explosives and Firing Range	Petroleum-derived Gas Refining, Manufacturing, Processing and Bulk Storage
Adhesives and Resins Manufacturing, Processing and Bulk Storage	Fertilizer Manufacturing, Processing and Bulk Storage	Pharmaceutical Manufacturing and Processing
Airstrips and Hangars Operation	Fire Retardant Manufacturing, Processing and Bulk Storage	Plastics (including Fibreglass) Manufacturing and Processing
Antifreeze and De-icing Manufacturing and Bulk Storage	Fire Training	Port Activities, including Operation and Maintenance of Wharves and Docks
Asphalt and Bitumen Manufacturing	Flocculants Manufacturing, Processing and Bulk Storage	Pulp, Paper and Paperboard Manufacturing and Processing
Battery Manufacturing, Recycling and Bulk Storage	Foam and Expanded Foam Manufacturing and Processing	Rail Yards, Tracks and Spurs
Boat Manufacturing	Garages and Maintenance and Repair of Railcars, Marine Vehicles and Aviation Vehicles	Rubber Manufacturing and Processing
Chemical Manufacturing, Processing and Bulk Storage	Gasoline and Associated Products Storage in Fixed Tanks	Salt Manufacturing, Processing and Bulk Storage
Coal Gasification	Glass Manufacturing	Salvage Yard, including automobile wrecking
Commercial Autobody Shops	Importation of Fill Material of Unknown Quality	Soap and Detergent Manufacturing, Processing and Bulk Storage
Commercial Trucking and Container Terminals	Ink Manufacturing, Processing and Bulk Storage	Solvent Manufacturing, Processing and Bulk Storage
Concrete, Cement and Lime Manufacturing	Iron and Steel Manufacturing and Processing	Storage, maintenance, fuelling and repair of equipment, vehicles, and material used to maintain transportation systems
Cosmetics Manufacturing, Processing and Bulk Storage	Metal Treatment, Coating, Plating and Finishing	Tannery
Crude Oil Refining, Processing and Bulk Storage	Metal Fabrication	Textile Manufacturing and Processing
Discharge of Brine related to oil and gas production	Mining, Smelting and Refining; Ore Processing; Tailings Storage	Transformer Manufacturing, Processing and Use
Drum and Barrel and Tank Reconditioning and Recycling	Oil Production	Treatment of Sewage equal to or greater than 10,000 litres per day
Dye Manufacturing, Processing and Bulk Storage	Operation of Dry Cleaning Equipment (where chemicals are used)	Vehicles and Associated Parts Manufacturing
Electricity Generation, Transformation and Power Stations	Ordnance Use	Waste Disposal and Waste Management, including thermal treatment, landfilling and transfer of waste, other than use of biosoils as soil conditioners
Electronic and Computer Equipment Manufacturing	Paints Manufacturing, Processing and Bulk Storage	Wood Treating and Preservative Facility and Bulk Storage of Treated and Preserved Wood Products
Explosives and Ammunition Manufacturing, Production and Bulk Storage	Pesticides (including Herbicides, Fungicides and Anti-Fouling Agents) Manufacturing, Processing, Bulk Storage and Large-Scale Applications	

Source: O. Reg. 153/04: Records of Site Condition- Table 2 – Potentially Contaminating Activities

Catchment areas with high risk site activities (**Table 4.2.1.1**) are discouraged from incorporating LID BMPs that utilize infiltration (Priority 1) because of the associated contamination risk to groundwater. Catchment areas with high risk site activities do not preclude the use of those LID BMPs that utilize filtration, evapotranspiration (ET) or re-use as the primary processes. Additionally, catchments not directly impacted by the respective high risk site activities such as rainwater originating from rooftops, employee parking facilities or directly falling on permeable surfaces is generally considered relatively 'clean' and should not be excluded from infiltration.

4.2.2 Shallow and Deep Groundwater Systems

Groundwater is the water stored in the pores of a geologic unit. Pores can include the space between sand grains or the space within fractures in a rock mass. Groundwater flows within the geologic unit, 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 open to the ***geologic formation***. Groundwater levels in shallow formations tend to be high in the uplands where groundwater recharge is occurring and lower in the vicinity of streams in where groundwater discharge contributes to streamflow.

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.

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. Above the water-table, 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 4.2.2.** Groundwater can move slowly from one aquifer to another across the intervening aquitard, from an area of higher potential to one of lower potential.

A ***perched aquifer*** is an unconfined aquifer underlain 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.

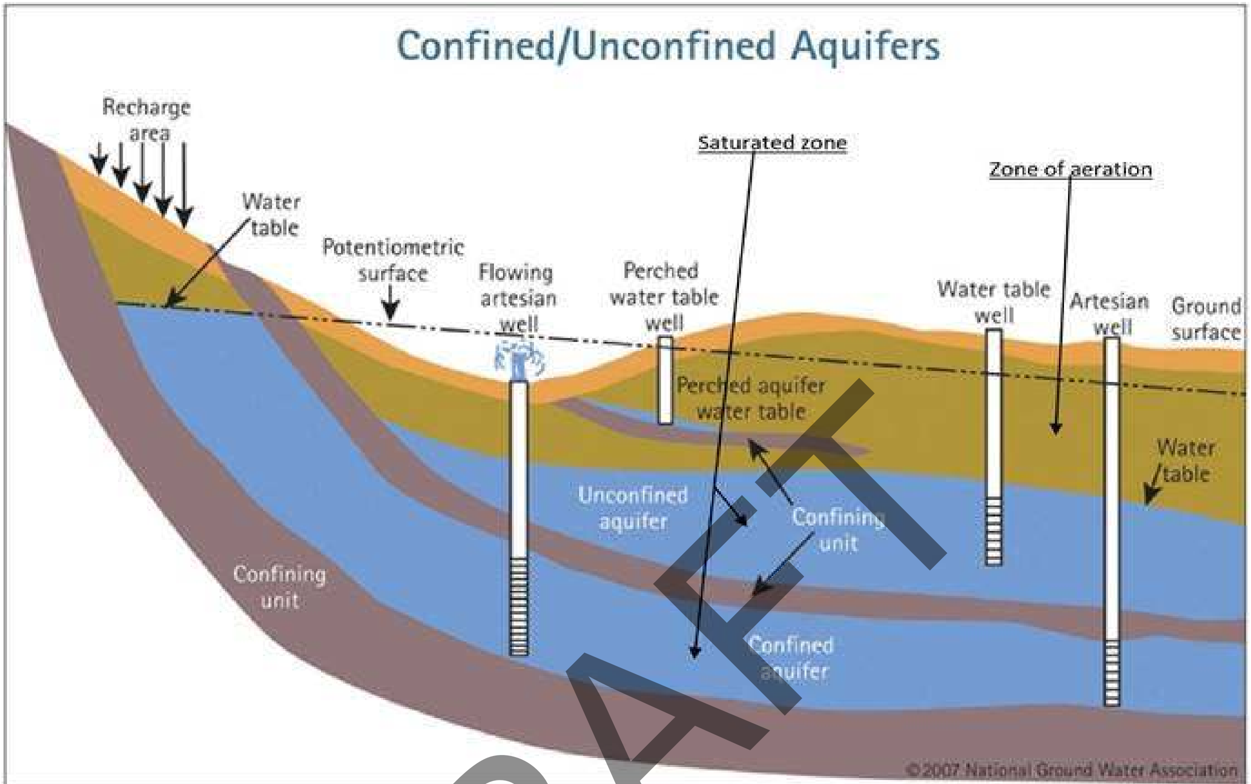


Figure 4.2.2: Confined, unconfined, and perched aquifers.

When implementing infiltration-based LIDs, it is important to be able to predict the potential impacts on the groundwater system. This is sometimes difficulty 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. A review of previous geologic and hydrogeologic studies from the area, including Source Water Protection groundwater studies, should be done at an early stage of project planning. This review should be supplemented with an analysis of on-site monitoring data, if available, 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 should be implemented to determine 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 Southern 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 cold water 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 LIDs 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 restore natural (pre-development) hydrologic conditions. As noted earlier, urban stormwater can contain contaminants, many of which are be reduced by removal processes that occur as infiltrated stormwater percolates through soils. However, groundwater quality issues may arise when LIDs are implemented on a large development-scale 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 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.

Although infiltration based LIDs interact directly with shallow aquifers, their impact on deep groundwater resources must also be considered. Municipal wells for public supply are often drilled into deeper and/or confined aquifer to avoid surface contamination and are therefore less vulnerable to water quality impacts by infiltration-based LID BMPs. Even so, long-term degradation of water quality in shallow aquifers can eventually affect the quality in deeper aquifers in upland areas where vertical flow between the shallow and deeper aquifers is occurring.

4.2.5 Data Sources and Process for Determining Risks

Groundwater monitoring programs are typically undertaken on a long-term basis in order to capture seasonal and yearly trends in groundwater levels and water quality. 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 at ontario.ca/page/well-records. 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 (PGWMN) – The PGWMN is a partnership program between the MOECC, 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 4.2.5** shows the geographic distribution of the PGWMN.

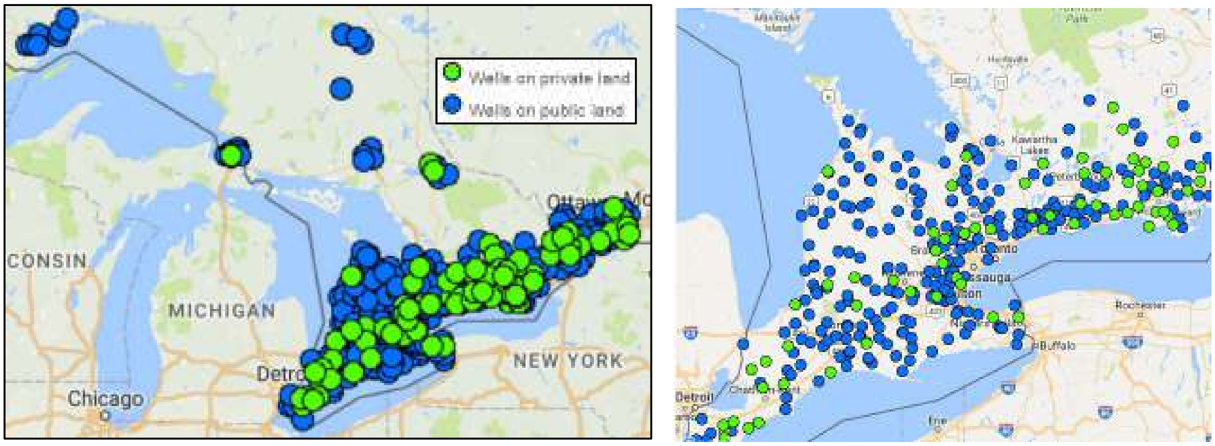


Figure 4.2.5: Provincial Groundwater Monitoring Network

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 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 MOECC, these plans can provide valuable information on local hydrologic and hydrogeologic conditions that can be serve as the foundation for infiltration policy development. Through extensive scientific analysis, 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. To assess demands and potential stressors, water budgets were mandated for all watersheds in Ontario. A tiered system of analysis was conducted where all watersheds underwent Conceptual Water Budget and 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 Water Protection Water Budgets studies are described below:

1. **Conceptual Water Budget**: These high-level studies take into consideration precipitation, evapotranspiration, infiltration, recharge, runoff and groundwater flow to quantify overall inputs and outputs to an entire watershed. The conceptual water budget also considers the effects of water taking for human uses and considers, in general terms, the effects of predicted climate change over a 25-year period.

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 at http://www.ctcswp.ca/wp-content/uploads/2016/03/CLOCA-Tier1-SPC-Presentation.pdf. 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 at https://www.grandriver.ca/en/our-watershed/resources/Documents/Water_Supplies_Tier2.pdf.

4. **Tier 3 Local Area Water Budget (and Water Quantity Risk Assessment and Threats Identification)**: A Tier 3 Local Area Water Budget level shifts focus from the subwatershed level to local areas containing municipal water sources. These areas are Water Quantity Wellhead Protection Areas (WHPA-Q) or Water Quantity Intake Protection Zones (IPZ-Q). Several Tier 3 studies found that the "local areas" in municipalities with high groundwater use could actually span across multiple subwatersheds. The goals of the Tier 3 analysis are water quantity risk assessment and threats identification. The local water source is analysed using even more complex models, in some cases integrated surface water/groundwater model, to assess vulnerability to overuse under different development scenarios and water supply scenarios including current, planned and drought conditions. If the Tier 3 analysis determines that the municipal water source is unable to meet current or future conditions, the source is assigned a significant risk level. Threats are required to be identified and dealt with via Source Protection Planning in all municipal water sources with significant risk levels. A Tier 3 water budget study for the York Region municipal water supply system can be found at http://www.ctcswp.ca/wp-content/uploads/2014/08/RPT_20131114_Earthfx_York_Tier3 WBLocAreaRiskAssFNL.pdf.

Groundwater Vulnerability Analysis

A groundwater vulnerability analysis identifies sources of municipal drinking water that are susceptible to contamination. Source Water Plans can identify three groundwater features that are susceptible to groundwater contamination. These are Wellhead Protection Areas, Highly Vulnerable Aquifers and Significant Groundwater Recharge Areas. One of the main goals of a groundwater vulnerability analysis is to map these areas. Design of infiltration-based LIDs should take into consideration the location of high vulnerability areas identified in these studies.

Water Quality Wellhead Protection Area (WHPA): The area around a well where land use activities have the greatest potential to affect water quality is known as the water quality 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.

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

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 Trichloroethlene. Within an ICA, all drinking water threat activities related to the specific issue are considered significant drinking water threats, regardless of the vulnerability scoring. Activities which increase or contribute to the risk are not permitted.

Significant Groundwater Recharge Areas: Significant Groundwater Recharge 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. 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 may coincide with SGRAs but the in many cases ESGRAs do not support sufficient recharge volume to be considered significant on a broader level than the associated ecological feature.

4.2.6 Infiltration Guidelines

Maintaining natural infiltration capacities (rates and geographic distribution) is important for ensuring the long-term viability of groundwater sources and associated ecological habitat. 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 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, ICAs and SGRAs, infiltration-based LID practices should not accept runoff from contributing catchment areas that contain high risk site activities (**Table 4.2.1.1**).

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

3. For all sites within ICAs, 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.

4. For all sites within WHPAs with vulnerability scores equal to or greater than eight (8), provided the contributing catchment areas do not contain high risk site activities (**Table 4.2.1.1**), runoff from onsite paved surfaces (roads, sidewalks and parking surfaces) totaling less than 200 m^2 can be infiltrated without restrictions. Runoff from paved surfaces equal to or larger than 200 m^2 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.

5. For all sites within WHPAs with vulnerability scores equal to or greater than two (2) but less than eight (8), provided the contributing catchment areas do not contain high risk site activities (**Table 4.2.1.1**), runoff from onsite paved surfaces (roads, sidewalks and parking surfaces) totaling less than 2000 m^2 can be infiltrated without restrictions. Runoff from paved surfaces equal to or larger than 2000 m^2 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.

Caution and due diligence should be used when implementing infiltration-based LID BMPs in areas where karst features and fractured sedimentary rock are common. 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.

It is recommended that consultation with local agencies regarding the Source Protection Policies be completed early and often in the development of SWM infiltration policies.

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 LIDs 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 4.2.7.1** identifies design factors that can enhance the treatment properties of infiltration-based LIDs.

Table 4.2.7.1: 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 refers to phosphorus soil test index values in parts per million (ppm). See www.omafra.gov.on.ca for more information on soil testing and a list of accredited soil laboratories.

Source: Adapted from CVC/TRCA LID SWM Planning and Design Guide

When designing infiltration-based LIDs 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.

Figure 4.2.7.1: Inlet gate to prevent chloride loading during winter months

When designing infiltration-based LIDs 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 procedural and policy framework for the implementation 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 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 LIDs in a cold climate such as Ontario are identified in **Table 4.2.7.2.**

Table 4.2.7.2: Design Factors for Winter Operation

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.
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 a winter bypass at the inlet to prevent water from entering the facility during periods of the year when road de-icing occurs (**Figure 4.2.7.1**)
This design modification decreases direct interaction between local groundwater and filter media that accumulates chloride.	Increase the distance (depth) between the invert of the facility and the seasonally high groundwater table.

5 Criteria for Model Selection

A key objective of this manual is to provide guidance regarding criteria for selecting a technical approach for predicting and assessing the performance of stormwater management plans on a long-term basis. While some simple stormwater designs or LID measures can be evaluated through relatively straightforward calculations (see the Stormwater Management Planning and Design Manual (MOE, 2003) for several examples), the complexity of many new stormwater designs will require the use of a modelling tool. Broadly speaking, a model is "an assembly of concepts in the form of mathematical equations or statistical terms that portrays a behavior of an object, process or natural phenomenon" and can vary in a complexity from a simple spreadsheet to detailed numerical simulations.

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. The 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. Models developed to predict stormwater quality should include parameters such as suspended solids, sediment transport, nutrients, including nitrogen and phosphorous, and temperature.

This chapter of the manual discusses the selection of an appropriate modelling approach to analyze the effects of LID measure implementation on the local surface water and groundwater systems. The model selection methodology is suitable for addressing new developments, infill-developments, redevelopments, and retrofits. It attempts to match the level of model complexity to the principal considerations of the project, including scale of the proposed development or SWM retrofit, 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 are broken down into four model classes, which are described in **Section 5.2**. Specific site conditions that should be addressed when developing a modelling approach are introduced in **Section 5.3**. The recommended screening factors to guide model selection and study methodology are discussed. A model selection framework is then presented to guide study teams towards a level of modelling effort that can address the nature of the proposed development and/or SWM retrofit while considering the context of the local setting (**Section 5.4**). **Section 5.5** provides an overview of the steps required to construct, calibrate, and apply a model. A discussion of the data required to drive an assessment of the potential effects of LIDs are presented in **Section 5.6**.

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 guide a practitioner towards a defensible modelling approach that will allow the potential impacts of a development project to be adequately assessed. No particular modelling package or tool is explicitly favoured in this document; rather, the discussion and selection framework is intended to guide the adoption of a modelling strategy that can address both the nature of the physical setting and the type of proposed stormwater management system. For example, if a development is proposed near sensitive groundwater-dependent streams or wetlands, the recommended modelling approach would include consideration of the impacts to the groundwater and surface water systems. In addition, if the proposed development and/or retrofit are within a protected area identified by a Source Water Protection Plan the modelling approach would be commensurate with the assessment requirements.

The chapter 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 MOECC-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.

This chapter has not been written solely for practicing modellers. Ideally this document should be useful to a broad cross-section of professionals. 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 at the approval agencies should be able to refer to this document and reach similar conclusions regarding the suitability of a modelling methodology. It is hoped that, the model selection framework will create a common understanding of the criteria to be evaluated when choosing a modelling approach.

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 verify, through the use of quantitative tools such as water budget models, that the methods selected will mitigate the increase in runoff and the loss of natural recharge due 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 LIDs and other design improvements will 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 features may raise the water table causing interference with the LID performance; and
- demonstrate that the proposed LIDs 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 measures 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 features are available, building costs can be minimized while siting can be modified to maximize the effectiveness of LID features.

5.1.1 Preserving Natural Hydrologic Function

Effective hydrologic design tools can allow natural drainage features to be incorporated into the overall site design. This can include ensuring pre-development runoff volume and runoff quality is maintained to preserve the natural conveyance and sediment transport functions of the natural drainage features when they are incorporated into the site stormwater system. Conversely, 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 ensure there are no deleterious hydrologic or hydrogeologic impacts to significant ecological features. A simple sizing of LID features to meet the volume requirement is often 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

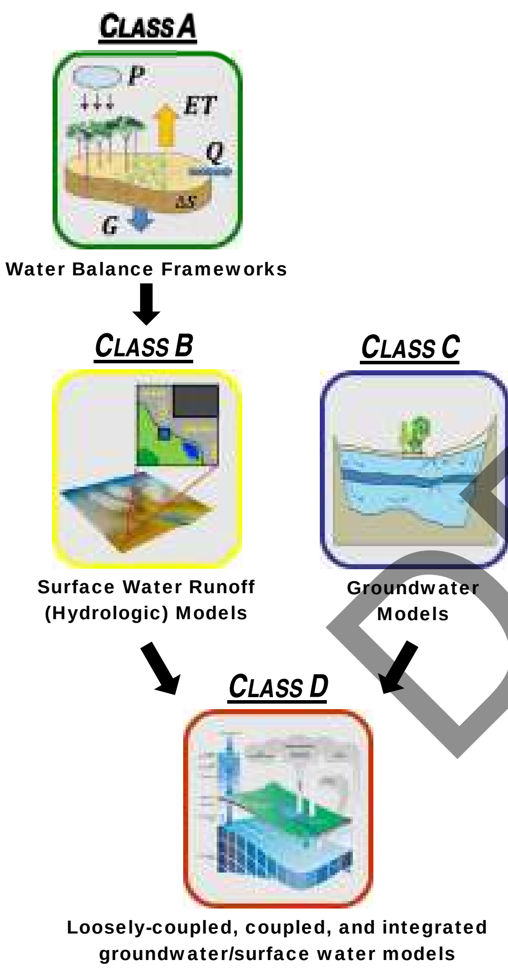


Figure 5.1: Hierarchy of model types.

This section outlines four basic model classes from which a project proponent could select for detailed analysis of LID measures. 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** .

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 features. **Class B** captures more sophisticated *hydrologic models and surface runoff models* that can explicitly represent small scale features on a 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.

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.

5.2.1 Planning Level Tools

As part of a parallel process, 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 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 removals estimates for pre- and post-development scenarios. The toll is built upon the open source EPA SWMM5 model providing a user-friendly interface for novice modeller and cross-compatibility with SWMM5 for further model development.

The LID TTT is currently in Beta Version and is being tested by stakeholders and industry with final release planned for mid-2017. Additional detail will be provided within Draft 2 of this manual.

5.2.2 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 5.1**). 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 (MOEE, 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.

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.

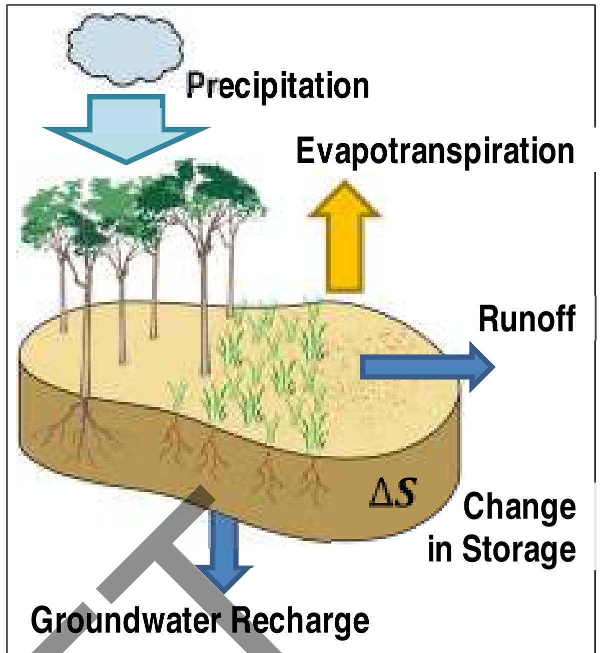


Figure 5.1: Hydrologic components of a simple water balance. (modified from Toews, 2007).

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.

5.2.2.1 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 process 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 (2006)) are provided in **Table 5.1.**

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:

$$\text{Inputs} = \text{Outputs} + \text{Change in Storage}$$

$$P = Int + AET + DS + IF + GW - RO + \Delta s$$

Where

P	=	precipitation
Int	=	interception by the vegetative canopy (lost to evaporation)
DS	=	depression storage on impervious surfaces (lost to evaporation)
RO	=	overland runoff to streams (Hortonian and Dunnian)
AET	=	actual evapotranspiration
IF	=	interflow to streams
GW	=	groundwater discharge
Δs	=	change in groundwater and soil moisture storage

Solving for the change in storage, this equation can be written as:

$$\Delta s = P - Int - DS - RO - AET - IF - GW$$

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 5.1: 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}.		

5.2.2.2 LID Representation Within Water Balance Models

Evaluating the effectiveness of LID measures 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, percent impervious, 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, percent impervious, depression storage, and runoff factors to account for changes likely to occur under "post-development with no LIDs" 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, percent impervious, depression storage, and runoff factors to account for changes likely to occur under "post-development with LIDs" 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 measures were in mitigating any adverse changes. An example is presented below illustrating how the method is applied.

Representing LID measures 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 measures 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 measures include planting across the site to restore the coverage back to 20% than 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 measures 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.

5.2.2.3 Example: Spreadsheet Water Balance

The tables below 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 measures 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 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 5.6.1**).

Table 5.2: Simple spreadsheet based water balance example.

SIMPLE MONTHLY WATER BALANCE MODEL – Existing Conditions

Location: Toronto; Latitude: 43.0 degree; Max. Soil Moisture (SM_{max}): 25 mm; Runoff Factor (RF): 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	0.4	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	9.7	
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	25.7	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	25.7	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: Toronto; Latitude: 43.0 degree; Max. Soil Moisture (SM_{max}): 25 mm; Runoff Factor (RF): 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	25.7	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	25.7	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: Toronto; Latitude: 43.0 degree; Max. Soil Moisture (SM_{max}): 25 mm; Runoff Factor (RF): 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	46.3	706
Monthly Potential ET[2] (PET)	*Hamon Eqn. (see note)*	0.0	0.0	25.7	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	25.7	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 5.3: Pre- and Post- Development water balance elements with and without LIDs.

Water Balance Component	Pre-Development Flows (mm/yr)	Post-Development Flows without LIDs (mm/yr)	Post-Development Flows with LIDs (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

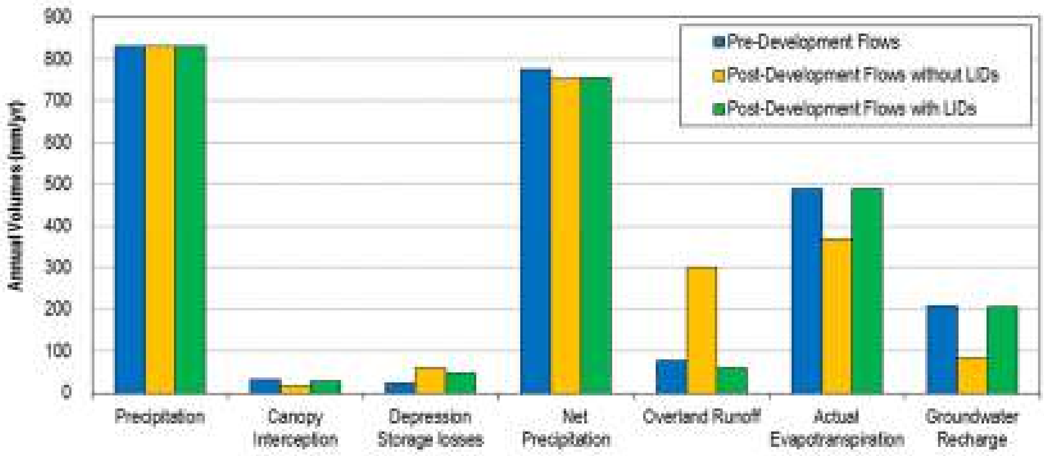


Figure 5.2: Pre- and Post- Development water balance elements with and without LIDs.

As shown in Table **5.3** and **Figure 5.2**, the "Post-Development without LIDs" 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 LIDs" 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.

5.2.2.4 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.

5.2.2.5 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.

5.2.2.6 Considerations: Winter Conditions

Water balance codes vary as to whether they represent winter processes. Some modes, such as the USGS Thornthwaite Monthly Water Balance model (**Figure 5.3**), can account for snow accumulation and snow melt using a temperature or energy balance method, such as 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.

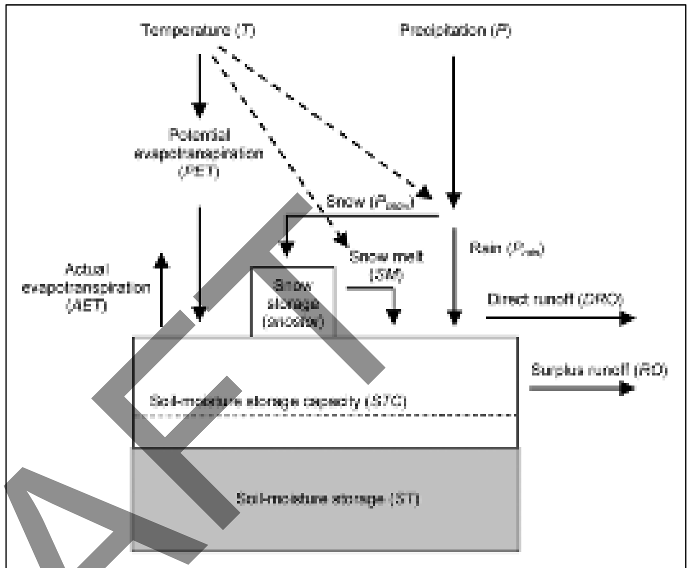


Figure 5.3: Process schematic from the USGS Thornthwaite Monthly Water Balance model (McCabe

5.2.2.7 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 measures. Others have been specifically developed to aid in LID assessments. Several common codes employed in Ontario are discussed below.

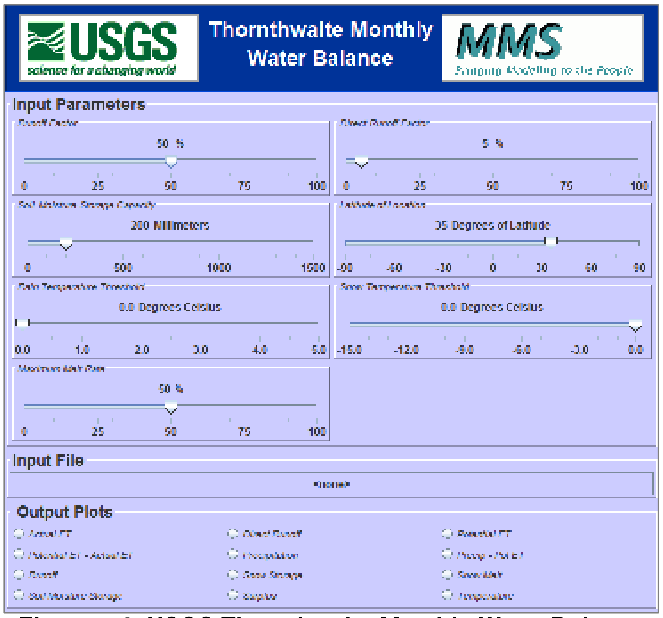


Figure 5.4: USGS Thornthwaite Monthly Water Balance Model (McCabe & Markstrom, 2007).

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 total suspended solids (TSS). 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 5.4: 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. http://water.usgs.gov/lookup/get?crresearch/mms/thorn
LIDRA (Low impact development rapid assessment)	Drexel University and eDesign Dynamics LLC	http://www.llidratool.net
Water Balance Model (powered by QUALHYMO)	Partnership for Water Sustainability in British Columbia	http://bc.waterbalance.ca/water-balance-model/
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/

5.2.3 Class B: Surface Water Runoff (Hydrologic) Models

There are a wide variety of surface water models available that 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 model 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, combined model may be advantageous. A stand-alone hydraulic 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, total 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 detention, retention 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 features, 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 5.2.4.**

5.2.3.1 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 measures 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 measures.

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 measures 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.

5.2.3.2 Considerations: Spatial Scale - Lumped vs. Distributed Models

Hydrologic models can be broadly classified as *lumped-parameter or distributed-parameter* models (Figure 5.5). ***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.

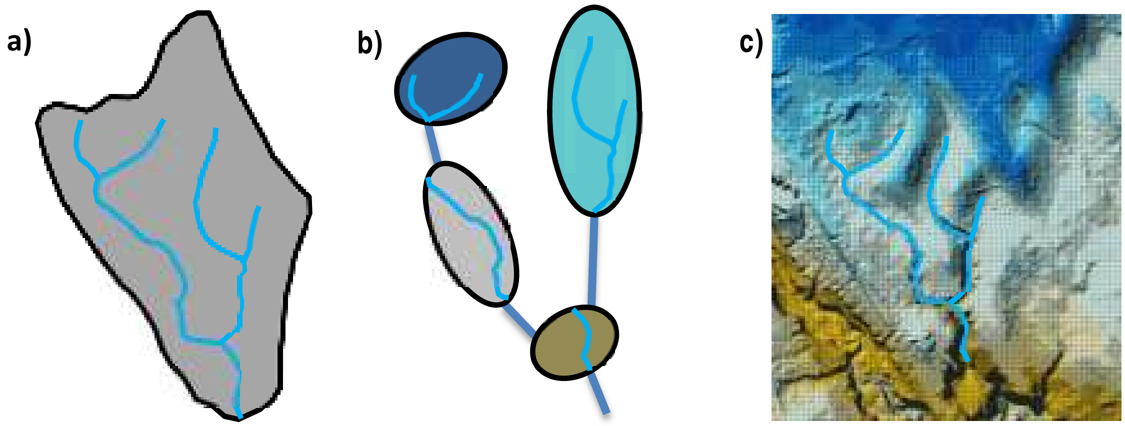


Figure 5.5: Schematic representations of a) lumped, b) semi-distributed, and c) fully distributed hydrologic models.

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 5.2.5.

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 features within a comprehensive stormwater management plan requires, as a starting point, that the LID features and elements be uniquely represented within the model.

5.2.3.3 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. Stormwater designs must demonstrate 80% Total Suspended Solids removal (MOE, 2003) and in some jurisdictions 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, total 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.

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.

5.2.3.4 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 5.6**). 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.

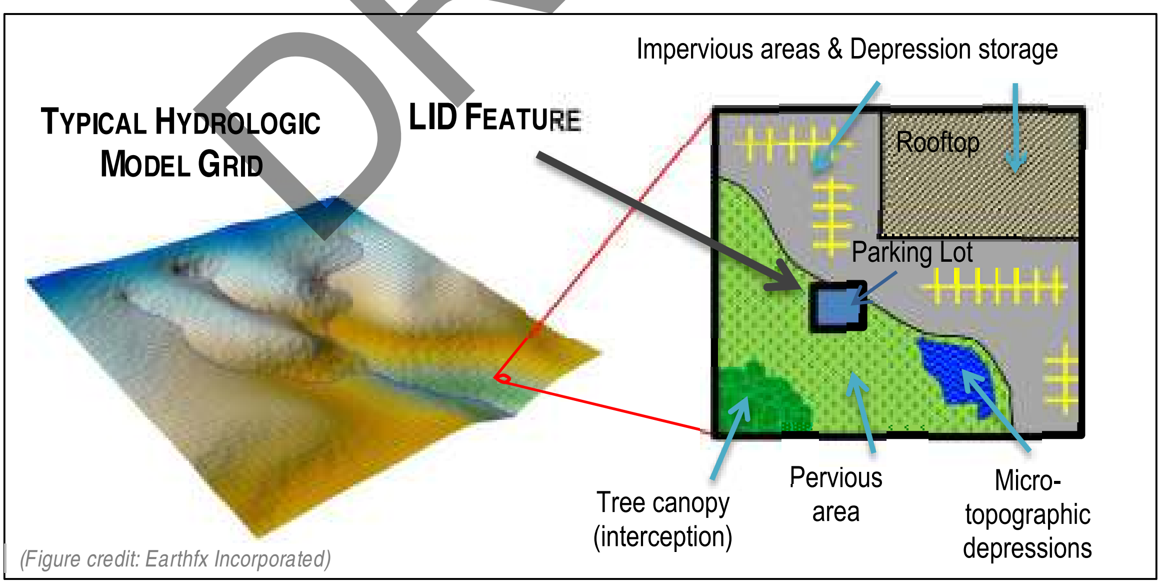


Figure 5.6: Pervious and impervious portions a typical hydrologic model cell or HRU with the integration of an LID Reservoir.

Many models represent LIDs 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 Figure 5.7 (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 5.8).

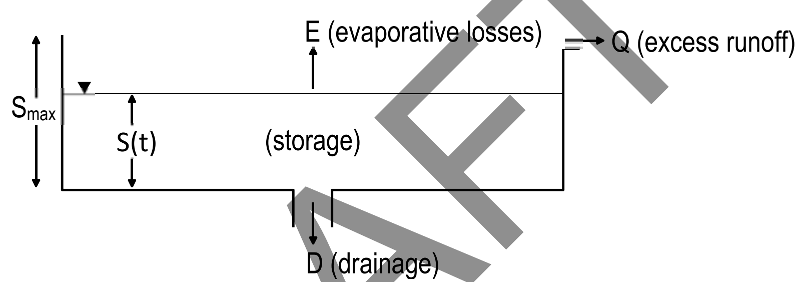


Figure 5.7: A simple numerical reservoir used to model LID functionality is applied on a grid cell-by-cell basis.

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.

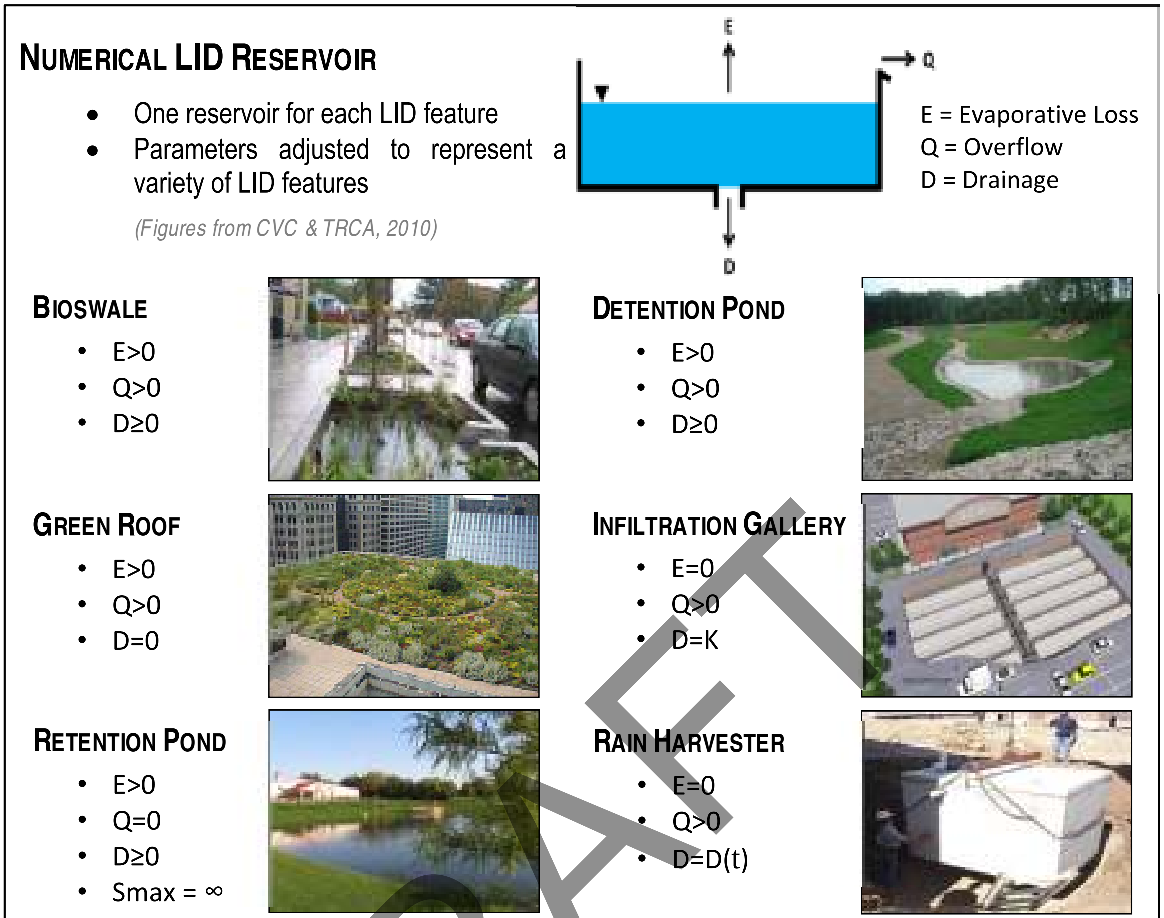


Figure 5.8: Representation of various LID features varying the numerical parameters of the LID reservoir.

5.2.3.5 Example: SWMM Modelling to Evaluate LID Performance

A case study of the USEPA SWMM model for assessing LID features 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 features 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 practices 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.

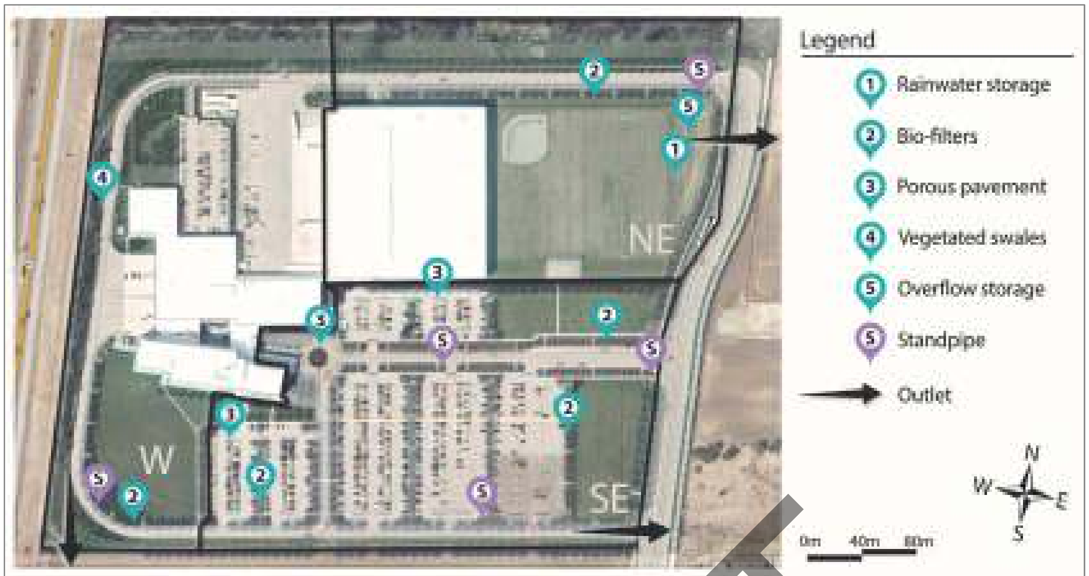


Figure 5.9: Site plan of the Honda Campus showing locations of LID features.

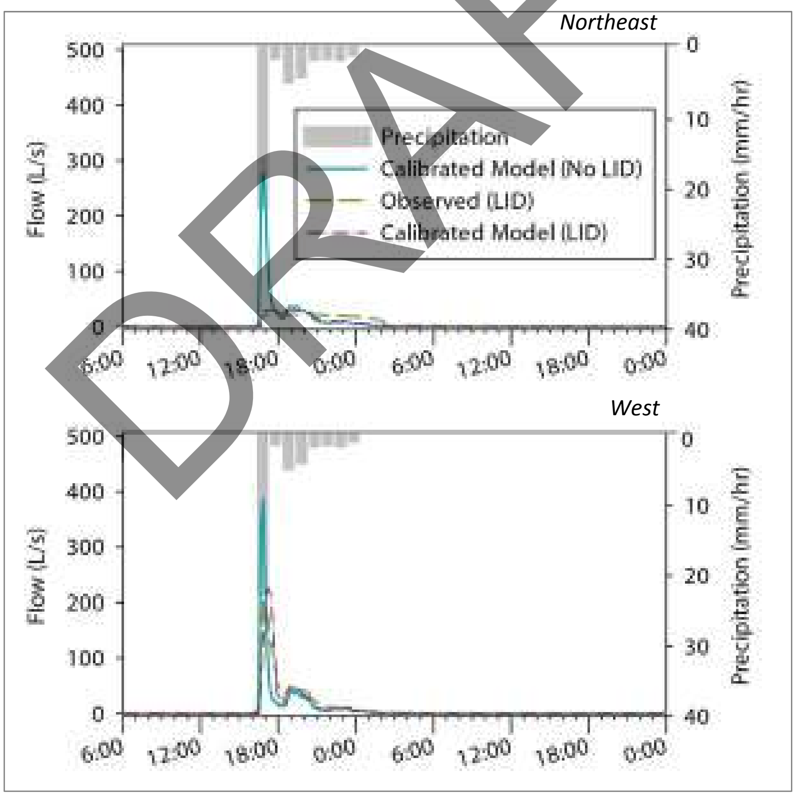


Figure 5.10: Event hydrographs showing response to a July 8-9, 2013 storm event and USEPA SWMM model simulation of LID and No LID response to a storm event.

Further details and technical discussion relating to this study can be found online at the STEP website.

5.2.3.6 Example: The Aurora Community Centre Parking Lot and Stream Bank Improvements Design

The existing parking lot of the Aurora Community Centre (Figure 5.11a) 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 features to improve both water quality and downstream erosion.

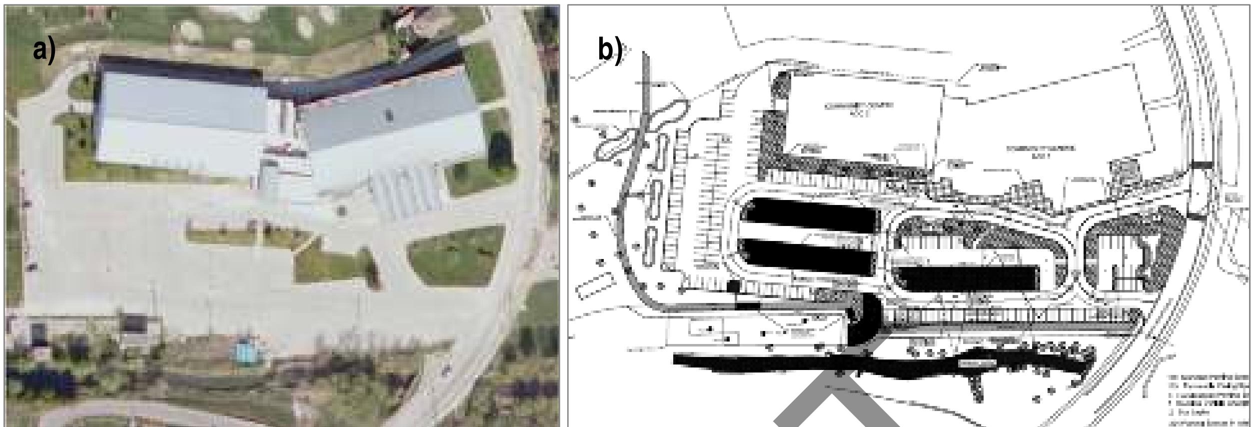


Figure 5.11: a) Existing condition of the ACC parking lot with b) the proposed stormwater management and LID measures.

The proposed stormwater management and LID measures for the ACC parking lot (Figure 5.11b) 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.

5.2.3.7 Common Model Codes

Table 5.5 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.

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.

Table 5.5: Commonly used hydrologic models in Ontario (after Conservation Ontario, 2007).

Model Name	Lumped Parameter 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

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 LIDs 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.

5.2.4 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 5.2.5**).

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 measures.

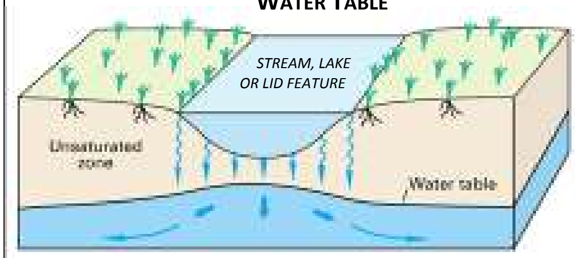
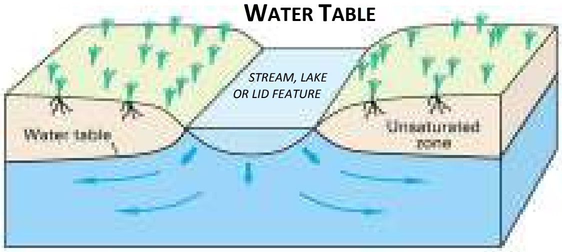
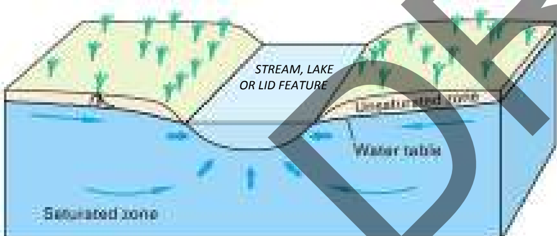
5.2.4.1 Considerations: Boundary Conditions

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 **5.6**). 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 features such as infiltration basins, stormwater detention and retention ponds, and engineered wetlands (a case study is presented in **Section 5.2.5**).

Table 5.6: 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 Features
LOOSING FEATURE DISCONNECTED FROM THE WATER TABLE  	• 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
LOOSING FEATURE IN CONTACT WITH THE WATER TABLE  	• 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 features • 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 fill range of possible seasonal hydrologic conditions

5.2.4.2 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 measures 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.

5.2.4.3 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 measures 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 LIDs" and "without LIDs" scenarios using the same estimation methodology. The groundwater model would then be run for the two scenarios. By subtracting heads for the "without LIDs" 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 LIDs" scenario from the baseline conditions, should yield smaller drawdowns if the LIDs 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 (see **Table 5.6**).

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 measures. 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.

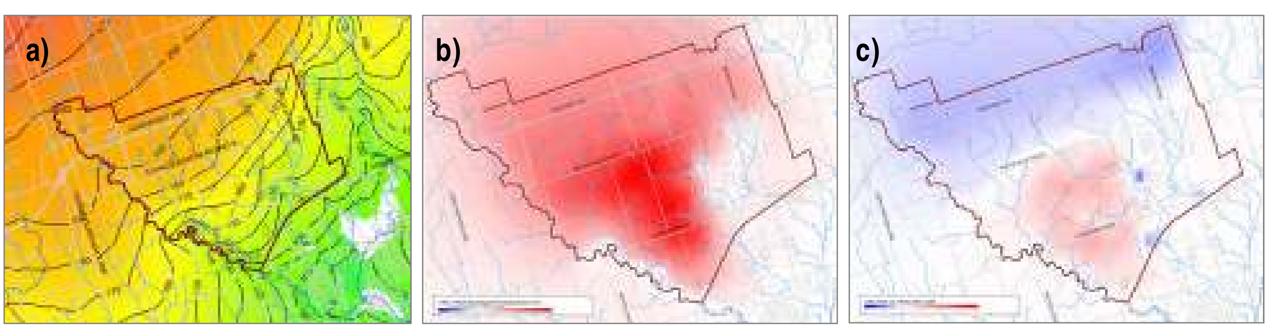


Figure 5.12: Simulated groundwater a) head in the Thorncliffe Aquifer Complex; b) drawdown due to development, and c) drawdown due to development with LID implementation.

5.2.4.4 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 5.13). A solution developed by Hantush (1967) is given as:

$$s_1(x,t) = \frac{4R\bar{H}t}{S_y}\left[-i^2erfc\left(\frac{L-x}{2\sqrt{F\cdot t}}\right) - i^2erfc\left(\frac{L+x}{2\sqrt{F\cdot t}}\right)\right] \quad \text{beneath the recharge strip}$$

$$s_2(x,t) = \frac{4R\bar{H}t}{S_y}\left[-i^2erfc\left(\frac{L+x}{2\sqrt{F\cdot t}}\right) - i^2erfc\left(\frac{x-L}{2\sqrt{F\cdot t}}\right)\right] \quad \text{outside the recharge strip}$$

$$F = \frac{K\bar{H}}{S_y}$$

Where	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

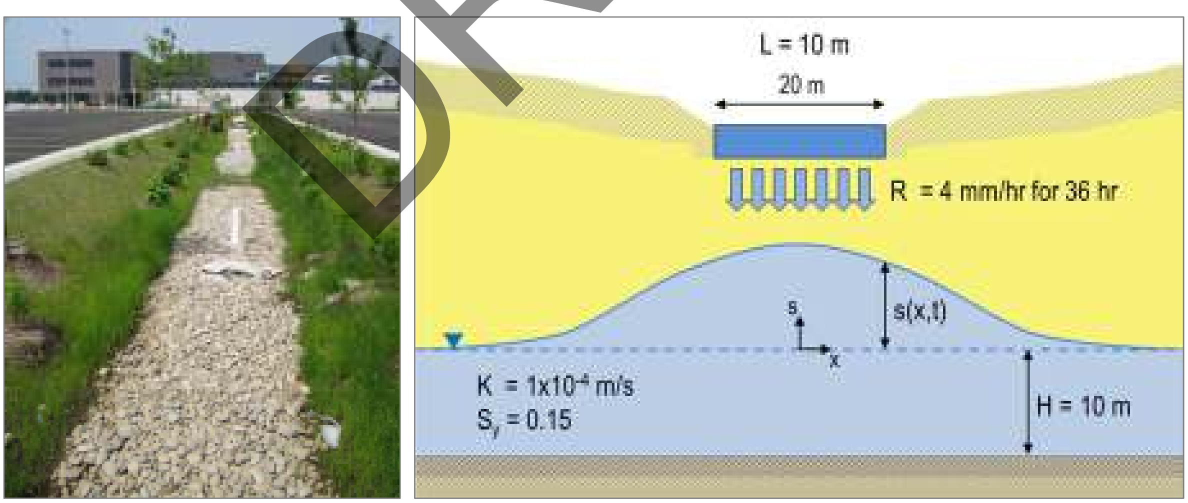


Figure 5.13: Typical bioswale (Conestoga College, Cambridge Campus. Photo credit: CVC) (left) and site sketch of the bioswale problem (right).

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. The figure below 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 (**Figure 5.13**). The bioswale is assumed to provide constant recharge at 4 mm/hr for 36 hours.

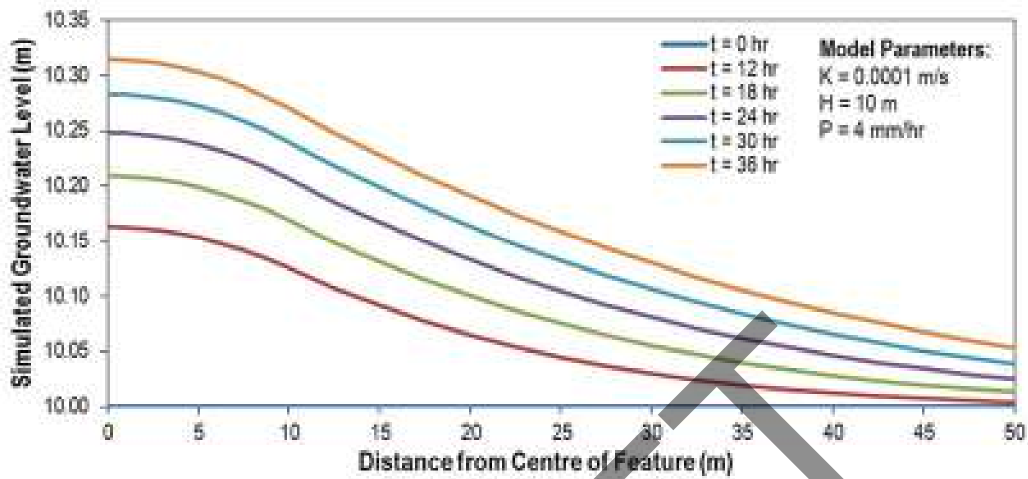


Figure 5.14: Simulated groundwater levels adjacent to a 20-m wide bioswale after 36 hrs of infiltration at 4 mm/hr based on an analytical solution by Hantush (1967).

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.

5.2.4.5 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. **Figure 5.15 (a)** shows the stream network in the Lovers, Hewitt, and Barrie Creek subwatersheds near the City of Barrie. **Figure 5.15 (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 5.15 (c)** shows the simulated groundwater levels in the same area.

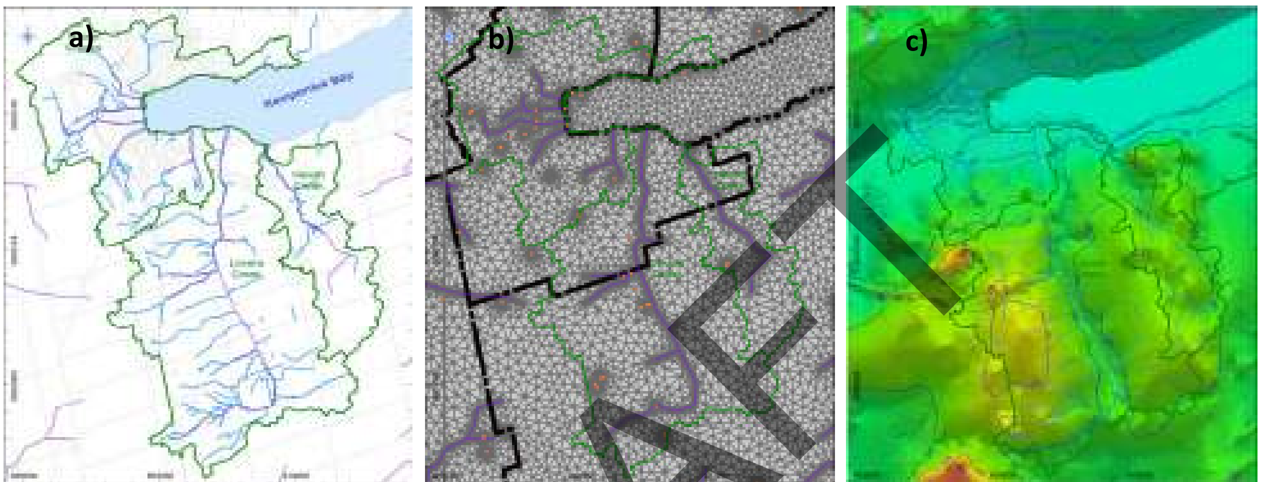


Figure 5.15: a) Watershed boundaries and stream network, b) finite-element numerical mesh, and c) simulated groundwater levels in the Lovers, Hewitt, and Barrie Creek subwatersheds which drain into Lake Simcoe, Ontario.

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.

5.2.4.6 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 5.16 (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 5.16 (b)** shows the simulated heads near the bioswale after 36 hours using a uniform time step of 0.25 hrs. **Figure 5.17** shows the simulated heads over time and the values correspond quite closely to those obtained with the analytical model **(Figure 5.14**). 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.

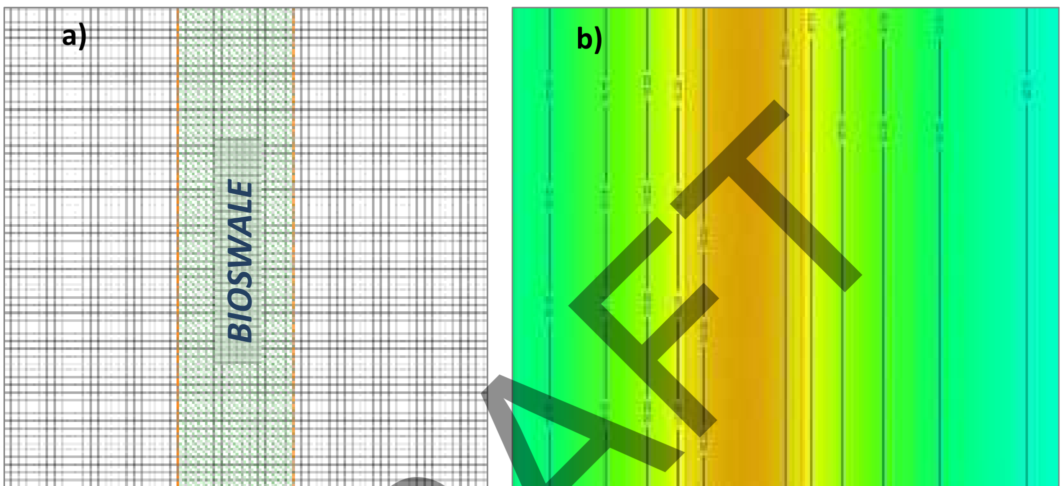


Figure 5.16: a) portion of finite-difference grid in the vicinity of the 20-m wide bioswale; and b) simulated groundwater levels at the end of 36 hrs of infiltration at 4 mm/hr with MODFLOW.

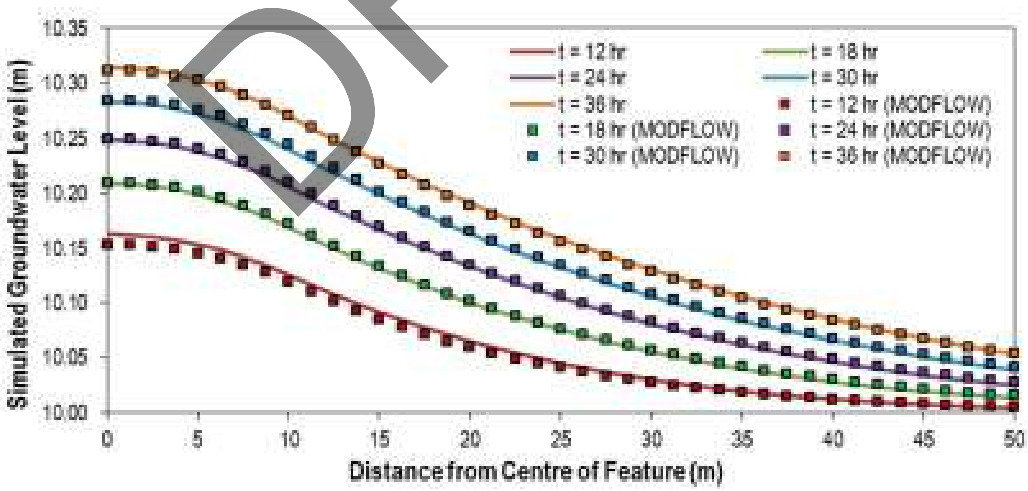


Figure 5.17: Simulated groundwater levels adjacent to a 20-m wide bioswale after 36 hrs of infiltration at 4 mm/hr based on a numerical MODFLOW model.

5.2.4.7 SOURCE WATER PROTECTION PROGRAM MODELLING RESOURCES

In response to the May 2000 Walkerton tragedy, the Ontario government enacted the Clean Water Act and began implementing a watershed-based Source Water 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 measures. Locations and extents of the groundwater models for the Tier 2 and Tier 3 Assessments are shown in **Figure 5.18**. At the time of this writing, a team of Conservation Authority, municipal, academic, private sector, and Provincial experts is developing guidance for managing the models developed under the Source Water Protection Program to help inform municipal and provincial planning for the models. In some jurisdictions, for example, the York-Peel-Durham-Toronto and the Conservation Authorities Moraine Coalition (CAMC-YPDT), guidelines have been developed for conducting future studies with the SWP models.

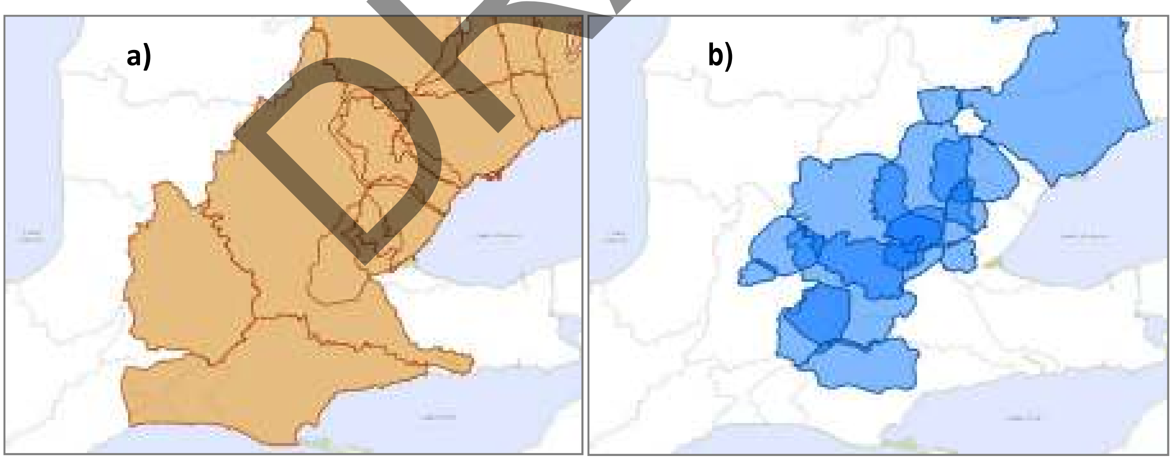


Figure 5.18: Groundwater models created for (a) Tier 2 Assessments and (b) Tier 3 Assessments under the Ontario Source Water Protection Program.

Note to the Reviewers: MNRF, in consultation with CAMC-YPDT and a private contractor, are in the process of producing a Model Management Guidance Document for the models developed under the Source Water Protection Program. We recommend the key points of the manual be included in this document when available.

It should be recognized that all numerical groundwater and hydrologic model codes have their strengths and weaknesses. The Tier 3 Source Water 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.

5.2.4.8 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 5.7: 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

5.2.5 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 LIDs 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 MNRF 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.

5.2.5.1 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.

5.2.5.2 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 Water 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.

5.2.5.3 Couple or Integrated Modelling Exercises

Integrated hydrologic models, on the other hand, attempt to consider the hydrologic, hydraulic, and groundwater flow process simultaneously (**Figure 5.19**), 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.

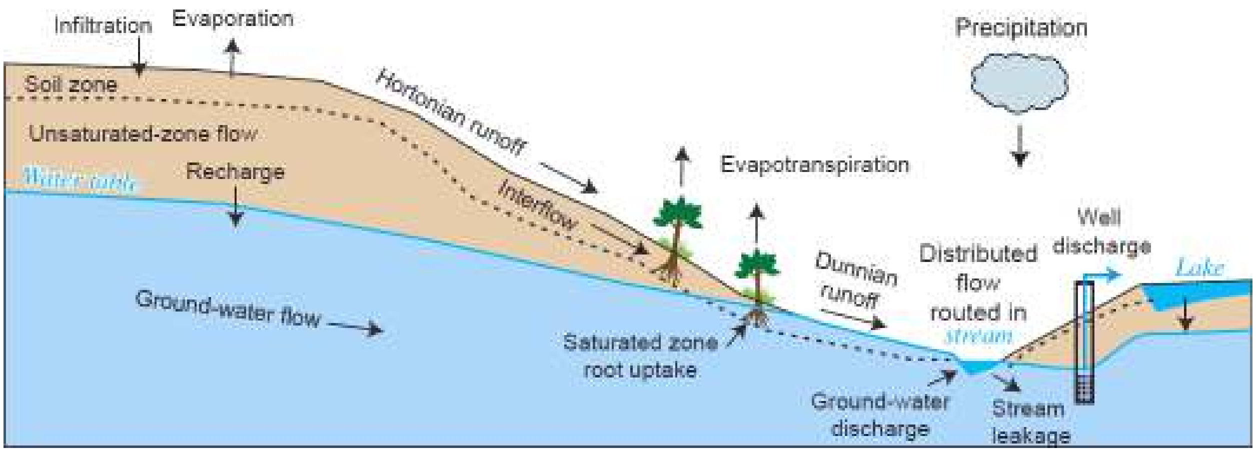


Figure 5.19: Hydrologic, hydraulic, and groundwater flow processes typically represented in an integrated model.

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.

5.2.5.4 Considerations: Complexity

Integrated models are able to 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 Water 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.

5.2.5.5 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 measures by altering land cover and percent imperviousness within each HRU (hydrologic response unit) or model cell. As noted in in **Section 5.2.3**, 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 LIDs through the addition of an in-cell LID reservoir (**Figure 5.7**) or similar scheme as was discussed in **Section 5.2.3**, . 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 measures 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 LIDs” scenario and additional changes to imperviousness, land cover, and the placement of LID measures would be input to the integrated model for simulating the “with LIDs” 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 5.2.4, subtracting heads for the “without LIDs” 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 LIDs” scenario from the baseline conditions, should yield smaller drawdowns if the LIDs 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.

5.2.5.6 Common Model Codes

There are a number of integrated modelling codes available. 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 5.20a**. 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.

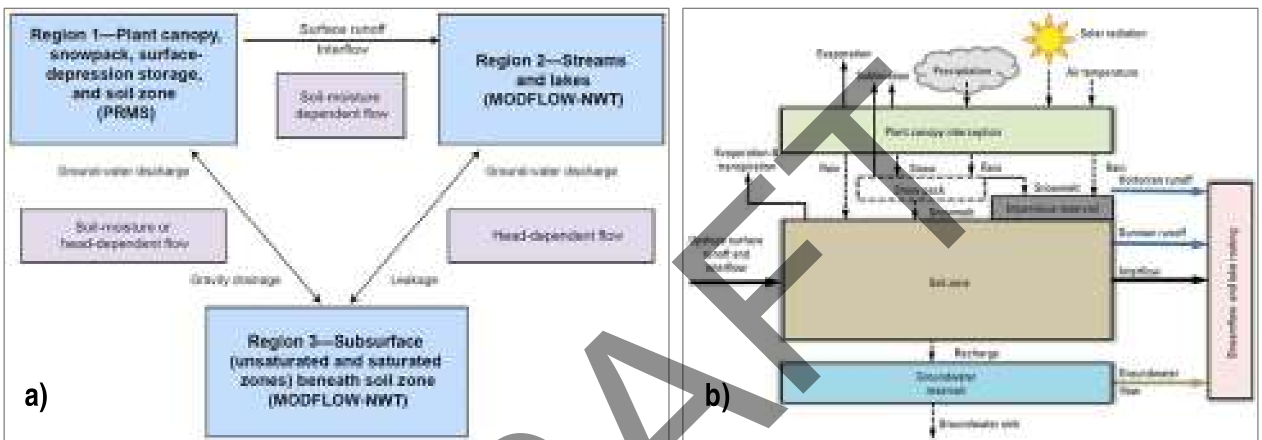


Figure 5.20: a) Interaction between the various submodels within the GSFLOW code (modified from Markstrom *et al*., 2008); and, b) hydrologic processes represented in PRMS (from Markstrom, *et al*., 2015).

PRMS processes daily climate data and then partitions it between all the storage reservoirs (e.g., canopy storage, snowpack, depression storage, soil moisture storage) and flows (e.g., evapotranspiration, overland runoff, interflow and groundwater recharge) as shown in the flow chart in Figure 5.20b. 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.

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).

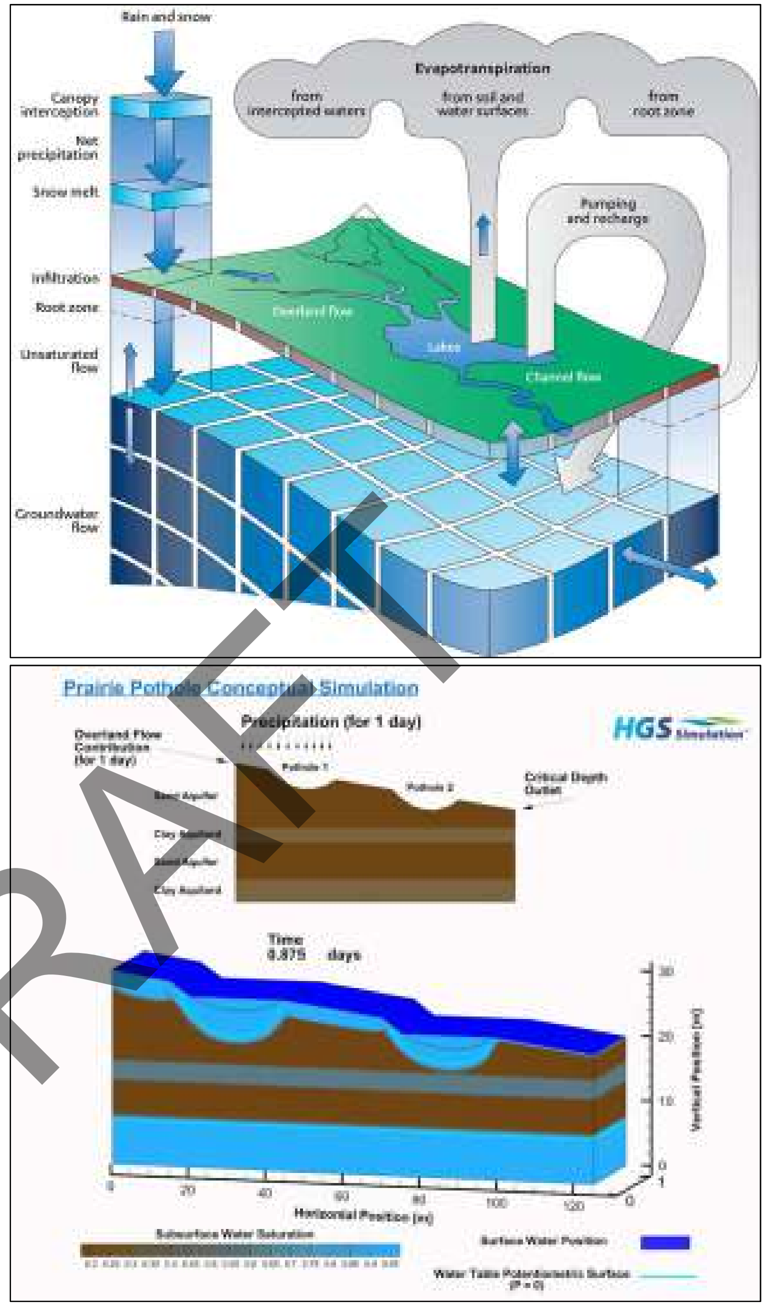


Figure 5.22: Example of a HydroGeoSphere application to simulate prairie potholes in Saskatchewan.

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.

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 5.8: 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/

5.2.5.7 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 5.35:** Surficial geology mapping (OGS, 2010) Whitemans Creek subwatershed (Earthfx, 2016).). 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.

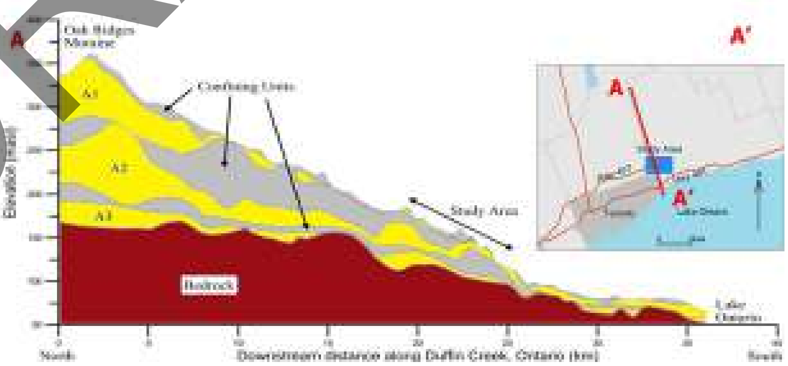


Figure 5.23: North-South hydrogeologic section through the proposed Seaton lands development.

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.

Figure 5.24: Change in simulated runoff under various development scenarios.

A loosely-coupled surface water/groundwater model was used to assess the site. A sub regional model was extracted for the Rouge River/Duffins Creek watersheds from an existing regional-scale groundwater model (Kassenaar 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 Water 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 features could be represented using simple reservoirs.

The updated groundwater and surface water models were used to simulate baseline runoff (Figure 5.24) 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.

The models were run under various development conditions and the results were compared to baseline conditions. Under the "without LIDs" 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 5.25**). Significant decreases in groundwater discharge to wetlands and streams were also predicted.

A variety of LID features were integrated into the "with LIDs" 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 LIDs" and "without LIDs" scenarios showed that the LID measures helped to reduce overall groundwater drawdowns by 86% (Figure 5.25), restored 42% of lost groundwater discharge to streams, and reduced increased runoff generation by 80%. The models were used to test other LID measures and results were provided to other members of the study team for use in improving LID design and assessing erosion. Simulated runoff volumes (Figure 5.24) were tabulated and provided to the stormwater management modelling team for simulating the SWMFs and channel hydraulics using Visual OTTHYMO.

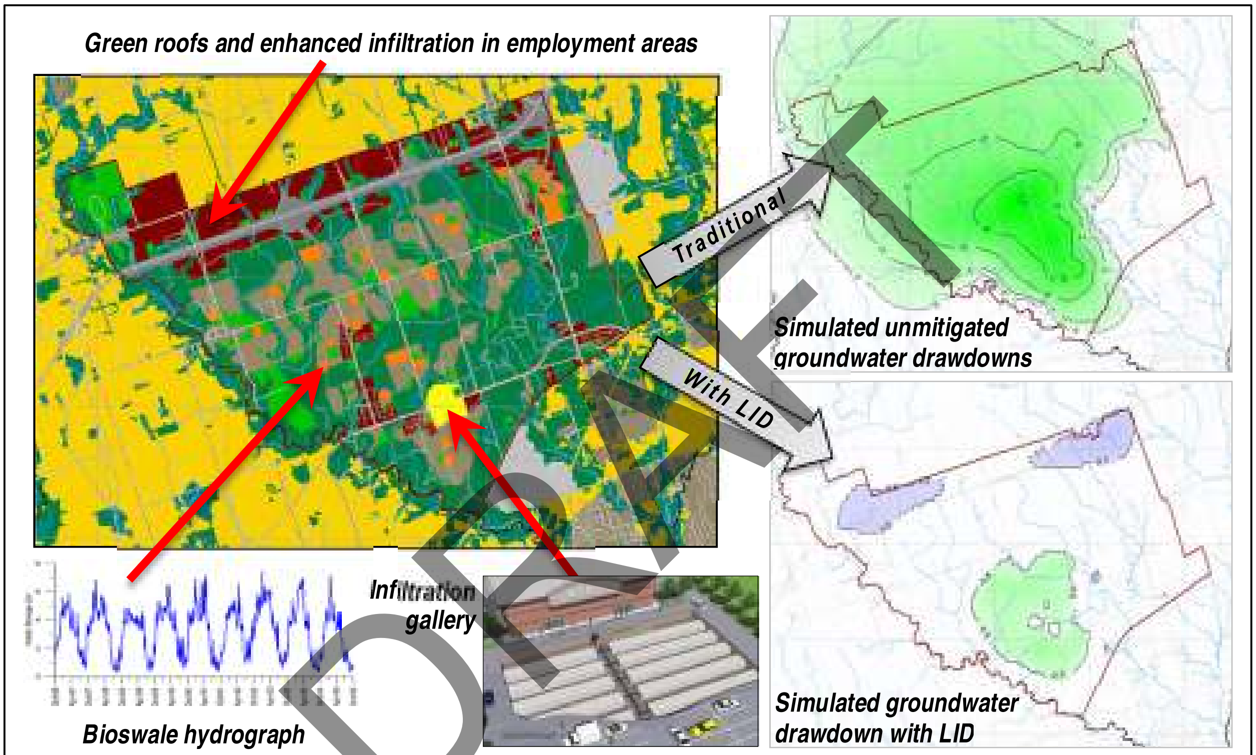


Figure 5.25: Assessment of surface water/groundwater interactions under different development scenarios (courtesy Earthfx Incorporated).

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.

5.2.5.8 Example: Integrated Analysis of the Proposed Babcock Ranch Community Development (Earthfx, 2013)

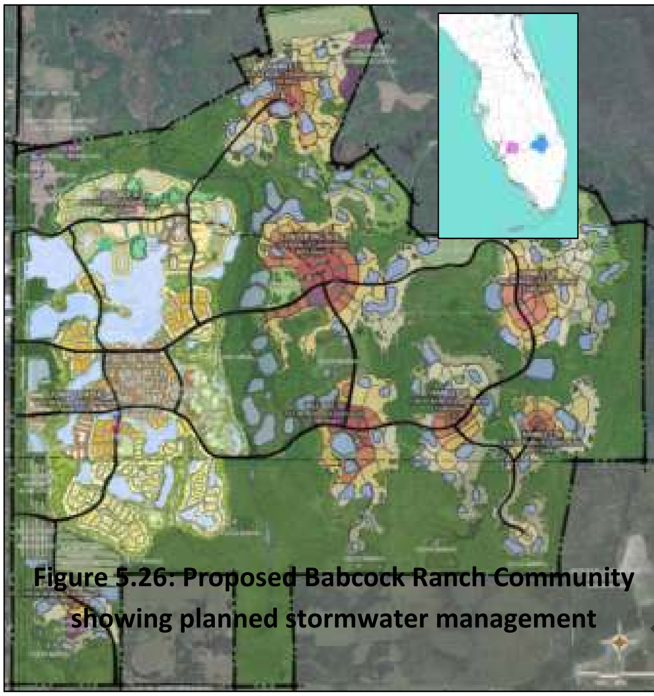


Figure 5.26: Proposed Babcock Ranch Community showing planned stormwater management

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 5.26**). 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.

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 5.27**).

Figure 5.27: Typical existing hydraulic structures incorporated into the integrated surface water/groundwater model (left, middle), and artist's rendering of planned mixed-use urban water

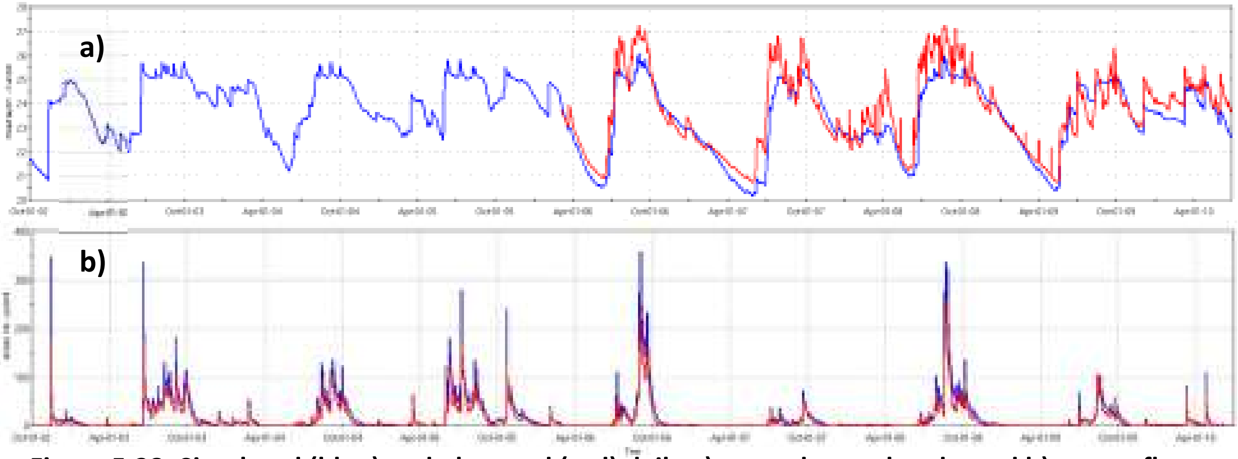


Figure 5.28: Simulated (blue) and observed (red) daily a) groundwater heads, and b) streamflow.

The calibration period (presented on Figure 5.28) 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 5.29: Increase in wetland/storm pond hydroperiod between current and post-

To represent Natural Conditions, anthropogenic features such as roads, ditches, berms and water control structures were removed from the model. For Post-development ("with LIDs") Conditions, all proposed SWM control structures, ponds and treatment marshes were added. Comparisons of simulated daily streamflow, wetland stage, and heads showed that leakage (infiltration losses) from the SWM lakes under Post-development Conditions helped mitigate changes in groundwater recharge and decreased average daily discharge during storm events (**Figure 5.30**). The final design also moderated wetland hydroperiods (**Figure 5.29)** within the natural features in the BRC as compared to the

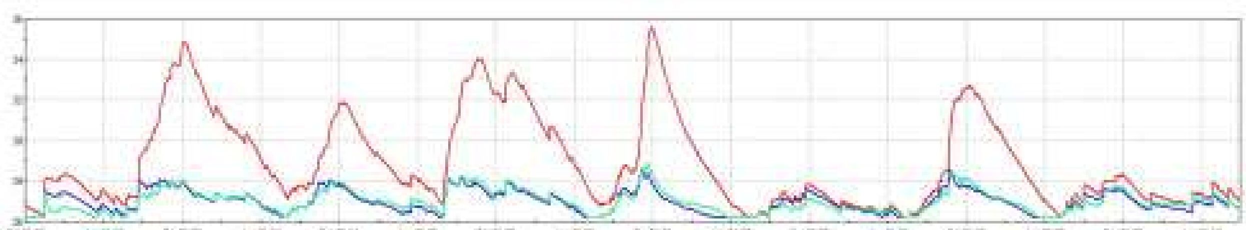


Figure 5.30: Simulated wetland stage under current (red), natural (green), and post-development conditions (blue). Offsite runoff is reduced in the post-development scenario returning this feature to a

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 SWM 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 small-scale developments, retrofits, redevelopments, or infill-developments that have a lower potential for affecting the water balance, Class C or D models would likely be unwarranted. An exception to this would be subwatershed scale stormwater management retrofits employing a range of LID measures 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 LIDs 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

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 municipal or county agencies. 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 LIDs and other mitigation measures, and (3) demonstrate their effectiveness. 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.

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 measures 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 measures. For example, in one proposed development with 19,500 homes (see the Babcock Range Integrated Model Example in **Section 5.2.5**), 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 measures may require a more complex approach. A development with a significant reliance on LID measures 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 SWM 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 SWM 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 measures. 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 measures. 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. As discussed in **Section 5.3.6**, 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 LIDs 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 LIDs. 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 5.31**) and tabulated values (e.g., Saxton and Rawls, 2006).

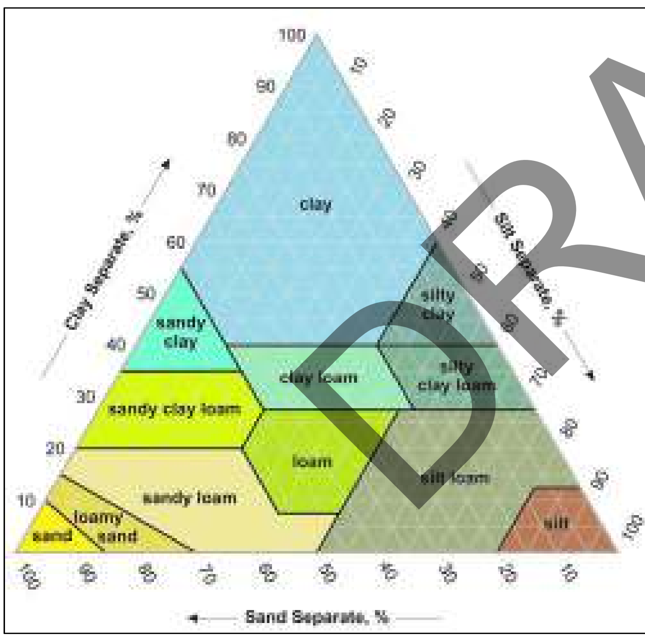


Figure 5.31: Soil classification system.

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 5.32**), double ring infiltrometer, single ring infiltrometer, and or a Philip-Dunn infiltrometer to determine the in-situ saturated hydraulic conductivity. Site testing of infiltration rates as per the LID Stormwater Planning and Design Guide Version 1.0 (TRCA/CVC 2010), Appendix C at the likely interface of the proposed infiltration based facility with the native soils is recommended during detailed design of LID features.

Testing should be performed within the approximate location and invert of proposed LID features. 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 (Version 1.0, Appendix C (TRCA/CVC 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.

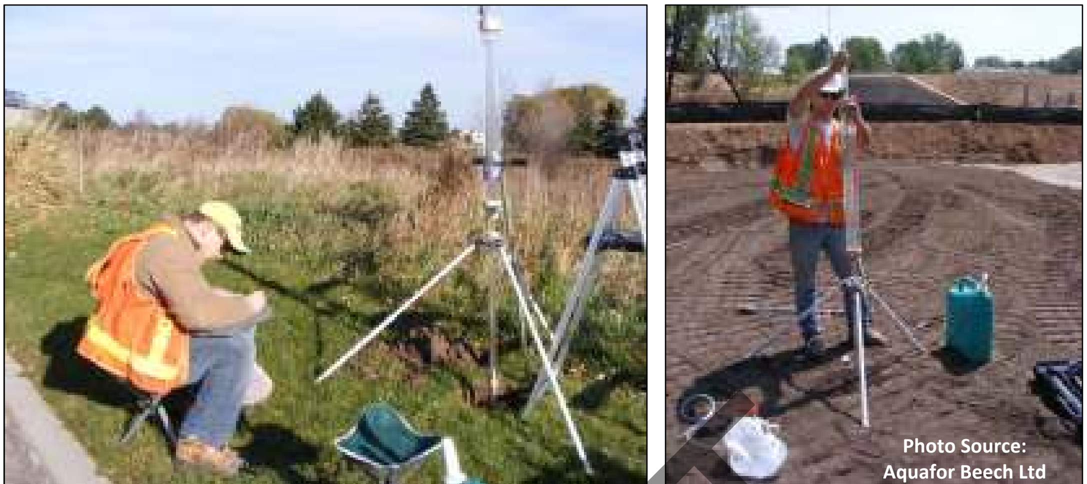


Figure 5.32: Infiltration testing conducted during IMAX Parking Lot Reconstruction Project - Mississauga(left) and Upper Middle Road Bioretention Project – Halton Region (right).

Infiltration testing is also typically combined with monitoring wells or shallow piezometers, typically consisting of 50mm 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 (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, and 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 agency;
- 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 following section presents a modelling selection framework that 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 Section 5.3, 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 SWM 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 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.

5.4.1 Using the Model Selection Framework

The Model Selection Framework is intended to guide the selection of a defensible modelling strategy. A blank framework table is presented in **Section 5.4.2**. 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.**

5.4.1.1 To Scope a Future Modelling Approach

For a practitioner planning to scope a future modelling study, the use of the Model Selection Framework table (**Section 5.4.2**) is described in the following steps:

1. Copy the value from the *Recommended 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 recommended 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 collect 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 recommended approach, be prepared to *justify* this decision.

5.4.1.2 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 (**Section 5.4.2**) 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. *Recommend 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 measures 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?

5.4.1.3 Disagreement between the Recommended and Proposed Level of Modelling Effort

In case of disagreement between the recommended 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 measures. 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. Dogmatic adherence to the framework defeats the intent of the framework: *to recommend an appropriate and rational level of scientific and engineering effort to assess the impacts of a proposed urban development*.

5.4.1.4 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.

5.4.2 Model Selection Rationale Checklist

SITE FACTOR	RATIONALE	DETAILED CONSIDERATIONS	NOTES	RECOMMEND 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		
		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	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 measures 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 measures is more complex and requires more sophisticated models. Proposed stormwater sewer system and non-LID SWM 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 LIDs, mostly large scale, isolated components	B/C		
		Widespread, distributed infiltration and storage	Complex management plan, with many, distributed LID features	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, 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		
		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 LIDs must be evaluated	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 measures.*	Thick (>5-8m), highly permeable soils (gravel to medium sand) at surface	High capacity to accept additional infiltration/recharge	A/B		

SITE FACTOR	RATIONALE	DETAILED CONSIDERATIONS	NOTES	RECOMMEND CLASS OF MODELLING EFFORT	(PROPOSED) CLASS OF MODELLING EFFORT (A/B/C/D)	JUSTIFICATION REQUIRED? (Y/N)
	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)*	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		

5.4.3 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 (introduced in **Section 5.2.5**). A completed selection table is presented as **Table 5.9**, 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 Water 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 measures 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 SWM Plan considered a large number (69) end-of-pipe SWMF along with other control measures. As well, LID measures 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 measures. 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 was 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 measures. 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 measures. Assessment of the effectiveness of infiltration-based LID measures 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 features.

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 5.9: Example Model Evaluation Exercise - Seaton Lands MESP.

SITE FACTOR	RATIONALE	DETAILED CONSIDERATIONS	NOTES	RECOMMEND 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 measures 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 measures is more complex and requires more sophisticated models. Proposed stormwater sewer system and non-LID SWM 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 LIDs, mostly large scale, isolated components	B/C		
		Widespread, distributed infiltration and storage	Complex management plan, with many, distributed LID features	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		
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 LIDs must be evaluated	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 measures.*	Thick (>5-8m), highly permeable soils (gravel to medium sand) at surface	High capacity to accept additional infiltration/recharge	A/B	B & D	No

SITE FACTOR	RATIONALE	DETAILED CONSIDERATIONS	NOTES	RECOMMEND CLASS OF MODELLING EFFORT	(PROPOSED) CLASS OF MODELLING EFFORT (A/B/C/D)	JUSTIFICATION REQUIRED? (Y/N)
	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)*	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**	

5.4.4 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 measures 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 measures across the site. Proposed LID features 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 features.

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 measures.

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 5.10**.

Table 5.10: Example Model Evaluation Exercise - Wateridge Village Subdivision LID Design – Phase 1A

SITE FACTOR	RATIONALE	DETAILED CONSIDERATIONS	NOTES	RECOMMEND 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 measures 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 measures is more complex and requires more sophisticated models. Proposed stormwater sewer system and non-LID SWM 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 LIDs, mostly large scale, isolated components	B/C		
		Widespread, distributed infiltration and storage	Complex management plan, with many, distributed LID features	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		
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 LIDs must be evaluated	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 measures.*	Thick (>5-8m), highly permeable soils (gravel to medium sand) at surface	High capacity to accept additional infiltration/recharge	A/B		

SITE FACTOR	RATIONALE	DETAILED CONSIDERATIONS	NOTES	RECOMMEND CLASS OF MODELLING EFFORT	(PROPOSED) CLASS OF MODELLING EFFORT (A/B/C/D)	JUSTIFICATION REQUIRED? (Y/N)
	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)*	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		Yes (See Text)
		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***	

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 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 reader is also advised to consult the documentation for the model code selected and various texts on model development, calibration, and application (discussed in **Section 5.5.10**).

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 agency. Before undertaking any modelling study, it is advisable to pre-consult with the regulator to ensure the planned technical approach is aligned with the regulators expectations.

5.5.1 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 measures. 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.

5.5.2 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 5.6** 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.

5.5.3 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.

5.5.4 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 5.5.2**) 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 5.2.3**) 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.

5.5.5 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.

5.5.6 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 5.11** provides a summary of the typical datasets available by model class which can be employed during calibration.

Table 5.11: 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 5.33** provides several examples of streamflow and groundwater levels plots.

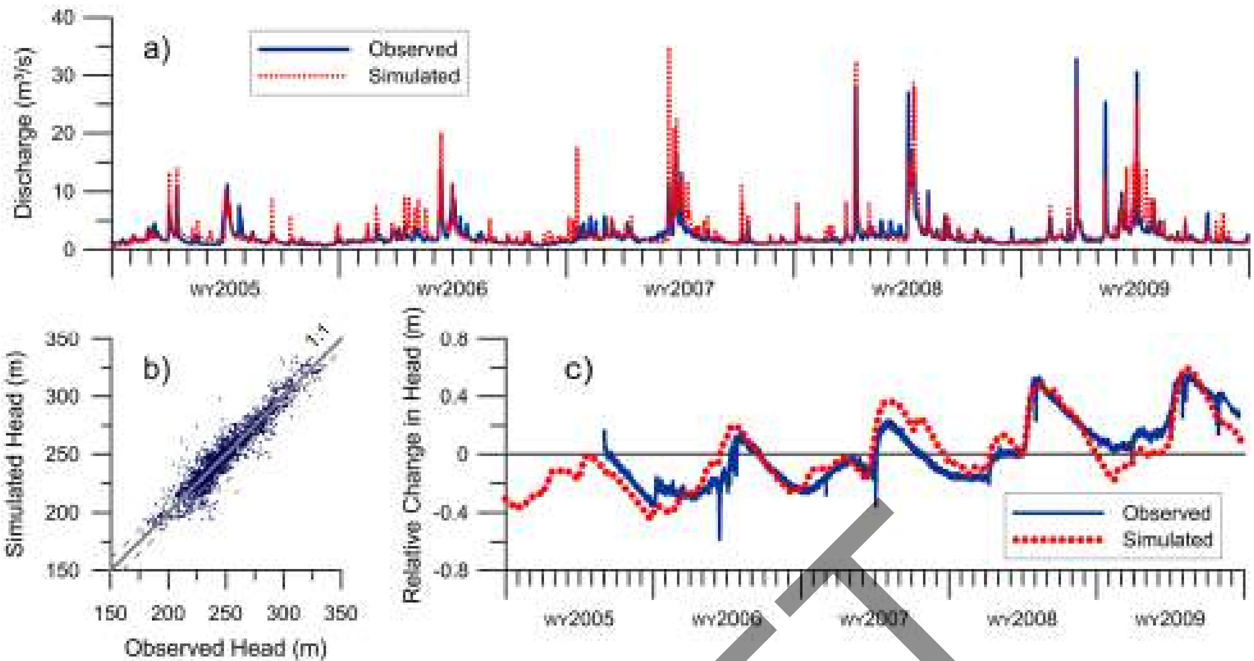


Figure 5.33: Typical model calibration plots. a. Simulated and observed streamflow, b. Scatter plot of simulated versus observed groundwater heads, c. Simulated and observed heads at a transient monitoring well (Marchildon *et al.*, 2015).

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 models performance. By comparing the simulated outputs against the measured observed dataset, the goodness-of-fit or accuracy of the model can be tested. **Table 5.12** 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, percent bias, and Nash-Sutcliffe Efficiencies (Table 5.12). 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 5.12: 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	$\text{PBIAS} = \frac{\sum(Q_s - Q_o)}{\sum Q_o}\times 100$	0
Nash-Sutcliffe Efficiency	$\text{NSE} = 1 - \frac{\sum(Q_o - Q_s)^2}{\sum(Q_o - \overline{Q_o})^2}$	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 5.12** 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 percent 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.

5.5.6.1 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 5.12**).

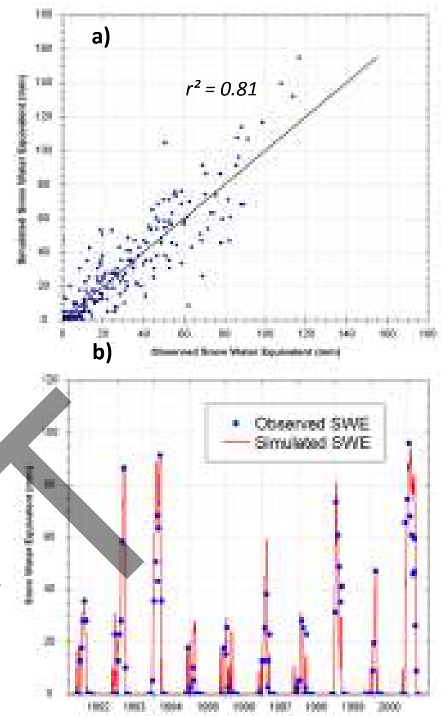


Figure 5.34: Simulated snowpack water equivalencies versus field observations; a) scatter plot, b) time series. (Earthfx, 2016)

5.5.6.2 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.

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 TSS 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 5.12**).

5.5.6.3 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:

1. Estimate all model parameters, including land use-specific accumulation and depletion/removal rates, wash-off rates, and sub-surface concentrations.
2. 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.
3. Calibrate to in-stream water temperature.
4. Compare simulated and observed in-stream concentrations at each of the calibration stations.
5. Compare annual nonpoint source loading rates with expected values presented in available literature.
6. Analyze the results of comparisons in Steps 3, 4, and 5 to determine appropriate instream and/or nonpoint source parameter adjustments.

5.5.6.4 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 5.33b.** 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 5.33c.** Common performance measures for groundwater models include mean error, absolute mean error, and root mean squared error (**Table 5.12**).

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.)

5.5.6.5 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.

5.5.6.6 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.

5.5.7 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.

5.5.8 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 5.5.3**). 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 measures. LID features 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.

5.5.9 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 regulators 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):

1. A description of the purpose and scope of the model application.
2. Identification of the model selected to perform the task, its applicability and limitations.
3. A discussion of the modelling approach.
4. 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.
5. A description of the model construction, verification, calibration, and validation processes.
6. A discussion of model limitations.
7. A description of the post-development design scenarios being simulated and any other changes made to the baseline model.
8. A discussion of model parameter sensitivity and uncertainty addressed to anyone that will use model results.
9. A presentation of the simulation results and their interpretation, recommendations and conclusions.

A modelling report should discuss the model verification (**Section 5.5.5**), model calibration (**Section 5.5.6**), and model validation (**Section 5.5.7**) 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 for the reader. 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.

5.5.10 Further Reading

The preceding chapter has provided a basic overview of a very complex and challenging topic. The following references are provided for readers seeking 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.
Guidance on the development, evaluation, and application of environmental models 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.
BMP Modeling Concepts and Simulation 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.
Water Budget Overview Conservation Ontario, 2010. Integrated Watershed Management – Navigating Ontario's Future, A Water Budget Overview for Ontario, 36 p.
Australian groundwater modelling guidelines 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 Anderson, M.P. and Woessner,W.M., 2002, Applied groundwater modeling – Simulation of flow and advective transport:, Academic Press, San Diego, CA, 381 p.
Integrated Surface and Groundwater Model Review and Technical Guide AquaResource Inc., 2011. Integrated Surface and Groundwater Model Review and Technical Guide: prepared for the Ontario Ministry of Natural Resources, 116 p.

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 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.

5.6.1 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 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 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.

5.6.2 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 scare 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.

5.6.3 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 CAs 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.

5.6.4 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 Natural Resources and Forestry (MNRF). 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.

5.6.5 Stream Network, Lake, Pond, and Wetland Mapping Products

The Water Resources Information Program (WRIP) operating with MNRF 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.

5.6.6 Soils or Surficial Geology Data

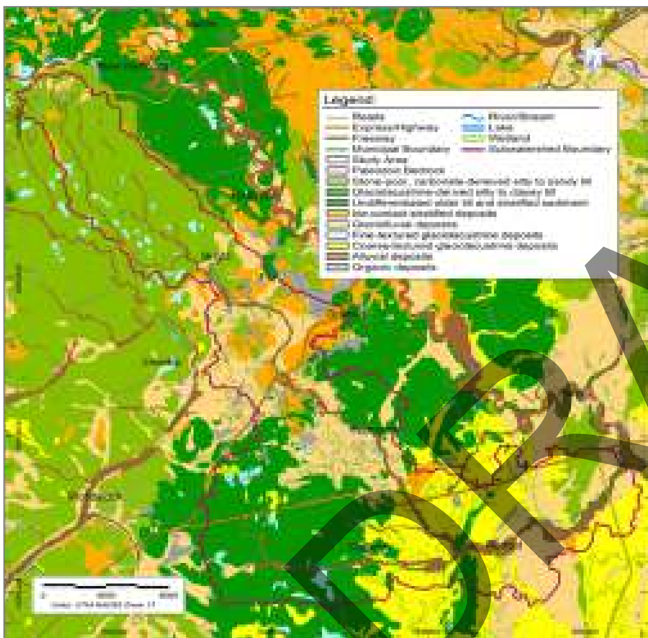


Figure 5.35: Surficial geology mapping (OGS, 2010) Whitemans Creek subwatershed (Earthfx, 2016).

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). 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.

5.6.7 Land Coverage Data

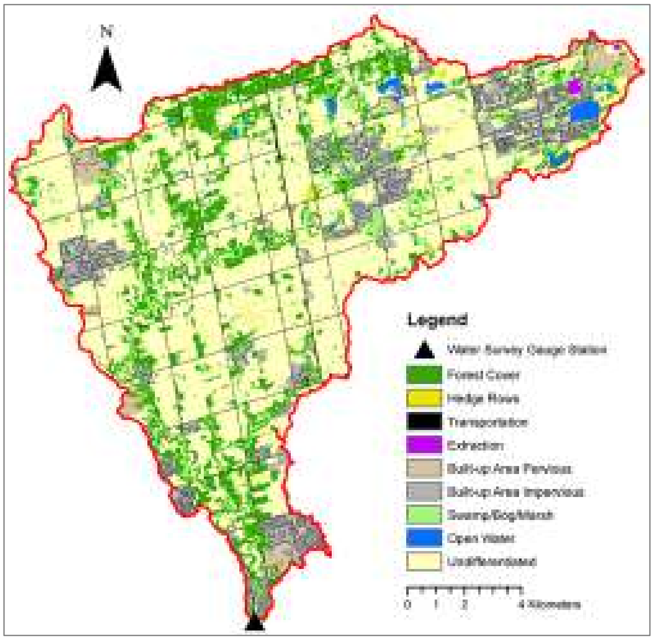


Figure 5.36: Land coverage mapping of the East Humber River subwatershed derived from SOLRIS (v1.2) (Thompson, 2013).

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 for most of southern Ontario is included in the Southern Ontario Land Resource Information System (SOLRIS v2) mapping compiled by MNRF (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.

Detailed mapping and classification of the land cover of northern Ontario was recently completed by MNRF (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.

5.6.8 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 MOECC 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.

5.6.9 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 5.13: 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 Canada and some 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 Canada and some CAs
		Hourly	
	Solar Radiation	Hourly	Environment Canada (Historical Only); some CAs, Universities and Research Institutions
	Pan Evaporation	Hourly	
	Other	Wind Speed	Environment 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 EC Climate stations and CAs

Table 5.14: 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	MOECC 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 MOECC 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	MOECC Static Water Level Data	Single measurements at time of construction, QA/QC issues, good spatial coverage
	MOECC 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 5.15: 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* (OMNRF), 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*, CAs 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 Features	Surface Characteristics	Dimensions Outflow Rates	Design specifications
	Subsurface Characteristics	Dimensions Infiltration rate LID feature into surrounding soils.	MOECC 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.

6 Climate Change

Along with land use changes resulting from population growth and aging infrastructure, climate change is an additional factor that must be considered by stormwater practitioners in Ontario. 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 $1.03 Billion in the Greater Toronto Area alone (Insurance Bureau of Canada, 2016). This was the most expensive natural disaster in Ontario history.

Climate is directly related to stormwater management. Changes in rainfall 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 managers, 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 are also likely to increase. As a means of providing greater resiliency to climate change, green infrastructure (GI) and low impact development (LID) BMPs 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 using historical climate data may not perform as expected under future climatic conditions.

The following information is presented in this chapter to provide guidance with respect to climate change and stormwater management in Ontario:

- **Section 6.1**: Overview of climate change
- **Section 6.2**: Observed global climate change parameters
- **Section 6.**3: Observed climate change parameters in Ontario and identifies potential impacts
- **Section 6.4**: Overview of Ontario's Adaptation Strategy and Action Plan
- **Section 6.5**: Roles and responsibilities of municipalities in climate change adaptation planning
- **Section 6.6**: Need for assessing the impacts of climate change on development planning and design at the site and municipal scale
- **Section 6.7**: Modelling approaches for assessing climate change in an urban context including models that can be adopted to assess the effects of future climate on stormwater management infrastructure
- **Section 6.8**: A 4-step climate change adaptation process and how LIDs can build climate change resiliency
- **Section 6.9**: Existing planning tools that can be used for climate change adaptation

6.1 Definition of 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 (Ontario Climate Change Strategy, 2015). Weather patterns are highly variable and therefore climate can appear to be changing depending on the time scale selected for averaging. Climate change, however, refers to a consistent, observable trend in the long-term average values. For example, an average increase of 0.05°C per year in the annual average temperature over the last 100 years would be an indicator climate change. Climate change could also be reflected in a long-term increase in the frequency or severity of extreme weather events. For example, if a 100-millimeter rainfall event 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 historic observations further back in time.

6.2 Global Climate Change

The Fifth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) concluded that "warming in the climate system is unequivocal, with many of the observed changes unprecedented over decades to millennia: warming of the atmosphere and the ocean, diminishing snow and ice, rising sea levels and increasing concentrations of greenhouse gases. Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850" (IPCC, 2013). Global average annual surface temperature increased 0.74°C between 1906 and 2005 (IPCC, 2007c). Also, temperatures over land areas have warmed at a faster rate than over oceans (IPCC, 2007b). Precipitation increased 0.5-1% per decade in the 20th century over most land areas in the Northern Hemisphere. Some observed global changes in climate relevant to water resources are summarized in **Table 6.1**.

Table 6.1: Observed changes in global climate relevant to water resources (from Bates et al., 2008, IPCC, 2001b, and Solomon et al., 2007) (from EBNFLO Environmental and AquaResource Inc., 2010).

Observed Changes in Global Climate	
Increase in the number, frequency and intensity of heavy precipitation events, even in areas where total precipitation has decreased.	Decrease in snow cover in most areas of the cryosphere, especially during the spring and summer months
Reductions (approximately two weeks) in the annual duration of lake and river ice cover in the mid and high latitudes of the Northern Hemisphere.	Increase in actual ET from 1950 to 2000 over most dry regions (greater availability of water on or near land surface from increased precipitation and larger atmospheric capacity for water vapour due to higher temperature).
Increase in annual runoff in high latitudes	Altered river flow in regions where winter precipitation falls as snow; more winter precipitation falling as rain.
Higher water temperatures in lakes	Earlier snowmelt, due to warmer temperatures.
Fewer numbers of frost days, cold days, cold nights and more frequent hot days and hot nights.	Decrease in diurnal temperature range (0.07°C per decade) between 1950 and 2004 but little change from 1979 to 2004 as maximum and minimum temperatures increase at same rate

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. Projections indicate that by 2050, the average annual temperature in Ontario will increase by between 2.5 °C and 3.7 °C (MOECC, 2014). This is on top of a 1.4 ° C increase that has already occurred between 1948 and 2008. 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*". 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)

The Climate Ready document (2014) outlines several ways that climate change will impact Ontarians. The impacts that are directly related to stormwater management are discussed below.

Impacts on Infrastructure and Private Property

Existing stormwater infrastructure including storm sewers and stormwater management facilities have been designed with the assumption that rainfall will maintain historically observed patterns relating to annual distribution, intensity, duration and frequency. 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 being overwhelmed and surcharging causing urban flooding and damage to property. 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 have could 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.

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 at the watershed scale must be considered. Forests, which function as important habitat for a diverse range of flora and fauna, are susceptible to climate change. Changes in moisture and temperature will have an impact on the frequency and severity of fires, drought and severe storms that can damage forests. It is likely that the composition of Ontario's forests will be altered in response to these changes (Williamson et al, 2009).

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 resulting from algal blooms, these fish will lose habitat to warm water species that are better adapted to these conditions.

Local climate change in Ontario includes some of the effects summarized in **Table 6.2**. Predictions of future changes in Ontario climate are based on global circulation model (GCM) simulations. Over 30 different GCM-scenario combinations indicate that total annual precipitation could increase by 2 to 6%, while temperatures could increase by 2 to 4ºC by the 2050s over the Great Lakes Basin (Bruce et al., 2003). 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). Heat waves and drought may become more frequent and longer lasting.

Table 6.2: Observed changes in Ontario Climate (from EBNFLO Env. and AquaResource Inc., 2010).

Observed Changes in Ontario Climate	
Annual average air temperatures across the province increased from 0 to 1.4°C; the greatest warming occurred in the spring for the period 1948 to 2006, (Lemmen et al., 2008).	The number of warm days and night-time winter temperatures increased between 1951 and 2003 (Bruce et al., 2006a).
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).	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).
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 number of strong cyclones increased significantly across the Great Lakes over the period 1900 to 1990 (Angel and Isard, 1998).
Heavier, more frequent and intense rainfall events have been detected in the Great Lakes Basin since the 1970s.	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).
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).	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).
An increase in lake-effect snow has been recorded since 1915 (Burnett et al., 2003).	

6.4 Ontario's Adaptation Strategy and Action Plan

Ontario's Adaptation Strategy and Action Plan was outlined in the *Climate Ready* document in 2014. *Climate Ready* outlined a clear vision for the province with respect to climate change mitigation and adaptation, specifically:

> *"A province prepared for the impacts of a changing climate through implementation of policies and programs that minimize risks to our health and safety, the environment and the economy, and maximizes the benefits from opportunities which may arise."*

In order to achieve this vision, the *Climate Ready* document outlines five (5) goals, these are:

1. Avoid loss and unsustainable investment, and take advantage of economic opportunities;
2. Take reasonable and practical measures to increase climate resilience of ecosystems;
3. Create and share risk-management tools to support adaptation efforts across the province;
4. Achieve a better understanding of future climate change impacts across the province; and
5. Seek opportunities to collaborate with others.

The vision and goals as identified in the Climate Ready document are illustrated along with 37 identified actions in **Figure 6.1**.

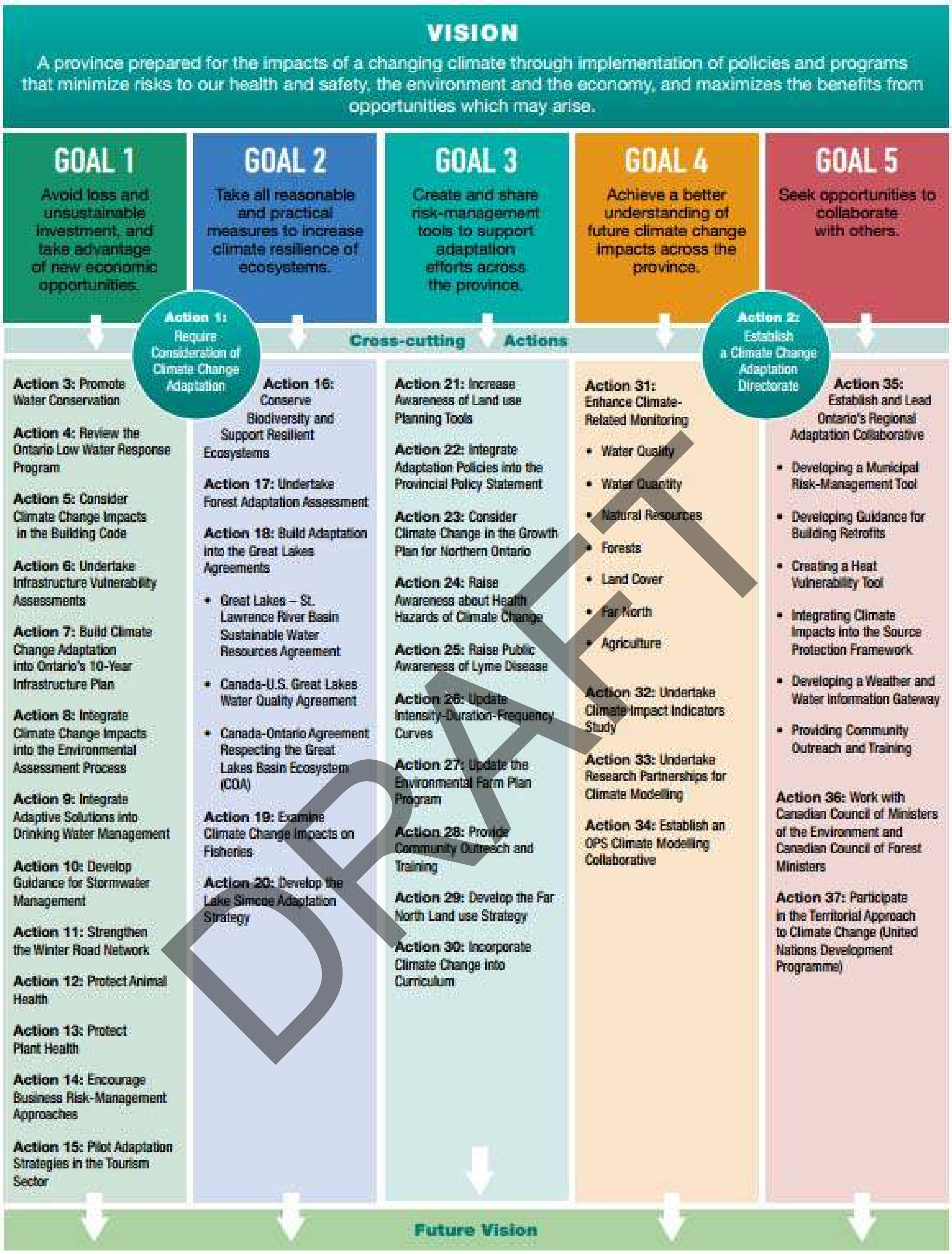


Figure 6.1: Ontario's Adaptation Strategy and Adaptation Plan Vison and Goals (Pg. 21 of Climate Ready, 2014).

Implementation principles are also outlined in the *Climate Ready* document to assist in achieving the goals, these include:

- 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, taking into account the effect of decisions on current and future generations.

For the purpose of this manual, it is important to define both mitigation and adaptation in the context of climate change. *Consideration of Climate Change in Environmental Assessment in Ontario* (MOECC, Draft-August 2016) defines the terms both **Climate Change Mitigation** and **Climate Change Adaptation**.

Climate Change Mitigation
The use of measures or actions to avoid or reduce greenhouse gas emissions, to avoid or reduce effects 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 effects. 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 and its effects.

Climate Change Co-Benefits
Many technologies including GI and LID achieve some level of both climate change mitigation and climate change adaptation. These are known as "climate co-benefits". A report submitted to the MOE in 2009 titled *Adapting to Climate Change in Ontario* by the Expert Panel on Climate Change Adaptation presented a strategy on how to build a climate resilient province. This report noted that:

> *"Where possible and appropriate, every policy and practice of government, the private sector and civil society should be reshaped and redesigned to achieve three objectives (Expert Panel on Climate Change Adaptation, 2009):*
>
> 1) *The maximum reduction in GHG emissions*
> 2) *The greatest possible reduction in vulnerability through adaptation and climate-resilient development, and*
> 3) *The integration and harmonization of these first two objectives with each other and with other policies such that the* ***joint benefits or co-benefits*** *of actions are maximized"*

As stormwater practitioners shift towards a planning and design strategy that takes into consideration the vision, goals and implementation principles of Ontario's Adaptation Strategy and Adaptation Plan, a focus on GI and LIDs that both increases the resiliency of urban infrastructure to extreme weather and absorbs carbon dioxide (a key greenhouse gas contributing to climate change) is essential.

6.5 Roles of Municipalities

Policies on climate change and climate change adaptation are being developed at the Federal, Provincial, and Municipal levels. It should be noted, however, that the implementation of these policies, especially with respect to water management, will likely be borne by the Municipalities and Conservation Authorities (CAs). Municipalities and CAs 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:

- actions that reduce greenhouse gas emissions that ultimately cause climate change
- actions that prepare for changes that are occurring, or are likely to occur, in the near future.

Example policies and activities that can reduce emissions include programs for tree planting, green building and energy efficiency incentives, water conservation and carpooling. 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, 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 LIDs measures 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). Low-impact development features have an important role in in mitigating effects of climate change at the watershed scale.

There are many non-technical publications available on climate change and climate change adaptation in Ontario. These include Climate Ready: Ontario's Adaptation Strategy and Action Plan (2011-2014) (https://dr6j45jk9xcmk.cloudfront.net/documents/817/2-2-5-climate-ready-en.pdf) and the Region of Peel Climate Change Strategy (https://www.peelregion.ca/planning/climatechange/reports/pdf/climate-chan-strat-rep.pdf).

Because of the increased responsibility and potential liabilities, the municipalities and CAs are likely to require additional analyses and assurances from the proponents of developments that their stormwater management facilities have been designed with consideration of future climate conditions, that the facilities will function as intended under future conditions, that mitigation to protect 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 Duty of Care, Liability and Legal Responsibility

Stormwater managers across Ontario are facing challenges that have a direct impact on the safe and effective management of stormwater. The rise in extreme weather events has caused increased public and government attention on stormwater management. This, coupled with aging municipal infrastructure and funding constraints, has resulted in municipal stormwater management systems that may be vulnerable to failure to meet expected levels of service. As these challenges continue to force stormwater managers to make policy and operational decisions, it is important that decision makers understand the legal obligations and potential liabilities associated with their decisions. Outlined below are potential legal liabilities associated with stormwater management considering climate change as noted by Stormwater Management in Ontario: Legal Issues in a Changing Climate (Zizzo and Allan, 2014):

- Changing information, including as related to climate change, could increase the number and size of lawsuits against municipalities, as those who are owed a duty (for example, residents receiving stormwater management services) become more vulnerable, particularly if the potential impacts of climate change that could be avoided are reasonable foreseeable;
- Relying on outdated standards (e.g. IDF design storms) or processes can be negligent if new information suggests that they should be reconsidered, even if the standards and processes were not negligent before the new information came to light; and
- Municipalities do not need to change all possible standards and processes and upgrade all of their infrastructure in light of climate change information; it is acceptable, after considering the risks, to determine that a particular action or investment is not worth the cost (i.e. have considered the policy).

Action to address the above noted potential liabilities are discusses in **Section 6.5.2**

6.5.2 Actions to Reduce Climate Change Liability

Regardless of the size, budget, or resources available, stormwater practitioners in Ontario must "turn their minds" to 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):

- Have a process for collecting new information and ensuring it is passed on to the appropriate parties within the municipality (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.
- When working with consultants and other professional service providers, make sure they are provided with and are considering the best available information.
- 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 for a municipality.
- Ensure active, valid policy 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 municipality has made a conscious decision to act or not to act based on appropriate social, political and economic factors.
- Set a clear standard of care by coordinating with similarly situated municipalities. Ensure information is shared and similar standard of practice is being applied within these municipalities.
- Work with other stormwater management actors (neighbour municipalities, Conservation Authorities and the Province) to develop best practices and industry standards.
- Enforce policy decision such as bylaws that have been made to mitigate the effects of extreme climate events.

Also important are the responsibilities of municipalities, Conservation Authorities and professional service providers in protecting the public from the adverse impacts of change. Specific roles of Municipalities in protecting against injury caused by climate impacts such as flooding and other extreme weather events include:

- applying a consistent and standardized management policy with respect to wastewater, combined sewer and stormwater management;

- considering how planning decisions impact water management systems, even at smaller scales; and
- effectively considering infrastructure improvement and upgrades and having a clear prioritization to these works.

Specific roles of Conservation Authorities in protecting against injury caused by climate impacts such as flooding and other extreme weather events include:

- update floodplain mapping in light of climate change risks;
- implement projects the protect against 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 "flood prevention 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

6.6.1 Need for Analysis

Consideration of climate change impacts on a development project is part of a standard environmental assessment (EA) to ensure that the project will not pose a risk to the public or the environment (Federal-Provincial-Territorial Committee on Climate Change and Environmental Assessment, 2003). Two aspects need to be considered:

1. the impact of the project on the environment, for example, through increased greenhouse gas emissions; and
2. possible changes to a project caused by 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 SWM. 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. FPTCCCEA (2003) provided a useful checklist to help assess whether climate change may impact a proposed project. A modified version, specific to land development, is provided in **Table 6.3**. Projects with stormwater management systems or receiving watercourses with moderate or high sensitivity should be assessed in more detail. Similarly, projects in proximity to ecological features that are moderately or highly sensitive to climate change, would require more detailed assessment to ensure that the measures developed to mitigate impacts on these features are effective under future climate conditions.

Table 6.3: Sample Worksheet for Ranking Project Sensitivity to Climate Change (modified from FPTCCCEA, 2003).

Climate Parameters	Sensitivity (high/moderate/low/none)
Increased Mean Temperature	
Increased Annual Rainfall	
Decreased Annual Snowfall	
Increased Frequency and Severity of Precipitation Extremes	
Changes in Lake Levels	
Change in Stream Flow Peaks and regieme	
Changes in Soil Moisture and Groundwater Recharge	
Increased Potential Evaporation Rate	

Once the need for a detailed analysis has been identified, the scale of the analysis needs to be determined. For a small development or retrofit, a site-scale analysis may be adequate. Site-scale assessments are discussed below; Watershed-scale assessments are discussed in the following section.

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 central requirement for good urban stormwater design is a clear understanding of the hydrologic setting of the development within the context of the surrounding watershed. 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, and 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 and how adaptation measures can be 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. Future impacts from development should attempt to evaluate the future condition of the complete hydrologic cycle. This is needed to evaluate stormwater management plans and to mitigate potential impacts on natural features, as well as to avoid unforeseen negative consequences of proposed adaptation strategies.

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 low impact design can be evaluated using these same tools. Where possible, site scale analysis should incorporate a rigorous understanding of the regional or watershed scale hydrologic regime.

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 rainfall 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 for components that are at risk of failure or malfunction because of predicted changes to rainfall patterns. In many cases, malfunction may be as simple as an increase in frequency of major stormwater management system responses. 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. 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.

6.7 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 models are used to generate overall site water budgets as well as estimate stormwater runoff volumes, flow rates, and water quality trends. 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 under future climate conditions which, as noted above, may include wetter warmer winters, drier summers, and more intense and frequent storm events and droughts. The 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.

6.7.1 Global Circulation Models

Climate change predictions are made with Global Circulation Models (GCMs) 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 GCM 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 Canada, 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 unbiased 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.

6.7.2 Downscaling of Global Circulation Models for use in Hydrologic Analysis

GCMs cannot predict behaviour at a scale smaller than the grid size. 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.

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).

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, OMNR has established a website (http://climate.aquamapper.com/) where future climate data sets can be downloaded for use in hydrologic models. 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 below. Downscaled data have also been incorporated into hydrologic and integrated models for predicting watershed behaviour under future climate conditions, as will be discussed in subsequent sections.

6.7.3 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 curves. Rainfall intensity-duration-frequency (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 agencies such as the Ministry of Transportation, Ministry of Environment and Climate Change, 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 Canada and available online (ftp://ftp.tor.ec.gc.ca/Pub/Engineering_Climate_Dataset/IDF/).

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 are typically 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. The government of Ontario is focusing on several initiatives to promote updated IDFs; these include (Climate Ready, 2014):

- considering ways to strategically expand the number of rain gauges throughout the province to improve data collection for IDF Curves;
- developing a web-based tool to provide IDF curves electronically at any location across Ontario (in collaboration with the University of Waterloo); and
- researching sophisticated techniques to calculate and update information such as IDF curves and extreme flow statistics in the future.

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. Intensity Duration Frequency (IDF) curves have been developed for future climate conditions and are available for the Province from the Ontario Climate Change Data Portal (www.ontarioccdp.ca). 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.

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.

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.

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 **Section 6.8.5** - Unplanned Negative Outcomes of Adaptation Strategies.

6.7.4 Use of Downscaled GCM data in Hydrologic Models

As noted earlier, 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. 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.

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. 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 percent change, can be used to create an ensemble of different climate input time series.

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 OMNR 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 6.2a** 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 6.2b** shows the range in monthly percent increase in the Orillia Brain precipitation data for the simulated 2041-2070-time frame for all GCM/emission scenarios. The OMNR website has adjusted data for a wide range of scenarios and Ontario climate stations.

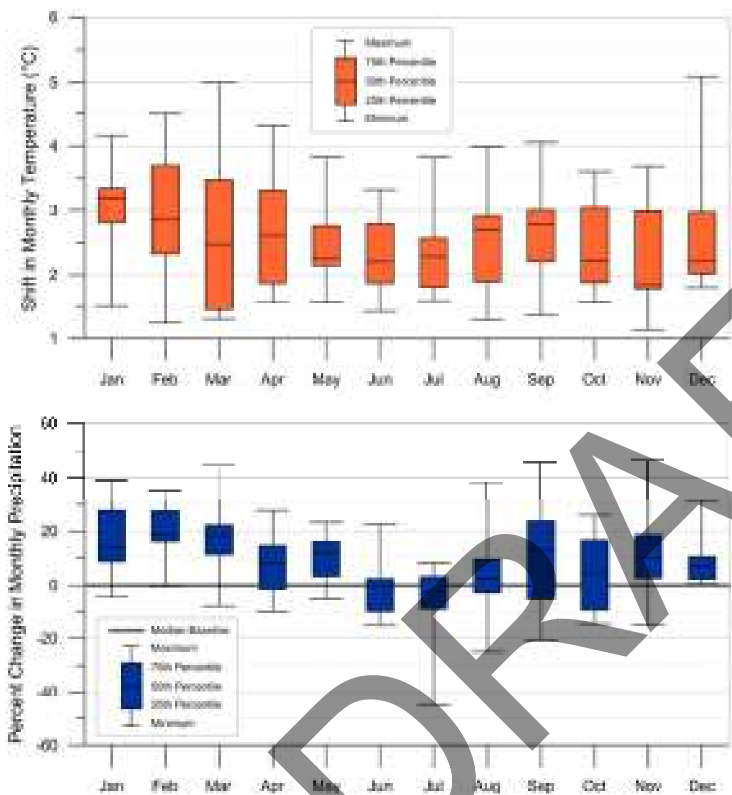


Figure 6.2: (a) shift in monthly temperatures and (b) scaling of monthly precipitation values for the simulated 2041-2070 time frame at Orillia Brain.

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).

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: the scatterplot and percentile method. In the scatterplot method, a relevant summary statistic for each GCM, such as the percent change in annual precipitation, is plotted against a second relevant statistic, such as the percent 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. 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 6.3**).

In 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 (e.g., http://climate.aquamapper.com/). 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.

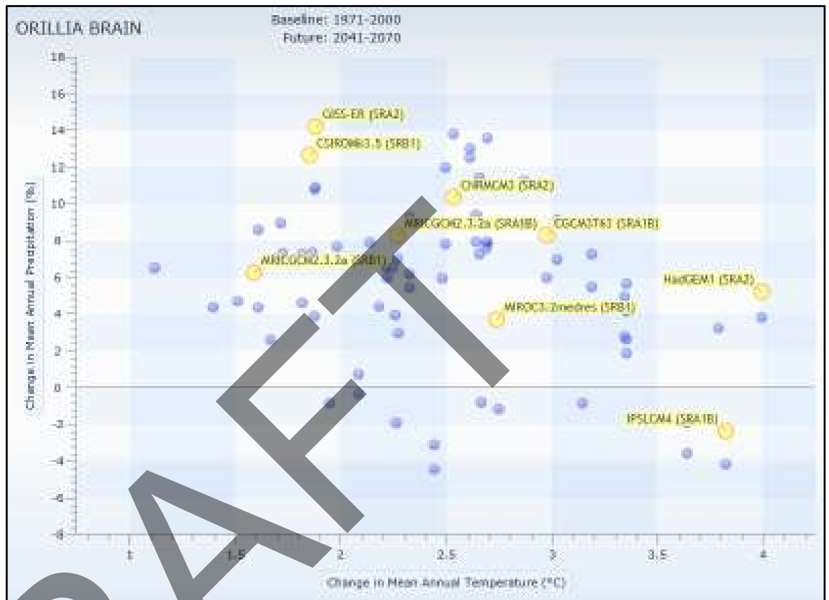


Figure 6.3: Scatterplot of climate scenarios, sampled at Orillia Brain and GCM scenario selection (yellow circles) based on percentile method.

6.7.5 Example of Climate Change Sensitivity of the Lake Simcoe Basin

Several climate change studies have been undertaken in the Lake Simcoe basins utilizing different methodologies. MacRitchie and Stainsby (2011) applied climate change projections from 10 GCMs 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 (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) 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 mnorthwest side of Lake Simcoe (**Figure**). 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 6.7**, 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 6.4: 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** . 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.

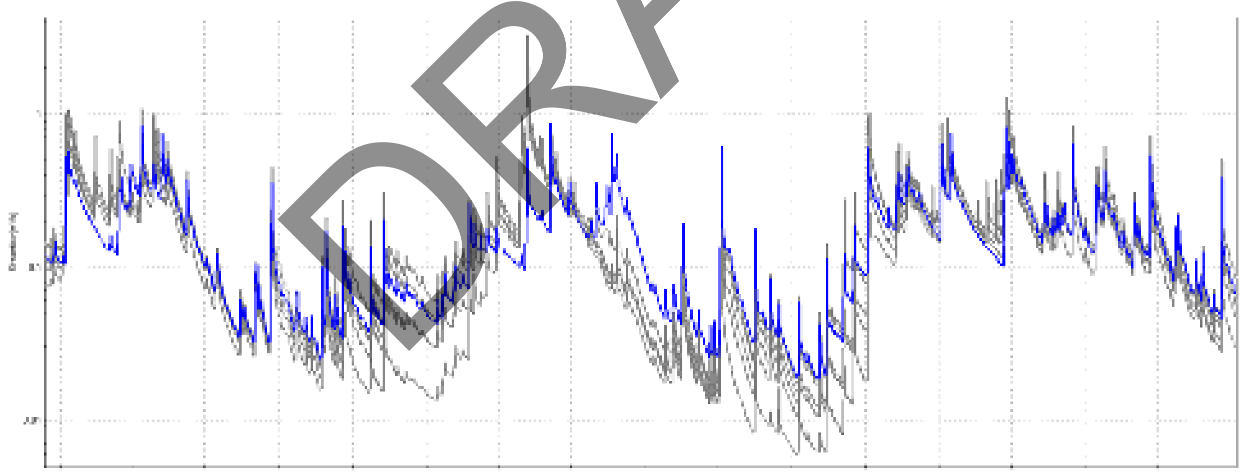


Figure 6.5: Historic streamflow (blue) in Shellswell Creek (South Oro) and predicted flows (grey) using precipitation and temperature data from downscaled from a range of Global Circulation Models (Wexler et al, 2014).

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 6.5**).

Groundwater recharge was predicted to increase with climate change across the most of the study area (as shown by the red areas on **Figure 6.4**). 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.

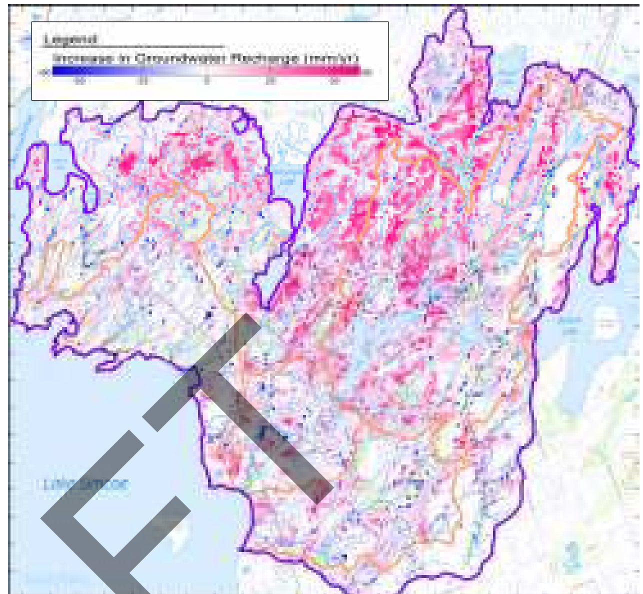


Figure 6.4: Predicted change in groundwater recharge under 2041-2070 climate conditions (Earthfx, 2014).

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.

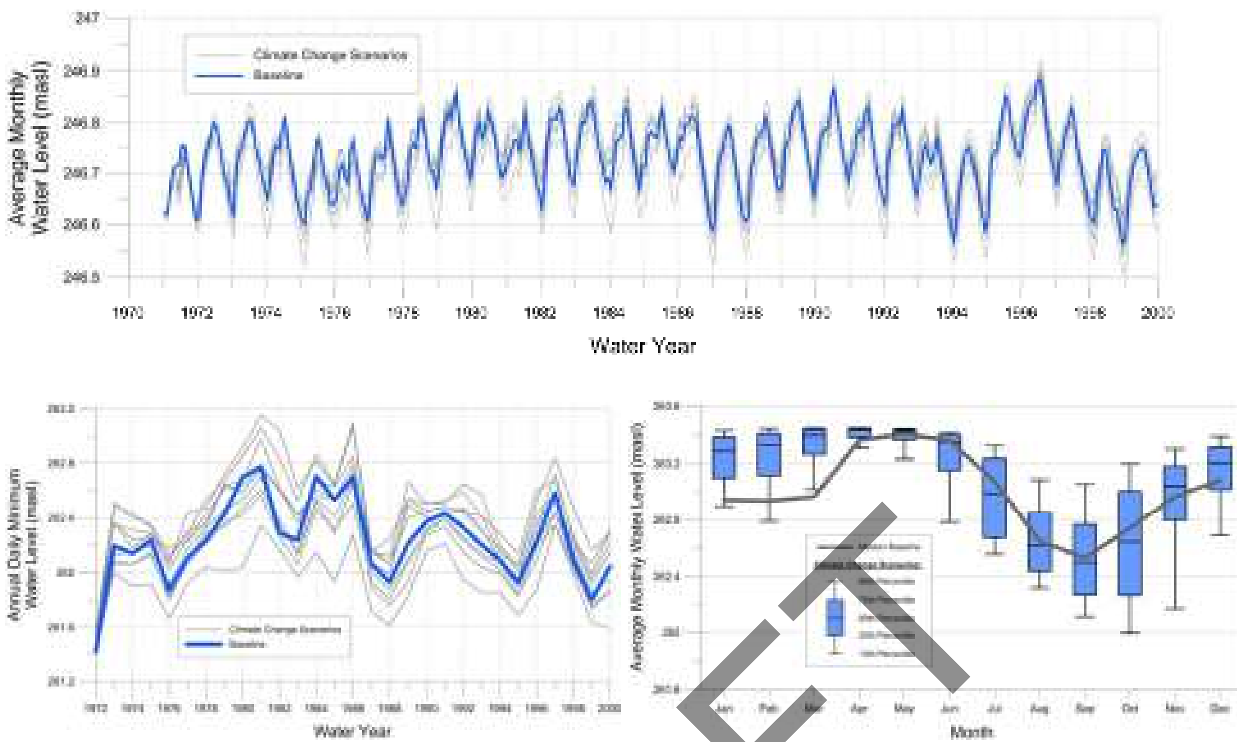


Figure 6.5: Monthly average groundwater level (upper), minimum annual water level (lower left), and monthly water level statics for 9 GSFLOW simulations of future climate conditions in the shallow bedrock aquifer (Earthfx, 2014).

6.8 Four-Step Climate Change Adaptation Process

This section of the document discusses a process that stormwater practitioners are encouraged to use to incorporate climate change adaptation strategies into stormwater management projects. This section is intended to describe how practitioners can establish bounding estimates for consideration during stormwater 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 process can be applied to all stormwater projects including:

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

The key climate change parameters that have the potential to impact a water resources project are listed in **Table 6.4.** Additional parameters may be relevant on a project-specific basis. These parameters should be considered during the design process for all water resources projects in Ontario to mitigate negative climate change impacts on the project level and within communities. 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 the planning and design phase. Waiting until planning and design has been completed before considering climate change may result in inefficiencies, unnecessary design alterations, and exposure to unnecessary legal risks. The climate change adaptation process proposed in this section has been broken down into a 4-step process which has been shown on the next page and described thereafter.

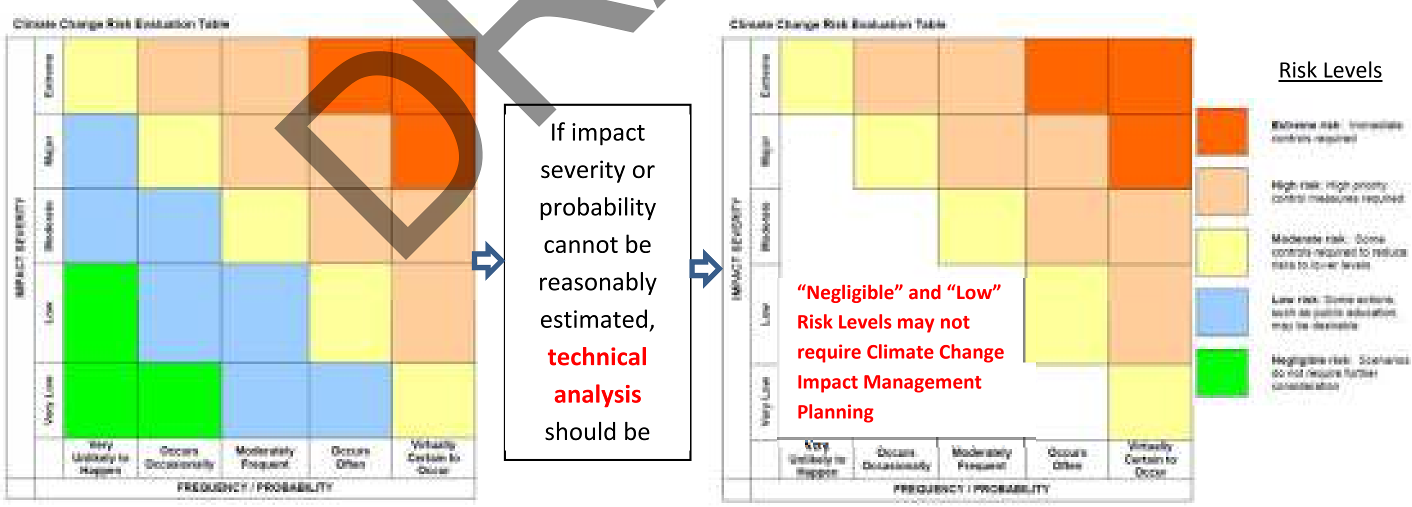
STEP 1: Identifying Climate Change Considerations

Climate Change Impact Screening Questions

- Is there a potential for a climate change parameter to cause a failure to meet design objectives?
- Is there a potential for a climate change parameter to result in the reduction of level of service to an unacceptable level?
- Is there a potential for a climate change parameter to cause a public hazard or safety issues for personnel on or around the project site?
- Is there a potential for a climate change parameter to cause damage to property on the project site or on adjacent lands?
- Is there potential for a climate change parameter to cause environmental degradation on the project site or from the project site?

If "Yes" to any of the above questions, proceed to STEP 2

STEP 2: Evaluating Risk caused by Climate Change Parameters



STEP 3: Climate Change Impact Management Planning

Apply adaptation measures to reduce the project's vulnerability to changes in climate parameters. This typically involves changes in the design to account for expected climate change impacts. Incorporating GI and LIDs into urban environments is an important climate change impact management planning strategy, other strategies are idetified in this section.

STEP 4: Monitoring and Adaptive Management

Implement a monitoring and adaptive management plan to reduce risks and adapt to future changes. This 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.

6.8.1 Step 1 – Identify Climate Change Considerations

Potential climate change impacts will differ depending on location, type of project and other the site-specific factors. During the first step of this process, it is suggested that the stormwater practitioner evaluate whether each climate change parameter expected in Ontario will cause impacts for any project component. Two projects scales are discussed below as examples. 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 6.4: Predicted climate parameters and possible impacts on example stormwater projects.

Climate Change Parameters	Example 1: Development of SWM Plan for a Site	Example 2: Development of City-Wide Stormwater Master Plan
Increased Mean Temperature	No significant Impact on stormwater design	Potential impact on in-ground stormwater infrastructure (freeze-thaw cycle impacts)
Increased Annual Rainfall	Impact on annual runoff volume and pollutant loading	Impact on local water balance
Decreased Annual Snowfall	Impact on winter and spring operation	Impact on freshet response
Increased Frequency and Severity of Precipitation Extremes	Impact on runoff rates and associated conveyance and storage sizing	Impact on urban flooding and erosion processes
Changes in Lake Levels and stream flows	Impact if site adjacent to lake or stream (outlet conditions and receiver requirements)	Impact on aquatic habitat, surface water consumption and assimilative capacity
Changes in Soil Moisture and Groundwater Recharge	No significant Impact on stormwater design	Impact on groundwater consumption and baseflow
Increased Potential Evaporation Rate	No significant impact on stormwater design	Impact on local water balance

6.8.2 Step 2 – Identify and Evaluate Risk caused by Climate Change Parameters

Once the potential impact of climate change parameters on a project have been considered, 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 risk assessment should be considered when any of the following are true:

<u>Climate Change Impact Screening Questions</u>

- Is there a potential for a climate change parameter to cause a failure to meet design objectives?
- Is there a potential for a climate change parameter to result in the reduction of service to an unacceptable level?
- What is the projected impact within the asset and or functional life of infrastructure receptors?

- Is there a potential for a climate change parameter to cause a public hazard or safety issues for personnel on or around the project site?
- Is there a potential for a climate change parameter to cause damage to property on the project site or on adjacent lands?
- Is there potential for a climate change parameter to cause environmental degradation on the project site or from the project site?

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 should asses the impacts of expected increased frequency and severity of precipitation extremes by including a modelling scenario that reflects predicted climate change. General considerations for climate change during the design process are identified in **Table 6.5**.

Table 6.5: Consideration for Climate Change during the Design Process.

General Considerations	Explanation
Capitalize on local knowledge and data;	A good knowledge of existing local conditions, including collection and analysis of historical 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 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.
Do not count on beneficial aspects of climate change	Projected climate change is anticipated to adversely affect most infrastructure commonly designed using IDF information. However, in some instances and some particular locations, there may be beneficial aspects, theoretically allowing a reduction in required design capacity as 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 requirements 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

General Considerations	Explanation
	climate change. A reasonable approach in some cases may be to make the necessary arrangements for anticipated future expansion

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 probability (certain to very unlikely) and impact severity (severe to negligible) of a climate change risks must be established. For climate change risks that meet a threshold level of probability and impact severity, adaptation strategies must be evaluated to avoid an unacceptable level of risk. **Figure 6.6: 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 using a risk evaluation matrix. 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 asses any climate change impact on a stormwater project.

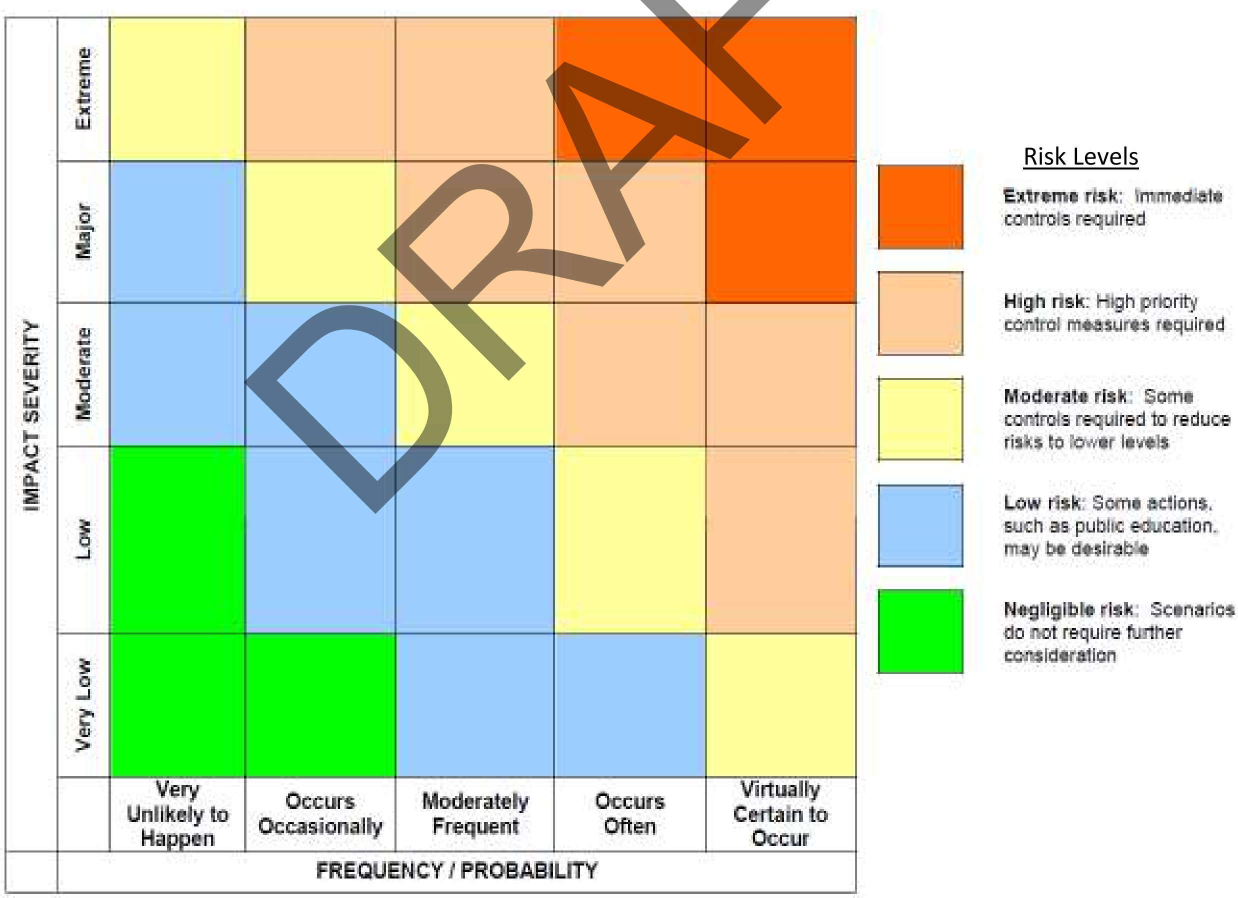


Figure 6.6: Climate Change Risk Evaluation Matrix (Bruce et al., 2006b).

As an example, consider the climate change risks associated with an existing urban stormwater management facility designed to provide both quality control and peak flow reduction (wet pond). As discussed earlier in the chapter, the hydrologic impacts of climate change on stormwater management systems include increased water temperatures, increased severity of storm events resulting in peak flow and single event runoff volume increases, and increased evapotranspiration. The two examples below provide a high-level risk assessment of climate change impacts on the stormwater management facility.

6.8.2.1 Example 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 a 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 SWM facilities especially during the long and dry summer months.

Figure 6.7 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 virtually certain to occur and the correlation between air temperature and water temperature in the SWM 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 cold water 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 SWM facility 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.

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 6.6: Climate Change Risk Evaluation Matrix (Bruce et al., 2006b).**

, the resulting climate change risk of Scenario 1 is moderate. Adaptation strategies to mitigate thermal pollution on the environment should be considered but climate change risks that are considered high or extreme should be given priority.

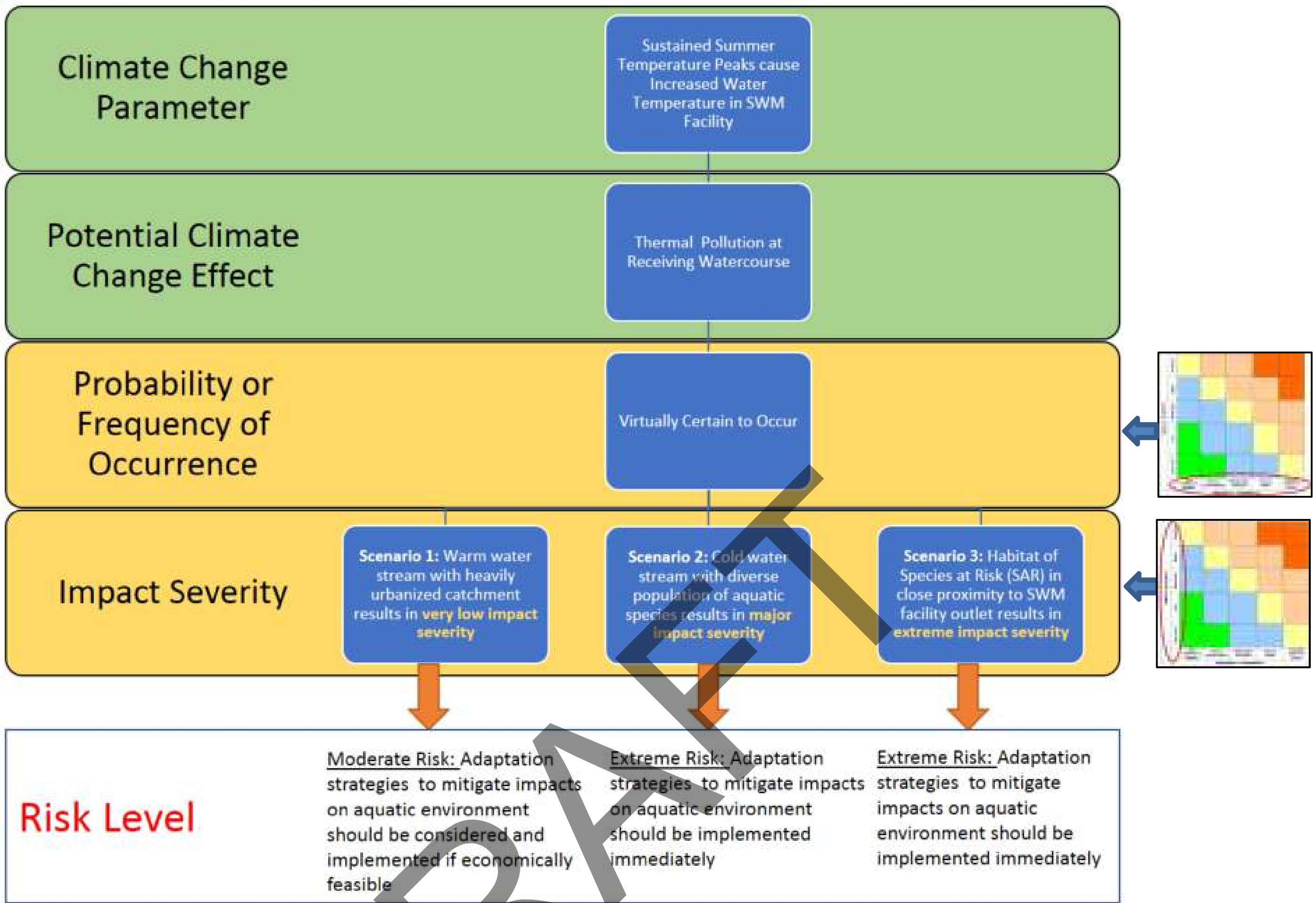


Figure 6.7: Example 1 – SWM Facility Temperature Increase Impacts on an Urban Watercourse.

6.8.2.2 Example 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 SWM 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, SWM facilities function by allowing sediment to settle during inter-event periods. Consecutive storms that lack a sufficient inter-event period can cause SWM facilities to discharge sediment-laden water.

Figure 6.8 illustrates a risk assessment process for evaluating three (3) different potential climate change effects related to increased storm intensity and severity. 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 step, impact severity might not be known with great accuracy. For example, 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 SWM facility, an extreme impact severity was assigned to the climate change risk. For the risk 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 6.6: Climate Change Risk Evaluation Matrix (Bruce et al., 2006b).**

, the risk classification for the exceedance of SWM 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.

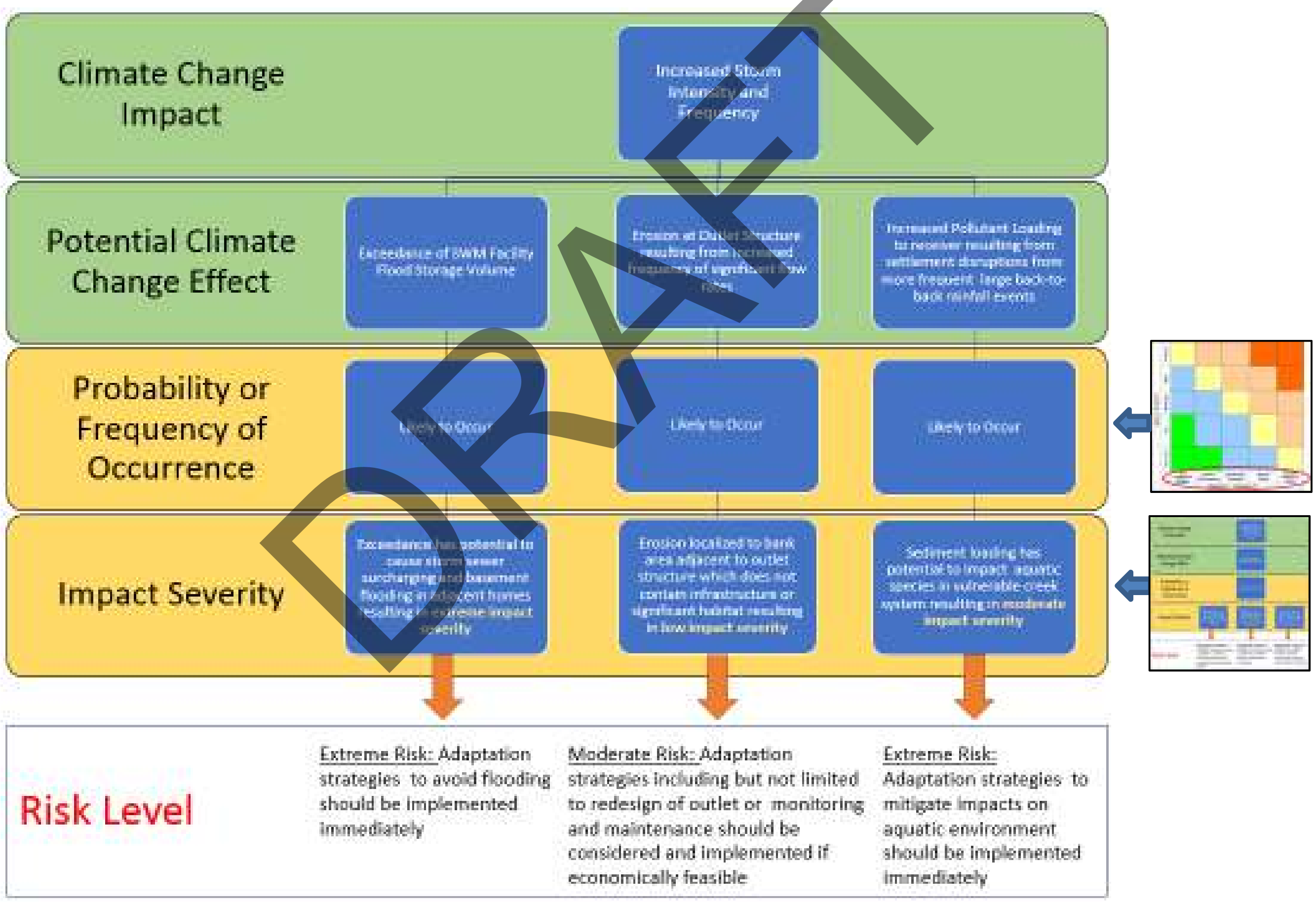


Figure 6.8: Example 2 – Increased Intensity and Frequency of Rainfall Events Risk.

It should be noted that technical analysis can not only provide more accuracy with respect to impact severity but can also provide a quantitative indicator of probability. In the above examples, probabilities were assigned to the climate change impact but not to the risk itself. In many cases, a probability can be assigned to the climate change risk via technical analysis. For example, hydrologic and hydraulic modelling may indicate that inflow volumes calculated using an IDF that has been modified to include a reasonable climate change increase in rainfall depth does not exceed the designed storage volume during the 1:100-year rainfall event. In this case, the expected level of service is maintained and 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 relating to climate projections and associated impacts to the local environment. Technical assessments to address climate change concerns may include but are not limited to those listed in **Table 6.6**.

Table 6.6: Technical Assessment of Climate Change Impacts for New Stormwater Projects

Technical Assessment Type	Description
Climate Change Updated Water Balance Analysis	Updated climate data sets from OMNR are used to analyse the effect of predicted changes in annual rainfall and temperature on site/study area water balance.
Climate Change Updated IDF Calculations	Hydrologic modelling or stormwater calculation (peak flows and runoff volumes) are updated to determine the impact on conveyance and storage facilities.
Site Planting Sensitivity Analysis to Climate Change	Updated climate extremes and normals from OMNR are compared to the tolerances of plant species at SWM facility.
Climate Change Updated Floodplain Mapping	Locally appropriate hydrologic parameters including extreme rainfall and/or melt events that take into consideration the anticipated impact of climate change are used to update floodplain mapping for creeks, rivers and lakes.

6.8.3 Step 3 – Climate Change Impact Management Planning

The impacts of climate change that have been demonstrated by technical analysis to cause significant problems such as failing to meet design objectives must be mitigated through climate change impact management planning. 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 changes in the design to account for expected climate change impacts. An example would be increasing the storage capacity of a stormwater management facility based on expected changes to intensity and frequency of extreme precipitation events.

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. Examples of adaptation strategies that have been successfully used to mitigate to the consequences of climate change:

a) removing or diverting flows from undersized storm sewers to mitigate the damages associated with more frequent intense storm events;
b) increasing the flood storage volume of existing ponds in flood prone areas and/or increasing the sizing requirements of future ponds to avoid an increased frequency of urban flooding;
c) utilizing LID or GI to reduce runoff volumes during all rainfall events (further discussed in Section 10.3.1);
d) expanding or rerouting major flow paths to avoid flooding associated with significant urban rainfall events;

e) increasing forecasting and warning capabilities;
f) modifying inspection and maintenance programs;
g) reducing seasonal storage levels in dams; and
h) replacing storm sewers.

Along with necessary updates to stormwater design standards, incorporating GI and LIDs into urban environments is an important climate change impact management planning strategy. LIDs allow for a built environment that can better handle weather stresses and help reduce climate-associated risk and costs. **Table 6.7** identifies the mechanisms and benefits of GI and LIDs compared to end-of-pipe stormwater management facilities.

Table 6.7: SWM Control Mechanisms and Benefits of LIDs and End-of-Pipe Facilities.

SWM Approach		Potential SWM Control Mechanism				SWM and Environmental Benefit				
		Infiltration*	Retention	Filtration	Evaporation/ Transpiration	Water Quality	Flood Control*	Erosion Control *	Water Balance *	Water Reuse
Source Controls	Bioretention	✓	✓	✓	✓	✓	X	✓	✓	X
	Bioretention Planters						X			X
	Permeable Pavement				X					
	Soakaways and Infiltration Chambers			X	X					X
	Rainwater Harvesting	X		X	X	X	X		X	
	Green Roofs	X					X		X	X
	Landscape Alternatives						X			X
	Soil Amendments		X				X			X
	Downspout Disconnection		X				X			X
	Filter Strips	✓	X	✓	✓	✓	X	✓	✓	X
	Prefabricated Modules	✓	✓	✓	✓	✓	X	✓	✓	X
Conveyance Controls	Perforate Pipe System	✓	✓	X	X	✓	X	✓	✓	X
	Enhanced Grass Swale	✓	✓	✓	✓	✓	X	✓	✓	X
	Bioswales	✓	✓	✓	✓	✓	X	✓	✓	X
End-of-Pipe	Wet Ponds	X	✓	X	✓	✓	✓	✓	X	✓
	Engineered Wetlands	X	✓	X	✓	✓	✓	✓	X	X
	Hybrid Facilities	X	✓	X	✓	✓	✓	✓	X	✓
	Dry Ponds	X	✓	X	✓	X	✓	✓	X	X
	Subsurface Storage	✓	✓	X	✓	✓	✓	✓	X	X

* Extent of performance and environmental benefits will be subject to site testing results to identify site constraints related to predominant soil types and characteristics, including the ability of the native soils to infiltrate stormwater runoff. Testing will be required to determine the hydraulic conductivity "K" of the native soils

Several scientific studies have highlighted the climate change resiliency of urban stormwater infrastructure when designed with source-based stormwater controls. A selection of these 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 measures, 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 practices 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 measures, 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 features. Increased rainfall associated with climate change produced additional runoff volume and higher peak flows from the catchment. The scenario with LIDs was found to provide adaptation benefits to stormwater volume and peak flow (Z. Zahmatkesh et al., 2014).

In Ontario, the City of Kitchener has undertaken an analysis of the impacts of both climate change and LID BMPs on their SWM system (storm sewers and SWM facilities) as part of their *Integrated Stormwater Management Master Plan* (Aquafor Beech, 2016). Based on the analysis of three (3) Climate Change Scenarios, the City's 1:5-year rainfall event (The Region of Waterloo and Area Municipal Design Guidelines and Supplemental Specifications for Municipal Services (DGSSMS) standard for storm sewer design) was predicted to increase by 17.4%. To account for this future change, an increase of the IDF curves by 20% was applied in all climate change hydrologic modelling scenarios. To assess the impact of new LID policies on existing conditions and climate change scenarios, a 12.5 mm reduction in runoff depth was applied to appropriate urban catchments. **Table 6.8** indicates the results of this analysis. Of note is that the implementation of a 12.5 mm reduction in runoff via new volume reduction policies is expected to reduce the total length of surcharging pipe from 13,763 m to 5,842 m. Increasing the IDFs by 20% to account for climate change results in 19,566 m of surcharging pipe however using LID as an adaptation strategy is expected to reduce this to 14,691 m, greatly decreasing the capital asset replacement cost.

Table 6.8: City of Kitchener 1:5-year Design Storm Flooding Summary with Climate Change and LID Scenarios.

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 meter based on discussions with the City

The results of these studies are in keeping with the design objectives of LID stormwater management BMPs: to create an urban development with a more natural water balance than a similar development built with conventional stormwater management BMPs. With LIDs, runoff is captured, detained and routed to facilities that promote the natural processes of infiltration and evapotranspiration. This stormwater control strategy can mitigate the impact of development on stormwater, specifically by reducing peak flow increases, runoff volume increases and pollutant loading to downstream receivers. Offsetting these negative impacts will increase the resiliency of urban and natural stormwater systems to future shifts in climate

6.8.4 Step 4 – Monitoring and Adaptive Management

The monitoring and adaptive management step is in place to incorporate lessons learned. The implementation of a monitoring and adaptive management plan reduces risks and allows for adaptation to 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 monitoring programs. Maintaining access to local rainfall records is important as is long-term monitoring programs that track responses in storm sewers, SWM 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. All monitoring can generally fall into two (2) categories, these are:

- Environmental Monitoring - designed to assess 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.

- Performance Monitoring - designed to evaluate whether a measure is implemented properly (compliance monitoring) and how well it performs, based on a range of performance indicators or targets (effectiveness monitoring). Typically, performance monitoring is completed for a Stormwater Master Plan and generally includes monitoring for compliance purposes and effectiveness monitoring.

Table 6.9 identifies stormwater monitoring components that could be included in a monitoring and adaptive management plan which incorporates future climate change

Table 6.9: Stormwater Monitoring Components

Monitoring Component	Parameter	Compliance Monitoring	Effectiveness Monitoring
Hydraulics (at facility)	• Capacity • Outlet design flows • Retention	☑	☑
Flow Rates (in Sewers)	• Peak flow rates • Base flow	☑	

Monitoring Component	Parameter	Compliance Monitoring	Effectiveness Monitoring
Hydrology (in receiving stream)	• Time series flows (continuous flows) • Spot flows, • Flood flows		☑
Hydrogeology	• Infiltration /recharge • Water Balance		☑
Water Quality (LID Features)	• Sediment removal • Outlet concentrations • Event mean concentrations7.1	☑	
Water Quality (in receiving stream)	• In stream concentrations • 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 asses. • 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		☑

The monitoring approach should utilize an adaptive environmental management approach which 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 advances scientific understanding and helps policy decisions
Acknowledges natural variability in contributing to ecological resilience and productivity

6.8.5 Unplanned Negative Outcomes of Adaptation Strategies

As stormwater practitioners in Ontario adapt stormwater infrastructure to observed and predicated 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 OMNRF) when considering modified pipe sizing across a large catchment or subwatershed area that is uncontrolled.

For catchments that drain to stormwater management facilities, there is still 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 must also be 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.

6.9 Planning Tools for Climate Change

The Ministry of Municipal Affairs has compiled a list of existing planning act tools to support climate change action in Ontario (MMAH, 2009). These tools are identified and described in this section:

Official Plans – Section 16-27

Municipal official plans are the primary vehicle for articulating a community's sustainable vision and overall planning policy direction. Municipalities may incorporate climate change policies into their official plans to identify specific actions to be taken to achieve climate change objectives. These policies can complement other municipal programs and initiatives that address climate change and reduce greenhouse gases (e.g., programs for tree planting, green building and energy efficiency incentives, water conservation and car pooling).

Protection of Settlement Area Boundaries – Sections 22, 34

Council refusal or non-decision regarding proposals for expanding a settlement boundary or establishing a new settlement area cannot be appealed to the Ontario Municipal Board. By building more compact communities, greenhouse gases associated with auto-dependent commutes can be reduced. Focusing development within existing boundaries helps to maintain those natural and agricultural areas that store carbon and buffer against extreme weather.

Complete Application Requirements – Subsections 22(5), 34(10.2), 51(18), 53(3)

Municipalities can establish the required information, material, or studies needed to assess planning applications for official plan amendments, zoning amendments, subdivisions and consents. These could include studies that are relevant to the proposed development with respect to a changing climate (e.g., stormwater management plans that address on-site mitigation of intense precipitation events).

Community Improvement Plans (CIPs) – Section 28

CIPs target parts of a community for strategic development or redevelopment. Municipalities can acquire, hold, clear, lease and sell land in designated areas and provide grant and loan incentives for landowners to undertake activities that address climate change mitigation and adaptation (e.g., building retrofits for energy efficiency, renewable and district energy systems, water conservation and efficiency systems and brownfield site remediation). In addition, prescribed upper-tier municipalities may develop plans related to affordable housing, infrastructure and transit corridors and upper and lower-tier municipalities may participate in each others grant and loan programs that facilitate the integration of community improvement programs related to climate change.

Zoning by-laws – Section 34

Municipalities may prohibit the use of land or erecting buildings and structures within areas that are significant features, hazard lands and areas prone to flooding (e.g., floodplains or valleylands). Prohibiting development in natural areas and hazard lands promotes ecological services that address climate change mitigation and adaptation (e.g., carbon sequestration and storm water retention and infiltration, while reducing economic, health and safety costs and risks).

Zoning by-laws promote more efficient land use patterns by allowing a greater mix of uses within a specified area to create the conditions for shorter commutes between workplaces and residences and by regulating heights, densities and lot sizes in order to achieve more compact neighbourhoods and communities. Through specification of setbacks and building envelopes, zoning by-laws can also promote more energy-efficient buildings.

Height and Density Bonusing – Section 37

Municipal councils may authorize additional building height and density in exchange for specified facilities, services or matters set out in the by-law. Climate change mitigation could be considered by including sustainable elements such as green roofs or improvements to public transit facilities.

Site Plan Control – Subsection 41(4)

Sustainable external design elements may be secured through a site plan control by-law. To address climate change mitigation and adaptation, elements could include green infrastructure and low-impact development features such as:

- natural and artificial permeable surfaces that promote infiltration and reduce stormwater runoff (e.g., infiltration swales, vegetated channels/ditches, interlocking pavers, porous asphalt)
- green roofs for rainwater capture and energy efficiency
- tree plantings that are suited to site conditions and which function to shade paved surfaces and reduce localized heat island effects
- weather-protected bicycle storage

Parkland Dedication – Subsection 42 (6.2)

Where on-site parkland dedication cannot be accommodated, municipalities may provide for a reduction in cash-in-lieu requirements in exchange for sustainability features that address climate change, including green roofs, permeable surfaces, tree plantings, renewable energy technologies, and water efficiency and conservation measures.

Plan of Subdivision – Section 51

Approval authorities may review subdivision plans to assess, among other things, aspects of design and layout that relate to climate change mitigation and adaptation, such as: orienting lots to maximize passive solar heating and lighting while decreasing energy consumption; consideration of energy supply; optimizing the use and efficiency of energy through compact design; and designing for non-motorized pathways and trails that support walking and cycling.

Conditions of approval may also include easements or land dedication for greenspaces and natural features, which store carbon and can reduce costs associated with stormwater management.

Development Permit System (DPS) – Section 70.2 and O. Reg. 608/06

The DPS is a streamlining tool that combines zoning, site plan control, and minor variance approvals. A DPS by-law can set out discretionary uses that may be permitted if criteria in the by-law are met. Climate change mitigation and adaptation could be considered by:

- specifying conditions to promote sustainable development including brownfield redevelopment, greenspace protection, transportation demand management or water management and conservation measures
- securing exterior building features such as green roofs to improve energy efficiency and reduce stormwater runoff
- expanding on matters only partly addressed through other tools such as site plan control (e.g., removal, restoration, or preservation of vegetation and features to promote carbon uptake and infiltration of stormwater)

Additional tools that have been used in municipalities across Ontario to plan for climate change include stormwater user fees, credits incentives and market based instruments; green streets policies and guidance; green parks; green parking lots; downspout disconnects, capacity development as well as community education and engagement. A long list of potential implementation strategies, programs, and policies are summarized in the Soak it Up! toolkit developed by Green Communities Canada, available at http://www.raincommunitysolutions.ca/en/toolkit/.

7 Approvals

The Ministry of the Environment and Climate Change (MOECC) is the lead ministry responsible for protecting, restoring and enhancing the environment to ensure public health and environmental quality. The ministry safeguards Ontario's environment by working towards cleaner air, water and land, and a healthier ecosystem for the people of Ontario.

The Environmental Assessment and Approval Branch (EAAB) of the MOECC issues Environmental Compliance Approval (ECA) for the treatment and disposal of sewage by municipal and private systems.

The following section describes the ECA process and submission requirements relating to stormwater management (sewage) works and Low Impact Development (LID) BMPs in compliance with Ontario Water Resources Act.

7.1 Modernization of the Approval Process – The ECA

On October 31, 2011, amendments to the Environmental Protection Act (EPA) MOECC, R.S.O. 1990, and Ontario Water Resources Act (OWRA) O.Reg 525/98 came into force, creating an instrument of approval to replace Certificates of Approval (CofA). This instrument is the Environmental Compliance Approval (ECA).

The Director no longer issues CofAs or provisional certificates of approval under the EPA or approvals under section 53 of the OWRA. However, existing Certificates of Approval, provisional certificates of approval and section 53 OWRA approvals and their terms and conditions will continue to apply and they may be amended, reviewed, suspended or revoked as if they were an ECA. Wherever the term Environmental Compliance Approval is used, it also applies to existing CofA, provisional CofA and approvals issued under section 53 of the OWRA.

Before the introduction of ECAs, businesses would apply for separate Cs of A for air, noise, waste or sewage projects. Now proponents can apply for an ECA for multiple activities and projects in multiple media. In other words, ECAs offer a one-window, multiple media approach and are required, for the purposes of this manual, for activities which fall under OWRA section 53 (sewage works). Under section 53, stormwater is considered sewage.

7.2 Application Guide

As part of the modernization of the approvals process, the MOECC has prepared a Guide to Applying for an Environmental Compliance Approval.

This guide sets out application requirements for obtaining an Environmental Compliance Approval (ECA). The ministry updates this guide regularly to ensure that it provides accurate information and guidance for those submitting an ECA Application, as the environmental standards and environmental management approaches evolve and develop. This guide covers applications for an ECA for activities involving air and noise emissions, Waste Management Systems, Waste Disposal Sites and Sewage Works. While this manual provides specific guidance relating to stormwater management (sewage) works and Low Impact Development (LID) BMPs, the MOECC Guide to Applying for an Environmental Compliance Approval shall remain the definitive source for application related direction.

For a link to the **Guide to Applying for an Environmental Compliance Approval, Version 1 (Dec, 2012)** visit the **Resource Directory**.

7.3 Application Checklist

As an additional resource to the Application Guide, the MOECC has also prepared a Checklist for Technical Requirements for Complete Environmental Compliance Approval Submission. Additional detail is provided in **Section 7.5.**

For a link to the **Checklist for Technical Requirements for Complete Environmental Compliance Approval Submission (February 2013)** visit the **Resource Directory.**

7.4 When is an ECA Required?

Section 53 of the OWRA requires that an approval must be obtained in order to establish, alter, extend or replace any sewage works (sewage works are defined as works used for the collection, transmission treatment or disposal of wastewater, but not including plumbing to which the *Building Code Act,* 1992 applies). Under the OWRA, sewage includes drainage, storm water, commercial wastes and industrial wastes and such other matter or substance as is specified by the regulations.

Operations that require approvals from a stormwater perspective include:

- Stormwater management facilities; and
- Storm sewers

The rule is: Everything that discharges stormwater or drainage (i.e. sewage) require approval unless specifically exempted.

7.4.1 Exemptions

In general, such, the need for, and nature of, an approval depends on the site and the activity. However, specific exemptions for certain types of sewage works equipment, system and application have been granted through legislation. The OWRA and Approval Exemption Regulation (O.Reg. 525/98) exempt minor sewage works from the approval requirements of the Act. As

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

1) designed to service one lot or parcel of land; AND
2) discharging into a storm sewer that is not a combined sewer; AND
3) not servicing industrial land or a structure located on industrial land; AND
4) not located on industrial land.

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

a) goods or materials other than fuel, or
b) services other than vehicle repair services

Other approval exemptions under Section 53 include:

5) drainage works under the Drainage Act or a sewage works where the main purpose of the work is to drain land for the purposes of agricultural activity;

6) drainage works under the *Cemeteries Act*, the *Public Transportation and Highways Improvement Act* or the *Railway Act.*

7) private sewage disposal systems which discharge to groundwater, that have a designed capacity of 10,000L/day or less. Note: these are approved under the *Building Code* by municipalities.

In all other circumstances beyond the aforementioned exemptions, an ECA from MOECC is required. If unsure about the exemption of your stormwater works, a pre-consultation meeting with the ministry is recommended (see **Section 7.5.1**). Frequently asked relating to when an ECA is required are detailed below:

1. **Is an ECA required for LID BMPs within the municipal ROW?**
   Yes - An ECA is required, as condition 1) above is not satisfied as a municipal ROW accepts drainage (i.e. services) more than one lot or parcel of land.

2. **Is an ECA required for LID BMP retrofits?**
   The requirement to apply for an receive an ECA is dependant on the site and the activity and must be assessed by applying the approval exemption conditions listed above.

3. **Is an ECA required for LID BMPs located individual lots within a proposed subdivision?**
   Yes - An ECA is required if the proposed LID BMPs form a fundamental part of the overall proposed stormwater management system required to meet the design objective and targets. In this case, the LID BMPs are servicing more than one lot or parcel of land

7.4.2 ECA Screening Process

Table 7.3.1 below provides a simple project screening methodology for determining if an ECA is required under most circumstance.

Screening Process – Does my SWM BMP Need an ECA?

Conditions	Key Screening Question	Yes	No	Result
1)	Does the proposed BMP facility accept drainage from (i.e. service) more than one lot or more than one (1) parcel of land?	☐	☐	If you answered **'no' to all** of the four (4) key screening questions, you **do not** require an ECA. If you answered **'yes' to any** the four (4) key screening questions, you **require** an ECA If you are unsure contact the MOECC.
2)	Does the proposed BMP facility discharge to anything other than a municipal storm sewer?	☐	☐	
2)	Is the municipal storm sewer to which the proposed BMP facility directly discharges to a combined sewer?	☐	☐	
3)	Does the proposed BMP accept drainage from (i.e. service) Industrial lands?	☐	☐	
3)	Does the proposed BMP accept drainage from (i.e. service) a structure located on Industrial lands?	☐	☐	
4)	Is the proposed BMP facility located on industrial lands?	☐	☐	
5) & 6)	Is the prosed BMP facility subject to the Drainage Act, *Cemeteries Act*, the *Public Transportation and Highways Improvement Act* or the *Railway Act?*	☐	☐	If **yes**, you do not require an ECA
7)	Is your proposed BMP facility a private stormwater (i.e. sewage) disposal systems which discharge to groundwater, that have a designed capacity of 10,000L/day or less.	☐	☐	If **yes**, you do not require an ECA

7.4.3 Other Approvals

It is also important to remember that it is your responsibility to be aware of and to understand, all legal requirements of the EPA, OWRA and other legislation applicable for your proposed project. Note that the Director's issuing of an ECA under one Act does not relieve you from obtaining any other approvals you might need under other Acts or provisions.

7.5 MOECC Environmental Compliance Approval Process

The information in this section should be presented as best practice guidance for those applying for an ECA related to stormwater management (sewage) works and Low Impact Development (LID) BMPs
The ECA review and approval process is comprised of six (6) stages:

Stage 1: Application preparation and Pre-consultation with the MOECC (if required)
Stage 2: Application Processing and Screening
Stage 3 Application Assignment
Stage 4: Review
Stage 5 Approval Decision
Stage 6: Appeal Provisions

Figure 7.5.1 has been reproduced from the Guide to Applying for an Environmental Compliance Approval which illustrates the ECA review and approval process following the six (6) steps identified above.

7.5.1 Pre-Consultation

Prior to submission, pre-consultation with the ministry staff may be a mandatory or optional step. A pre-consultation meeting is a dialogue between an applicant and the ministry before the applicant submits an ECA Application. It is also an opportunity to clarify if an ECA is needed for your specific SWM or LID BMP project as well as application requirements, and a chance to provide information that will support the application. Such consultations are meant:

- to help applicants define the environmental objectives for their project,
- to establish the general acceptability of the proposal, and
- to identify any special approval-related requirements.

It is important to note that a pre-application meeting with the ministry is not required for every application, nor does it necessarily speed up the application process or provide clarity beyond what has already been documented in published ministry guidance or this manual. The purpose of a pre-application meeting with the ministry is not to explain the basic application process to you.

To help you determine whether a pre-application meeting with the ministry could be useful in your case, the ministry has provided the checklist entitled **Pre-application Considerations checklist**. This helps you think about whether your particular project may be impacted by issues that might lengthen the ministry's review. You should use this checklist well in advance of submitting your ECA Application. The checklist can be found in Appendix 5 of the Guide to Applying for an Environmental Compliance Approval.

For a link to the **Guide to Applying for an Environmental Compliance Approval, Version 1 (Dec, 2012)** visit the **Resource Directory**.

If a pre-application meeting with the ministry is required, or if you would like to engage in it, you may initiate it by contacting the local district office serving the area in which the proposed activity is to be located.

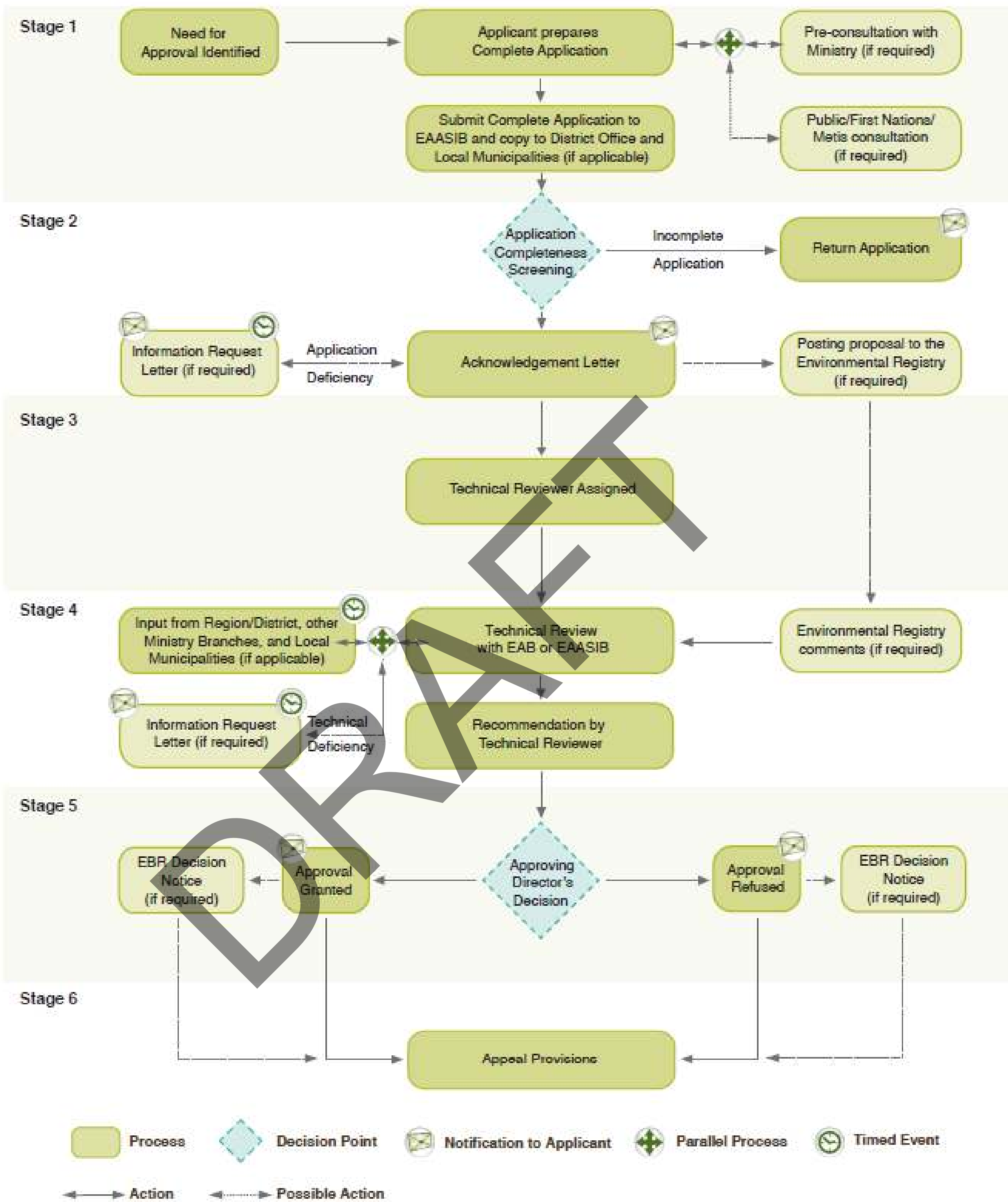


Figure 7.5.1 - ECA Application Review Process and Stages

7.5.2 Submission Screening Process

ECA applications cannot be reviewed until a screening level review confirms that all required information is provided. As part of the screening process, ministry staff of the Application Assessment Unit verifies that the submitted documentation and its content are complete. To do so, staff employ a "Pass/Fail" test to verify if, on the face of the application, the appropriate documents are included in the submission. The requirements for the test are spelled out in provincial environmental legislation and ministry policies and guidelines.

If the required documents are not submitted with the application, staff will return the application at this stage or at their discretion may contact you a provide you with an opportunity to provide the missing information within a prescribed period of time (typically 14-days) after which the ministry will consider your application withdrawn, will close the file accordingly and the submitted fee would be refunded in the amount reduced by any applicable non-refundable fee.
The return of applications which "Fail" the verification test, is part of the amendments that introduced ECAs is EPA section 20.14, which provides that the Director is not required to consider an ECA Application if the application does not meet requirements prescribed by regulation. In other words, if your application is incomplete, or if you provide information that does not meet prescribed standards, the Director can return it to you without considering whether to issue or refuse an ECA.

Of course, you can always re-apply, but doing so will take time and cause delay to your project or plans.

7.5.3 Technical Review Process

For application which "Pass" the screening process, ministry staff will engage in a preliminary review of the application and supporting documents and make a determination if the submission is complete.

If the submission is deemed incomplete, staff will return the application at this stage or at their discretion may contact you a provide you with an opportunity to provide the missing information within a prescribed period of time (typically 14-days) after which the ministry will consider your application withdrawn, will close the file accordingly and the submitted fee would be refunded in the amount reduced by any applicable non-refundable fee.

If the submission is deemed complete, a technical reviewer is assigned to your application. That person performs the technical review of the information and coordinates comments from any supplementary reviewers, as well as EBR comments (if required).

Following the review, the technical reviewer will prepare a recommendation to the Director to either approve the application (with a draft ECA) or refuse the application.

7.5.4 Submission Requirements

Ontario Regulation 255/11, *Applications for Environmental Compliance Approvals* made under the EPA (ECA Application Regulation), sets out prescribed requirements for a complete application for an ECA.

These minimum requirements allow the ministry to review an ECA Application to decide whether it is complete and therefore whether the Director should proceed to consider the application and make a decision to issue, refuse to issue, or amend an ECA.

These general minimum ECA application requirements for stormwater management include but are not limited to:

- You must use the correct form and provide all the applicable information requested.
- You must provide a detailed project and process description.
- You must provide a summary project description.
- You must provide information around ownership, land use and zoning, with some exceptions, as noted.
- You must provide a site plan, with some exceptions as noted.
- You must provide signatures certifying to the completeness and accuracy of the information.
- You must include a concise and defensible explanation of the SWM design, specifically the rationale for the selection and use of BMPs within each of the Priority 1-3 levels following the Mandatory Control Hierarchy (**Section 3.3.2**)
- Maps, plans and drawings must adhere to minimum information standards.

7.5.4.1 How to Avoid Poor Quality Stormwater Submissions

To avoid submitting incomplete applications which will slow the approval process or result in your application being returned, the following list details some of the actions or omissions which would result in an incomplete or poor quality submission

- Not including design details in plans. (Draft or conceptual plans that do not have sufficient detail to demonstrate compliance with the ministry's requirements are not acceptable; however final 'as built design plans' are unnecessary.)
- Not including reports that are needed to accurately describe the various elements, processes, function, site conditions, operation and maintenance activities (and associated costs) etc.
- Not including detailed technical information, such as a design reports or brief, SWM reports and associated engineering drawings.
- Submitting a technical analysis that is inconclusive, that is, your design and analyses do not show how your proposal is compliant with ministry requirements and relevant SWM criteria and targets.
- Submitting a technical report that does not outline site-specific conditions, potential environmental impacts and proposed environmental protection measures (including proper erosion and sediment control with construction staging plans) to meet current regulatory requirements.
- Incomplete application payment.
- Providing drawings or site specifications that are illegible or difficult to read.
- Not explaining acronyms or terms such that the ministry cannot understand your application.
- Submitting drawings, design reports and / or brief, SWM reports or other information that had to be prepared by someone with specific technical qualifications, for example, a professional engineer or professional geoscientist, without a stamp or signature for certification.

In general, a high-quality application will be one where the person preparing the application has procedures to identify and mitigate any mistakes, errors or omissions in the supporting documents that are developed.

7.5.4.3 Knowingly Providing False Information

The ministry also reminds applicants that it is an offence under section 184 of the EPA and section 98 of the OWRA to give false or misleading information to the ministry regarding matters under these Acts or the regulations related to them. A conviction for the offence of providing false information may result in a fine, imprisonment or both.

7.5.5 Submission Checklist for LID BMPs

The following section summarizes the minimum submission requirements and supporting documentation requirements to support the acquisition of an ECA per OWRA section 53 for either Industrial, Municipal Sewage Works or Private Sewage Works. **Table 7.5.5** summarizes the submission requirements relating to SWM and LID BMPs. **Table 7.5.5** Is not intended to be comprehensive, but rather has been developed to guide applicants in the preparation of LID BMP related ECA applications. The **Table 7.5.5** below summarizes the types of reports and information required concerning different types of sewage works. It should be noted that the content of the same type of report will vary depending on the type of works the report relates to.

It should be noted that the ministry may request additional information if necessary to review the application. All engineering design information you provide must be prepared and properly certified by a professional engineer licensed in Ontario.

Table 7.5.5 - Outlines the technical requirements for ECA Applications involving Industrial, Municipal and Private Stormwater (Sewage) Works.

Technical Requirement Section in Guide	Description	Industrial Stormwater Works	Municipal Stormwater Works	Private Stormwater Works	Requirement for LID BMPs
Pipe Data Form	Standard form [PIBS 6238] for sewage works involves storm sewers, ditches, sanitary sewers, forcemains and/or pumping stations(s). The information contained within the form and the stamped Final Plans or Issued for Approval (IFA) Drawings are the minimum requirements used to apply for an ECA	✓ Required for the establishment of new storm sewers, combined sewers and ditches.			✓ Not typically required for LID retrofits or infill-developments where existing storm sewer are to remain.
Design Report / Brief	Is the written record of the project and generally includes at a minimum all relevant project background and history, SWM criteria and demonstration as to how the proposed design meets the criteria. Includes design information and product information, supporting calculations and modelling files, O&M manuals etc.	✓	✓	✓	✓ See **Section 7.5.5.1**
Stormwater Management Plan	Illustrates the layout of the proposed SWM works including at a minimum detailed information relating the land-uses, drainage boundaries, discharge and monitoring locations	✓ (Include in site plan)	✓ (Include in IFA Drawings)	✓ (Include in IFA Drawings)	✓ (Include in IFA Drawings)
Stormwater Management (SWM) Report	The SWM report describes the hydrological and hydraulics site conditions and typically contains detailed design of stormwater controls and environmental restoration works, delineation/confirmation of constraint boundaries, sediment/erosion control plans, geotechnical studies, hydraulic and hydrologic analyses, and preservation and restoration/remediation plans. Typically combined with the Design Report/ Brief.	✓	✓ (Include in Design Report)	✓ (Include in Design Report)	✓ (Include in Design Report)
Preliminary Engineering Report	Description of any proposed stormwater management and/or treatment facilities, including analysis of stormwater flows, methods for stormwater source controls, retarding runoff, routing, and regulating flows through and in the collection system; retention, filtration and detention of stormwater; proposed methods of treatment; and a description of water quantity and quality targets as documented in the official watershed and/or subwatershed plans or names of the authorities (municipality, conservation authority, Ministry of Natural Resources, Ministry of the Environment) that established or approved the design criteria.	**n/a**	✓ (Include in Design Report)	✓ (Include in Design Report)	✓ (Include in Design Report) - See **Section 7.5.5.1**

Environmental Impact Analysis	Presents the anticipated impact of the works' final effluent on the receiver (that is, surface water body, land area, soil and/or groundwater) and its potential users (Assimilative capacity)	If applicable. Not typically required for stormwater management projects			
Site Plan	Shows the entire property where the facility is to be (or is) located, topographic features, site features (roads and adjoining lands), watercourses, drainage features, known flood levels, layout of proposed SWM works/ features and geotechnical information.	☑	☑ (Include in IFA Drawings)	☑ (Include in IFA Drawings)	☑ (Include in IFA Drawings)
Stormwater (Sewage) Quantity and Quality	Describes the quality and quantity of stormwater which is proposed to be managed. Quantity is typically described through detailed calculations or modelling and includes pre- and post development water balance calculations. Quality is described through literature relating to non-point source contaminants and/ or from local detailed monitoring studies (urban or receiver based) and expected performance of proposed SWM and LID BMPs based on modelling or literature.	☑	☑ (Include in Design Report)	☑ (Include in Design Report)	☑ (Include in Design Report)
Final Plans or Issued for Approval (IFA) Drawings	All final plans submitted in support of applications for approval of sewage works must bear, at a minimum, the project title, name of the municipality, name of the development or facility with which the project is associated, and name of the design engineer, including a signed and dated imprint of his/her registration seal. Where applicable, the plans must include the plan scale, geographic north, land surveying data and any municipal boundaries within the area shown. Detailed engineering plans should include plan views, elevations, sections and supplementary views which, together with the specifications and general layout plans, would provide the working information for finalizing of the construction contract for the works. These drawings should show dimensions and relative elevations of structures, the location and outline of equipment, location and size of piping, ground elevations and liquid/water levels at the minimum and maximum flow conditions.	n/a	☑	☑	☑ See the **Resource Directory** for design drawings requirements

Engineering Drawings and Specifications /Sewage Works – Specifications	Detailed technical specifications for all sewage works projects. The specifications should include all other information that a third-party contractor would be required to know to conform to the project's requirements and/or as stipulated under a current ECA. In the case of minor works, such as minor storm or sanitary sewer extensions, you can generally note these specifications (as recommended) on the final plans.	✓	✓ (Include in IFA Drawings or as separate section)	✓ (Include in IFA Drawings or as separate section)	✓ (Include as notes within IFA Drawings)
Detailed Description of proposed works (in addition to the detailed project and process description)	Provides sufficient detail so that someone can locate and identify the works in the field without the use of engineering drawings. Recommended to include locations, names, types, number, sizes and capacities of all vital structures and pieces of equipment in the proposed works, and must identify the role of the individual components in the process flow. You should describe the individual components of the works in separate paragraphs.	✓	✓	✓	✓ (Include in Design Report) - See **Section 7.5.5.2**
Operation and Maintenance Manual including Estimate Costs	A report detailing the maintenance recommendations based on the approved stormwater management BMPs. The report shall include, but is not limited to, the following recommendations: • Inspection frequency of all structures, apertures and functional design elements (minimum of once annually); • Sediment removal frequency, technique and equipment; • Method for the re-stabilization of all disturbed areas; • Sediments testing protocols and method of disposal (if applicable); • Effluent sampling protocol (if applicable for novel, or un-tested BMP approaches); • BMP design life expectancy; • Annual maintenance cost estimates; and • Replacement/ refurbishment recommendations/ plans at the conclusion of BMPs life cycle.	✓ (Include in Design Report)	✓ (Include in Design Report)	✓ (Include in Design Report)	✓ (Include in Design Report)
Seasonally High Groundwater Elevation	Represents the elevation to which the ground or surface water can be expected to rise due to a normal wet season. Typically measured in March to April or Late fall before snowfall	✓ (Include in Design Report and IFA Drawings)	✓ (Include in Design Report and IFA Drawings)	✓ (Include in Design Report and IFA Drawings)	✓ (Include in Design Report and IFA Drawings)

<table>
<tr><td>Geotechnical Investigation</td><td>Describes the site's general soil conditions, classifications and characteristics and stratigraphy. Can also include groundwater conditions.</td><td>☑ (Include in Design Report)</td><td>☑ (Include in Design Report)</td><td>☑ (Include in Design Report)</td><td>☑ (Include in Design Report)</td></tr>
<tr><td>In-situ Soil Infiltration Rates</td><td>Describes the results of experimentally derived in-situ native soil infiltration rates for BMPs that are intended to be full or partial infiltration systems in accordance with Appendix C of the LID Stormwater Planning and Design Guide – See the Resource Directory</td><td>☑ (Include in Design Report)</td><td>☑ (Include in Design Report)</td><td>☑ (Include in Design Report)</td><td>☑ (Include in Design Report)</td></tr>
<tr><td>Groundwater Mounding Analysis</td><td>Describes the results of the groundwater mounding analysis. See the Resource Directory

A groundwater mounding analysis is not required where:
<table>
<tr><td>Criterion</td><td>Condition 1</td><td>Condition 2</td></tr>
<tr><td>Area of the infiltration practice bottom</td><td>≤ 10 m²</td><td>≤ 25 m²</td></tr>
<tr><td>Distance separating the infiltration practice bottom from the seasonal high water table</td><td>≥ 2,0 m</td><td>≥ 2,0 m</td></tr>
<tr><td>Minimum saturated hydraulic conductivity of the subsoil within 2 m below infiltration practice bottom</td><td>≥ 15 mm/h (1)</td><td>≥ 40 mm/h (1)</td></tr>
</table>
(1) Before the safety factor being considered.</td><td>☑ (Include in Design Report)</td><td>☑ (Include in Design Report)</td><td>☑ (Include in Design Report)</td><td>☑ (Include in Design Report)</td></tr>
<tr><td>Mandatory Control Hierarchy</td><td>Documentation of the selection rationale from priority 1 approaches to priority 3 approaches, explicitly describing the site restriction or restraints which prevent the implementation including all relevant supporting documentation.</td><td>☑ (Include in Design Report)</td><td>☑ (Include in Design Report)</td><td>☑ (Include in Design Report)</td><td>☑ (Include in Design Report)</td></tr>
</table>

7.5.5.1 Design Report / Brief Requirements

As described previously, to avoid submitting incomplete applications which will slow the approval process or result in your application being returned, the following minimum requirements have been identified for the preparation of design report / brief for storm sewers and SWM facilities and LID BMPs.

Design Report / Brief – Storm Sewers

Design briefs prepared in support of storm sewer applications under Section 53 of the OWRA, are expected to contain the following minimum information:

a) Identification of sub-drainage areas and their runoff coefficients.
b) Anticipated rainfall frequency and intensity.
c) Generated flows and capacity of sewers selected.
d) Capacity of the receiving watercourse or existing storm sewers to accept the anticipated design flows.
e) Design data and calculations for individual sewers, including the required capacity, sewer slope, roughness coefficient, pipe capacity, flow velocity when full, depth of flow, and actual flow velocity at peak design flow if depth of flow is less than 0.3 of the pipe diameter.
f) Minimum separation distance from watermains.

Design Report- SWM Facilities

Design briefs prepared in support of SWM facility applications under Section 53 of the OWRA, are expected to contain the following minimum information:

a) Identification of the drainage area and the receiving water body.
b) summary of the design criteria:
    - major and minor flows, site-specific target flow rates, land use restrictions, that is, maximum percentage of imperviousness, minimum watercourse buffer strips, required level of treatment, etc.
    - identification of the design criteria sources:
        i. master drainage plan,
        ii. watershed plan and/or subwatershed plan
        iii. or names of the authorities (municipality, conservation authority, Ministry of Natural Resources, Ministry of the Environment) that established or approved the design criteria.
c) pre-and post-development water balances calculations and definition of infiltration targets based on post development infiltration deficit unless specified within studies noted in b) above.
d) Summary of fluvial geomorphology criteria and recommendations for baseflow and erosion thresholds etc.as required.
e) summary of information about anticipated storms and flows generated for pre-development, uncontrolled
f) post-development, controlled post-development conditions with hydrographs, including the methodology used for calculations (computer models, rational method, runoff coefficients, etc.) complete with drainage boundaries.
g) Information about hydraulic capacity of the receiving watercourse, swale, natural channel or existing storm sewers to accept the anticipated flows, including water balance calculations for determining the receiving stream baseflow.
h) Identification of proposed volume control facilities following the mandatory control hierarchy (See **Section 3.3.2**)

- Identification of proposed **Control Hierarchy Approach 1 (Retention**) – Low Impact Development retention technologies 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 re-use collected rainwater for internal or external uses respectively. Retention facility are required to achieve mandatory on-site water balance requirements.

- Identification of proposed **Control Hierarchy Approach 2 (LID Volume Capture and Release)** – Low Impact Development filtration technologies which utilize filtration to filter runoff using LIDs with appropriate filter media per the LID Stormwater Planning and Design Guide (2010, v1.0 as amended from time to time) by which 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 Volume Capture and Release may be infiltrated or evapotranspirated).

- Identification of proposed **Control Hierarchy Approach 3 (Other Volume Detention and Release) -** 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 contaminates from runoff; and/or facilitate the sedimentation and removal of contaminants respectively by which the controlled volume is treated and released to the municipal sewer networks or surface waters at a reduced rate.

- Documentation and rational for the selection process for the proposed control hierarchy with justification based on the site-specific conditions and environmental objectives.

i) Description and design details (including calculations) of the stormwater management works, including minor and major stormwater conveyance systems and stormwater volume, quantity and quality control facilities, together with the discharge control and emergency overflow features, outfall locations, and any temporary and permanent erosion and sediment control facilities including construction staging requirements.

j) Description of hydraulic routing of the anticipated and major (that is, 100-year or Regional) storms through the works, including hydrographs.

k) Detailed description of the proposed operation and maintenance procedures (O&M Manual) for the works, including an agreement between the local municipality and the applicant outlining a maintenance program that contains the name of the operating authority or the person responsible for the maintenance and operation. O&M Manuals shall include:
    - Inspection frequency of all structures, apertures and functional design elements (minimum of once annually);
    - Sediment removal frequency, technique and equipment;
    - Method for the re-stabilization of all disturbed areas;
    - Sediments testing protocols and method of disposal (if applicable);
    - Effluent sampling protocol (if applicable for novel; or un-tested LID BMP approaches);
    - BMP design life expectancy;
    - Annual maintenance cost estimates; and
    - Replacement/ refurbishment recommendations/ plans at the conclusion of BMPs life cycle.

7.5.5.2 LID BMP Detailed Description Examples

The following section provides examples of detailed description for various LID BMPs in support of the acquisition of ECA from the MOECC relating to LID BMPs within:

- A municipal right-of-way (ROW)
- A municipal building site (community centre)
- A commercial building
- A subdivision

Example Detailed Description 1 - LID BMPs within a municipal right-of-way (ROW)

The proposed retrofit will utilize 3 bioretention facilities at the intersection of (1. Street A, and Street B (surface area of 86m^2); 2. Street A and Street C (surface area of 85m2); and 3. Street A and Street D (surface area of 73m^2) in Anytown, Ontario to provide water quality control and reduce stormwater flows from the 0.304ha, 0.074ha & 0.086ha drainage areas respectively. Facility inverts are located within native medium to fine sands and is designed to recharge local soils and infiltrate rainfall depths of 19, 18.5 and 6mm for every event (facility 1, 2 & 3 respectively). Each facility will provide water quality control equivalent to Level 1 by treating the 25mm event through sedimentation, filtering, plant uptake, soil adsorption, & microbial processes. Bioretention medias used in this design have been shown to provide long-term TSS removal greater than 80% for the contributing drainage areas. Per the MOE guide "any stormwater management practice that can be demonstrated to meet the required long-term suspended solids removal for the selected levels under the conditions of the site is acceptable for water quality objectives."

Example Detailed Description 2 - LID BMPs within a municipal building site (community centre)

The proposed project includes reconstruction and stormwater management (SWM) retrofit of the existing Parking lot at the City Community Centre located at 123 Community Centre Lane in Anytown, Ontario. The existing site currently does not include SWM controls for quality, temperature and or volume and only limited water quantity control and discharges directly to the adjacent Water Creek through a series of outlets. The project includes a holistic SWM retrofit using Low Impact Development (LID) techniques per the Anytown Stormwater Management Master Plan. The project has received financial and project team support from the Conservation Authority. The project team included representatives from the City, CA and Region.

The SWM elements include 1630 sq.m of permeable interlocking concrete pavers (PICP) within the parking surface (controlling a drainage area of 0.738 ha) and 1400 sq.m of permeable interlocking concrete pavers (PICP) pedestrian pathways (accepting direct rainfall only); 230 sq.m of permeable grid paver to replace impervious access roads (accepting direct rainfall only); a 118 sq.m of rain garden (controlling a drainage area of 0.195 ha), 220 sq.m of bioswales (controlling a drainage area of 0.287 ha) as well as the conversion of an existing dry-pond into a 275 sq.m bioretention (rain garden) facility within the adjacent Park (controlling 0.236 ha) and the inclusion of an in-line propriety filtration device. In keeping with the objectives of the Lake Protection Plan, the design includes the use of phosphorous sorption materials (PSMs), specifically the use iron filings additives to bioretention media as well as the use of the in-line propriety filtration device. is designed to provide polishing as part of the treatment train of LID outflows through the removal of 60% of the total remaining phosphorous.

The project also includes the restoration of eroding stream banks of Water Creek and the naturalization of the riparian corridor through the removal and relocation of the existing asphalt parking surface away from the top-of-bank and naturalization through plantings.

Example Detailed Description 3 - LID BMPs at a Commercial Site

The subject project is for the establishment of stormwater management works at a commercial site redevelopment located at 123 Easy Street, Anytown, Ontario, for the collection, transmission, treatment and disposal of stormwater runoff from a total catchment area of approximately 0.618ha, to improve the quality of stormwater runoff as compared to existing conditions and to attenuate post-development peak flows and volumes for all storm events up to and including the 100 year return storm discharging to Water Creek to the maximum extent possible. The stormwater works consisting of one (1) 268 sq.m bioretention (rain garden) facility and one (1) 1,110 sq.m of permeable interlocking concrete pavers (PICP) parking lot facility located at the building front entrance employee parking lot which operate collectively to provide a total storage volume of approximately 523 cu.m.

The one (1) 268 sq.m bioretention (rain garden) facility located within the parking lot island at the building front entrance parking lot, services a catchment area of approximately 0.441ha, consisting of an estimated infiltration volume of 40.2 cu.m, a 0.5m deep filter media layer consisting of sand, fines and organic material, a 0.10m deep layer of pea gravel chocking course and a 200mm diameter perforated underdrain installed in a 0.20m thick layer of washed 20mm diameter clear stone and a 0.3m thick layer of washed 40mm diameter clear stone, wrapped in a nonwoven geo-textile filter cloth and an outlet control structure consisting of a series of three (3) catch basins discharging to Water Creek .
The 1,110 sq.m permeable interlocking concrete pavers (PICP) parking lot facility the building front entrance employee parking lot, services a catchment area of approximately 0.177ha, consisting of an estimated infiltration volume of 275 cu.m, consisting of an 80mm thick permeable unit paving stone, underlain by a 50mm thick 5-6mm diameter chip stone, a 0.2m thick layer of 200mm diameter clear stone, and a 0.4m thick layer of 400mm diameter clear stone and an outlet control structure consisting of a 200mm diameter perforated underdrain and a manhole with a overflow weir structure discharging to an on-site existing private storm sewer which discharging to Water Creek .

Example Detailed Description 4- LID BMPs at a Commercial Site

The subject project, which represents Phase 1 of the proposed Water Run Village, in Anytown, Ontario is located at the intersection of North Street and South Street. The subject application is for the establishment of stormwater management works within Phase 1 which is proposed to include the following LID BMPs on municipal lands which are subject to an ECA

1. 1165 sq.m of Bioswales, accepting 0.38ha, on East Road and West Road;
2. The South-West Channel within Block 19 accepting 22.37 ha of drainage and conveying the 100-year flow to a free outlet which consists of a combination of LID controls, specifically 242m of Enhanced Swale, and 265m of 525mm diam. perforated pipe (includes 8 DICBs; and conventional SWM controls, specifically 125m of 1200mm diam. concrete storm sewer including 3 manholes and 4 DICBs
3. Soil Amendments on all City parks (Blocks 18 and 17) and all boulevard areas that do not have bioswales consisting of 300mm of soil material with 20-30% Organic Content by dry weight overlain the native soils scarified (ripped) to a depth of 100mm.

Phase 1, also includes LIDs on private property including:

4. 58 Soakaway pits on all single and semi-detached residential units accepting roof-runoff, specifically lots 159-167, 175-177, 183-185, 264 -270, 280-286, 302-306, 312-314, 320-330, receiving drainage from 0.22ha, 0.12ha, 0.09ha, 0.25ha, 0.28ha, 0.18ha, 0.19ha,0.35ha and 0.17ha respectively consisting of washed 50mm diameter clear stone and, wrapped in a nonwoven geo-textile filter cloth. Each facility has on overflow to the municipal storm sewer located within the ROW.
5. Soil Amendments on all residential units consisting of 300mm of soil material with 20-30% Organic Content by dry weight overlain the native soils scarified (ripped) to a depth of 100mm.

7.6 LID Monitoring Expectations

The monitoring of stormwater management infrastructure and environmental receivers has provided insight into the effectiveness of stormwater management facilities and BMPs. Monitoring is done for compliance purposes as part of an ECA, to evaluate long-term performance trends or as a part of assumption protocols (see Chapter 10). With respect to ECA applications, compliance monitoring is essential to evaluate whether a stormwater management facility or BMP meets design criteria.

Monitoring of Design Objectives

LID monitoring associated with stormwater ECAs will differ significantly depending on project objectives. Monitoring programs for LID BMPs that are designed to reduce runoff volumes should analyse volume reductions over the course of a long monitoring period (e.g. spring through fall). At least two years of data should be collected to establish seasonal trends. Monitoring programs for LID BMPs that are designed for water quality enhancements using filtration (e.g. biofilters), should compare influent and effluent quality. It should be noted that runoff volume reduction resulting from infiltration-based LID BMPs also contributes to pollutant loading mitigation and should be considered. For more information on LID monitoring protocols see Chapter 10 of this manual.

Compliance monitoring to determine if LID BMPs are meeting design objectives may include:

- Confirming design infiltration rates are maintained;
- Confirming volume reductions are consistent with design objectives;
- Confirming water quality treatment is achieving targets; and/or
- Confirming that LID BMP is achieving design groundwater recharge.

7.6.1 Existing Monitoring Resources

There is a strong legacy of LID monitoring in Ontario conducted 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. Sources of data include:

- A monitoring guidance document published by CVC in 2015 titled "**Lessons Learned: CVC Stormwater Management and Low Impact Development Monition and Performance Assessment Guide**"
- Performance evaluations of several LID BMPs conducted by the Sustainable Technologies Evaluation Program - See the **Resource Directory**
- LID BMP monitoring plans, technical reports and case studies published by CVC - See the **Resource Directory**

On a border 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.

7.6.2 When a Monitoring Plan is Required

A **Compliance Monitoring Plan** should be provided as part of the ECA submission for most LID BMPs. Compliance monitoring should be considered during the design phase in the event that design modifications are needed to allow for monitoring (e.g. piezometers, monitoring ports, sumps, groundwater quality wells, etc.).

A Compliance Monitoring Plan is required for all LID BMPs proposed for New Development, Infill Development, Redevelopment, Intensification, Reurbanization and Linear Projects, excluding those that are in following exemption categories:

A. The project is a stormwater retrofit as defined in **Section 3.1** of this manual.
B. The project site is less than 5 ha, utilizes a LID BMP identified in the Low Impact Development (LID) Stormwater Management Guide (CVC/TRCA, 2011) and is not being implemented through a Plan of Subdivision.
C. The LID BMP is designed for TSS reductions only, is designed per the Low Impact Development (LID) Stormwater Management Guide (CVC/TRCA, 2011) and is not being implemented through a Plan of Subdivision.

If a LID BMP discharges to a sensitive receiver (e.g. Wetland, ANSI, Species at Risk Habitat), the above exemptions do not apply and compliance monitoring should be conducted. Pre-consultation with your local Conservation Authority or MNRF is recommended to confirm proximity to sensitive receivers.

Risk Based Monitoring

In areas where groundwater contamination is a significant concern, a risk-based approach to monitoring is required to confirm LID 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:

1. The project site includes any high-risk site activity as identified in **Table 4.2.1.1**; or
2. 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 an LID be found to be contributing to groundwater contamination BMP design and/or site management strategies should be modified immediately to avoid any additional pollutant loading.

8 Erosion and Sediment Control During Construction

Sediment accumulation in infiltration-based LID BMPs can result in malfunction and failure of the facilities. 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 LID BMPs are staged properly with other site construction activities and are provided with appropriate Erosion and Sediment Controls (ESC).

Figure 8.1 – Clay sediment accumulated on top of the mulch layer of a bioretention facility resulting from improper erosion and sediment controls.

8.1 Current Guidelines

ESC control methodologies and approaches 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 Erosions and Sediment Control program (CISEC - www.cisec.org) 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 the appropriate erosion controls on a subject site eliminates the erosion of soils during construction, reduces the reliance on sediment controls to reduce releases and thereby more completely 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 BMPs do not removal all suspended sediment found 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 am effective ESC plan with areas under the jurisdiction of the Greater Golden Horseshoe Area Conservation Authorities. 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

8.2 Basic Principles of ESC

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

1 Construction staging is a fundamental component of any ESC plan and is of particular relevance in the implementation of the LID BMPs.

2 Use a multi-barrier approach which begins with erosion controls, followed by sediment controls and avoids reliance on a single control point for sediment.

3 Retain existing vegetation to the greatest extent possible for a long as possible during construction.

4 Minimizes the land disturbance areas within the project site.

5 Reduce runoff velocities and detain runoff to promote settling.

6 Divert runoff from areas that are prone to erosion.

7 Minimize the slope length and gradient of disturbed areas.

8 Maintain overland sheet flow and avoid concentrated flows.

9 Store and stockpile soils away from all watercourses, drainage features and the top-of-slopes.

10 Ensure any end of pipe stormwater management facilities are fully functional and vegetated prior to development are grading.

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 (ECMs) as outlined in **Table 8.3** should be used.

8.3 Erosion and Sediment Controls BMPs

Table 8.3 identifies ESC Best Management 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 8.1,** erosion controls are the primary focus but a multi-barrier approach that uses both is necessary on all LID construction sites.

Table 8.3 – Summary of Erosion Control BMPs and Sediment Control BMPs

Erosion Control BMPs	Sediment Control BMPs

Diversion Structures
• Slope drains
• Diversion berms
• Conveyance channels
 	
Erosion Control Methods (ECMs)
• 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

8.4 Enhanced ESC for Infiltration Controls and LIDs

Protecting LIDs with a well-designed ESC plan is essential. During LID 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 elements as well as request dust control and general site clean-up as necessary.

Examples of construction best practices that should be considered when developing a 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 features (where possible). Construction materials stored up-gradient of excavated site are to be enclosed by appropriate sediment control fencing.
- Directing the concentration of runoff including overland flow routes and roof drainage away form LID facilities during construction.

- Ensuring all pipes are laid in a true line and gradient on a firm bed, free from loose material. Pipes are not to be laid on soil backfill or in a slurry and are to be securely positioned to avoid displacement before backfilling.
- Installing barriers in front of curb cuts to prevent sediment form 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**.

8.5 Erosion and Sediment Control Report

The development of an Erosion and Sediment Control Report (ESC Report) is a critical element of a successful LID BMP project. This should be a "living" document that is reviewed at all stages of construction as well as after storm events. The plan should be amended when inspections indicate ineffective practices or changes to the plan affect the discharge of pollutants. 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 areas of the site where flows concentrate.
3. Identify who will be responsible to oversee the implementation and maintenance of the practice.
4. Ultimately the responsibility lies with the owner and the general contractor as the owner usually posts a Letter of Credit with the municipality to address such issues and the owner holds back funds from the general contractor. Identify a chain of responsibility between the owner, general contractor, subcontractor and vendors involved in the project. Note: do not discount the vendors, many times problems are the result of a lack of communication between the contractor, vendors, and delivery drivers (i.e. creating mud on the streets and sediment issues).
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. Include a strategy for retaining records and who is responsible for them.

9 Operation and Maintenance (O&M)

Like all stormwater management controls, LID and / or conventional stormwater management approaches, adequate maintenance is essential to ensure the long-term stormwater management performance targets are achieved over the life span of the practice or BMP.

All stormwater BMPs, including LID BMPs are designed to retain pollutants carried by urban runoff and all have a finite capacity to perform this function in the absence of maintenance, until their treatment performance declines or they no longer function as intended. Their functional and treatment performance will only be sustained over the long term 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 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.

While the importance of adequate maintenance cannot be understated, a balance must be struck between the resources and funding available and the risks should the practice fail to achieve targets. Passive systems which are not an integral part of the overall stormwater management system (i.e. a retrofit or voluntarily implemented practice), while still requiring maintenance, may require a reduced level of effort. Conversely, a practice which is integral to the performance of the overall stormwater system or which is preserving the hydrologic function to 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 including, but not limited to, neighborhood beautification, public education, crime prevention, air quality, climate change and / or represent a significant feature which has been adopted by local residents, may require additional operation and maintenance resources and funding, regardless of its designed function. In this way, operation and maintenance resources can be allocated based on the relative risk of failure and the importance in the community based on the design goals and objectives.

It should be noted that for LID facilities which fall under provisions of the Ontario Water Resources Act provincial approvals for SWM facilities and BMPs and require an Environmental Compliance Approvals (ECA) from the Ontario Ministry of the Environment and Climate Change (See **Section 7 – Approvals**), inspection and maintenance requirements as well as all associated record keeping will be the responsibility

From the above, it is easy to identify that operation and maintenance for LIDs will share some basic activities, but that O&M can also be specialized based on the design itself. It is recommended that an O&M program be developed as part of the design and recorded within the design documentation (design brief or other) which is:

- Cost effective and efficient;
- Integrated into standard O&M activities and actions (i.e. roadway sweeping, catch basin cleaning, pipe flushing, vegetation maintenance, litter removal, sediment removal etc.)
- Leverages existing staff training, machinery and equipment;
- Includes a basic or standard list of O&M activities for each specific practices or group of practices to streamline standard operating procedures;
- Has the ability to be customized where needed based on risk, community importance or other; and

- Refined and adapted based on a feedback system which informs subsequent plans and activities.

The following sections of this chapter:

- Summarizes the differences between traditional SWM practices and LID BMPs:
- Describes the process for optimizing O&M activities and costs during the design process;
- Describes the process for limiting O&M liabilities resulting from construction;
- Directs the reader to resources which provide detailed accounts of the various operation, maintenance and inspection requirement for various LID BMPs;
- Summarizes the various O&M considerations and approaches for municipally owned systems
- Outlines municipal tools and approaches for mitigating O&M risks for LID BMPs on private property.

9.1 O&M for Municipally Owned Systems

Unlike conventional SWM systems that centralize treatment facilities in few locations on publicly owned land (e.g., detention ponds) an LID design approach involves smaller scale practices distributed throughout the drainage area, potentially on both public and private land. Implementing an LID approach can have major implications on municipalities and property managers with respect to operating and maintaining the stormwater infrastructure they are responsible for, as it increases the number and types of BMPs to be tracked, inspected and maintained. In essence, it is very likely that the current methodology, frequency, software, mapping and procedures will need to be refined and adapted to account for a new type of infrastructure – Green Infrastructure.

LID BMPs are green 'infrastructure' and do therefore provide a necessary function in communities. The relative importance of this function requires that maintenance personnel and inspectors are well versed in the design, intended function and maintenance requirements of each system. Just as contractor education is critical to ensure proper post-construction function, the education and training of the individuals servicing LID BMPs is vital to their long-continued operation.

Table 9.1 below summaries the various general categories of O&M activities for both conventional SWM practices and LID BMPs. **Table 9.1** is not intended to be comprehensives, but rather a comparison which demonstrates where O&M activities differ and where they are similar. Additional detail in regards to specific O&M activities for LIDs is provided in **Section 9.4**. Facility refurbishments is not considered operation and maintenance as they typically represent a capital activity, but should and are included in life cycle cost assessments.

Table 9.1 - O&M Activities: Conventional SWM Approaches vs. LIDs

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

(Adapted from: MOE, 2003 and TRCA/STEP, 2016)

9.2 Optimizing O & M During Design

To ensure LIDs and all BMPs represent a valued investment of capital dollars and are finically sustainable over their design life, it is important to optimize the design with a focus on long-term operation and maintenance. Consideration should be given to:

- **Standard Products:** Use of standard products such as curbs, inlet, overflows, and catch basins vs. specialized or one-off products. 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 of up to 2-years can be an effective means to ensure that when assumed, O&M activities are minimized. A significant cost is associated with LIDs that are deficient upon assumption;

- **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 significantly reduce O&M and increase life-expectancy of the facility;

- **Sediment Removal:** Sediment removal techniques will differ by pre-treatment practices but may involve hand tools, or high-pressure washer and vacuum trucks. The frequency of sediment removal will vary depending on pre-treatment practice and catchment conditions. By selecting pre-treatment devices which have easy assess to the accumulated sediment, are most appropriate for the workforce tasked with undertaking the removals, consider the type of equipment available and which balance the frequency of maintenance with the protection of the facility - O&M can be optimized;

- **4-Season Design:** By designing all LIDs with spring, summer, winter and fall conditions in mind, will reduce O&M costs. Consideration for vegetation deposition in the fall (i.e. blocked inlets, or temporary clogging of narrow jointed permeable pavements), and winter maintenance activities (ploughing, sanding and salting) are considered a mandatory requirement during design. A key optimization strategy can include behavioral change in regards to operation activities (i.e. sanding and salting), but also consideration of where snow if stockpiled during winter months and provisions for additional inlets or overflows for use during winter; and

- **Vegetation Selection:** By appropriate selecting vegetation which is suitable for the climate zone, local conditions as well as operational conditions, O&M can be optimized. Selection of salt and drought tolerant species, as well as species which can tolerate inundation will ensure plant survivability. Use of block plantings or limited plant pallets (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 will reduce opportunistic weed growth and reduce plant replacements. Additional detail is provided in the subsequent section.

9.2.1 Optimizing O & M and Vegetation

While not all LIDs include vegetation (i.e. permeable pavement, soakaway pits and chambers and perforated pipe systems) many can include turf, native or ornamental plantings (i.e. bioswales, bioretention areas, and green roofs etc.). Maintenance requirements for most LID technologies have little difference from most turf, landscaped, or natural areas and do not typically require new or specialized equipment (EPA, 2007). However, it is typically the vegetated component of the LIDs which create concern or apprehension in regards to operation and maintenance as opposed to the chambers, the piping networks or other more standard elements of a stormwater system which practitioners are familiar. However, 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 in the design process and can be used to limit operational and maintenance burdens. Common practices in vegetation selection to limit O&M requirements are detailed in the **Table 9.2.1.**

Table 9.2.1 – Vegetation Selection Strategies to Limit O&M During Design

	Vegetation Selection in Design	Other Considerations
Lower O&M ↓ **Higher O&M**	• Rock mulches • Turf and / or sod • Naturalized plantings (not ornamental). Can include native plants • Trees and shrubs only • Ornamental perennial plants and grasses (lower species diversity - limited number of species) • Ornamental perennial plants and grasses (high species diversity – greater number of species) • Annuals	**Lower climate change co-benefits from ET, habitat and aesthetics.** ↓ **Greater climate change co-benefits from ET, habitat and aesthetics.**

As such, for vegetated practices, there may be a general requirement for a transfer of 'traditional' SWM maintenance resources and funds (outlet inspections, pond dredging, vacuum trucks to empty OGS systems etc.) to a more landscaped based SWM maintenance program. Municipalities generally have the required staff and infrastructure within other departments (such as the Parks Department, Urban Forestry, and Operations) including staff with training and expertise in arboriculture, horticultural, and / or landscape architecture, whereas private properties have access to trained service professionals from the landscape industry. Therefore, the adaptation of traditional operation and maintenance practices to LID may require only a transfer of funding and additional training on the function and acceptable practices of LIDs specifically.

Furthermore, in developing the procedures and methodologies to guide the maintenance and inspection of the landscape components of LID BMPs, it must be recognized that the landscape is a living system that evolves in response to the environment and natural successional processes. Consequently, the maintenance program must 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 served as the basis for developing the landscape maintenance program:

- 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.

9.2.2 O & M Manuals and Design Briefs

As a component of any SWM plan to support development, the proponent shall be required to complete and provide a report detailing the maintenance recommendations based on the approved stormwater management BMPs. The report shall include, but is not limited to, the following recommendations:

- Inspection frequency of all structures, apertures and functional design elements (minimum of once annually);
- Sediment removal frequency, technique and equipment;
- Method for the re-stabilization of all disturbed areas;
- Sediments testing protocols and method of disposal (if applicable);
- Effluent sampling protocol (if applicable for novel; or un-tested LID BMP approaches);
- BMP design life expectancy; and
- Replacement/ refurbishment recommendations/ plans at the conclusion of BMPs life cycle.

The costs associated with the maintenance of the various stormwater management plan elements may vary with the type and size. The proponents shall submit a maintenance program estimate for the duration of the anticipated life-cycle of each element of the proposed BMPs. Sources such as the TRCA/CVC LID Planning and Design Guide (2010) and the TRCA/ STEP Assessment of Life Cycle Costs for Low Impact Development Stormwater Management Practices (2013) or most recent should be consulted when developing O&M and life-cycle costs. See the **Resource Directory.**

9.3 Optimizing O & M During Construction

Even with sound design following the various guidance documents (see the **Resource Directory)** and through design optimization strategies as detailed above, 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:

- 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 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.

9.4 Operation and Maintenance Requirements for LID

In 2016, the Toronto and Region Conversation Authority (TRCA) under the Sustainable Technologies Evaluation Program (STEP) released the Low Impact Development Stormwater Management Practice Inspection and Maintenance Guide (Version 1.0).

This guidance document is intended to assist municipalities and industrial/commercial/institutional (ICI) property managers with developing their capacity to integrate LID BMPs into their stormwater infrastructure 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 brief summary in provide in **Section 9.5.**

- **Part 2** of the document establishes standard cold climate protocols for inspection, testing and maintenance of seven (7) types of structural LID BMPs. This guidance document has dedicated chapters to:
    - Bioretention and Dry Swales
    - Enhanced Swales
    - Vegetated Filter Strips and Soil Amendment Areas
    - Permeable Pavements
    - Underground Infiltration Systems
    - Green Roofs
    - Rainwater Cisterns

  Each chapter of Part 2 provides a detailed 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.

For a link to the **Low Impact Development Stormwater Management Practice Inspection and Maintenance Guide (Version 1.0)** visit the **Resource Directory.**

9.5 O&M for Municipally and Private Owned 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 9.5.1** adapted from the 2016 Low Impact Development Stormwater Management Practice Inspection and Maintenance Guide summarizes key questions which highlight the preliminary work and key decisions that need to be made to establish the scope of an LID BMP inspection and maintenance program.

Table 9.5.1 – Key O&M Program Scope Setting Questions adapted from the Low Impact Development Stormwater Management Practice Inspection and Maintenance Guide (Version 1.0)

Key Questions	Description/ Summary	Relevant Section †
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.	**Section 1.1**
2. Who is Responsible?	Assigning responsibility for inspection and maintenance tasks is an important policy question and one that may have multiple answers depending on the location and function of the BMP.	**Section 1.2**
3. What is the Current Status of Legal Tools for Inspection and Maintenance?	When part of a SWM system approved under an MOECC ECA process, stormwater utility fee credit program, or combined sewer overflow (CSO) abatement program, municipalities must have the legal authority to require inspection and maintenance of BMPs located on private property, or it is likely that these duties will be neglected. The proper legal authority includes assigning maintenance responsibility through a municipal stormwater infrastructure program policy, legally binding maintenance agreements between the municipality and property owner, easements that provide adequate access to BMPs, and enforcement mechanisms.	**Section 1.3 & 3.3**
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.	**Section 1.4 & Table 1.1**
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.	**Section 1.5 & Table 1.2**
6. Should the Responsible Party Use In-House Resources, a Contractor or Both?	Large municipalities and property management organizations with numerous properties and BMPs to maintain may choose to use in-house staff to conduct BMP maintenance. However, for small to medium-sized organizations, employing private contractors is often more efficient than hiring new staff and purchasing equipment.	**Section 1.6**
7. 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 SWM 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.	**Section 1.7 & Section 3.3.2**

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

For a link to the **Low Impact Development Stormwater Management Practice Inspection and Maintenance Guide (Version 1.0)** visit the **Resource Directory.**

9.5.1 Approaches to Assigning Responsibilities

As detailed in Section 2.0 of the 2016 Low Impact Development Stormwater Management Practice Inspection and Maintenance Guide (Version 1.0) – Visit the **Resource Directory -** a critical policy decision facing municipalities regarding inspection and maintenance of stormwater infrastructure is who will be responsible, and for what types of tasks because the decision affects 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:

1. **Property owner approach**: Property owners are responsible for performing all inspection, maintenance and repair/rehabilitation for BMPs on their properties and associated record keeping. 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.

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 (e.g., could include those implemented as part of a stormwater utility fee credit program or CSO abatement plan).

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

Each of the three approaches detailed above are summarized in **Table 9.5.2**, including their strengths and weaknesses.

Table 9.5.2 - Three General Approaches to Assigning Responsibilities

Typical Program Characteristics	Strengths/Weaknesses
Property Owner Approach	
• 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 • 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	**Strengths:** • Least costly approach for municipalities **Weaknesses:** • Highest potential for non-compliance
Public Approach	
• Municipality responsible for inspection and maintenance tasks for all regulated BMPs and any others that qualify for inclusion in their program (e.g., part of a stormwater utility fee credit program or CSO abatement plan) • BMPs required to meet regulatory requirements should only be located on public property or in rights-of-way • 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:** • Municipality has the most control over Maintenance practices and schedules • Compliance enforcement issues are minimized **Weaknesses:** • Most costly approach for municipalities
Hybrid Approach	
• Municipality inspects and maintains BMPs on public land, and within rights-of-way or easements on private property • 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	**Strengths:** • Maximum flexibility • Useful during transition from property owner to public approaches as programs mature **Weaknesses:** • Potential for noncompliance if roles & responsibilities are not made clear to all parties

Source: adapted from the Low Impact Development Stormwater Management Practice Inspection and Maintenance Guide (Version 1.0) and CWP, 2008.

9.6 Private Property O&M – Municipal Tools and Approaches

The approval and subsequent O&M activities of LID BMPs on private property has repeatedly been identified as a common concern for Ontario municipalities. While this concern is valid, many Ontario and neighboring U.S. municipalities have developed solutions to mitigate the risks of O&M non-compliance, facility failure, ability for the municipality to maintain in the event of non-compliance and associated cost recovery mechanisms.

Table 9.6.1 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 mechanism and/ or approaches can be applied to a specific project or group of projects. It is intended that the mechanisms and approaches listed within **Table 9.6.1** be included, modified and / or adapted by the subject municipality responsible for approval based on the local context and existing legal framework.

Table 9.6.1 – Summary of Municipal Tools and Approaches relating to O&M Activities of LIDs BMPs on Private Property

Mechanism/ Requirement	Outcome	Applied Through
O&M Financial Responsibility • All costs for constructing and maintaining the SWM Facility/LID or structure shall be 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 shall be placed over the private facility/LID including an easement for access from the nearest vehicular entrance off of the municipal right-of-way and extending to the facility, and shall be dedicated to the municipality. This easement (if required) shall be such that it grants the municipality with the right-to enter and inspect the facility. The easement shall include 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. To be of legal standing, 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 shall supervise and certify 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)
Definition of O&M Activities Subject to ECA • Where a LID BMPs is subject to the Ontario Water Resources Act provincial approvals for SWM facilities and BMPs and require an Environmental Compliance Approvals (ECA) from the Ontario Ministry of the Environment and Climate Change (MOECC), the maintenance activity requirements and facility function should be measured against the property specific Environmental Compliance Approval (ECA) as issued and approved by the MOECC.	• Defines O&M activities to be completed and enforced	• MOECC Environmental Compliance Approval (ECA)
Definition of O&M Activities Not Subject to ECA • Where a LID BMPs is <u>not</u> subject to the Ontario Water Resources Act provincial approvals for SWM facilities and BMPs and do not require an Environmental Compliance Approvals (ECA) from the Ontario Ministry of the Environment and Climate Change (MOECC), the maintenance activity requirements and facility function should be measured against the O&M manual contained within the required design brief.	• Defines O&M activities to be completed and enforced	• Approvals (subdivision agreement, site plan or other)
Annual O&M Reporting & Inspection • An annual report shall be submitted by the property owner to the municipality verifying that the required maintenance activities as defined with the O&M manual (design brief) and /or ECA has been completed and the facility(ies) are functional and meet the designed performance target. The municipality shall reserve the right to inspect all such facility(ies) at its discretion provided 48 hours notice is given prior to inspection.	• Documents O&M activities on private property • Municipality reserves the verify maintenance has occurred	• Approvals (subdivision agreement, site plan or other) • By-law • SWM Utility or SWM Rate Structure if applicable.

Mechanism/ Requirement	Outcome	Applied Through
Mechanism for Assurance of O&M • For commercial properties, annual O&M and associated reporting requirements as specified, must be received and approved prior to the renewal of 1) SWM 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	• SWM Utility or SWM Rate Structure if applicable. • By-law
O&M Non-Compliance when Subject to ECA • Should repairs or maintenance to any LID feature be abandoned by the property owner, the municipality shall maintain the right to enter and perform the necessary maintenance as described within the Environmental Compliance Approval (ECA) as issued and approved by the MOECC, the municipality shall be obligated, at its discretion, to notify the MOECC of non-compliance and shall work with local enforcement officers to enforce the conditions of the ECA. Should the municipality be forced to undertake the prescribed maintenance activities, all costs shall be recovered through the provisions of the Property Standards By-law or other and collected through property tax.	• Utilizes existing compliance mechanism to enforce O&M • Permits the municipality to recover costs for maintenance activities through existing or amended by-laws	• MOECC Environmental Compliance Approval (ECA) • By-law
O&M Non-Compliance when Not Subject to ECA • Should repairs or maintenance to any LID feature be abandoned by the property owner, the municipality shall maintain the right to enter and perform the necessary maintenance as described within O&M manual contained within the required design brief. Should the municipality be forced to undertake the prescribed maintenance activities, all costs shall 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
Minimization of Post Construction O&M - Contingency Areas or Practices • The proponent shall 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 SWM targets in sensitive environments • Allows for a performance verification mechanism	• Approvals (subdivision agreement, site plan or other)

Mechanism/ Requirement	Outcome	Applied Through
Minimization of Post Construction O&M – Letter of Credit/ Construction Phasing • The proponent shall provide a letter of credit based on 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 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 SWM targets in sensitive environments • Allows for a performance verification mechanism	• Approvals (subdivision agreement, site plan or other)
Notice of O&M Responsibility - Notification to Buyers • The proponent agrees to 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 shall obligate the builder to notify purchasers of the exact location, size and intent of lot level facilities. The wording of the statement shall be to the satisfaction of the respective approval authority.	• 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 shall 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. • Legally establishes O&M requirements on the property title.	• Approvals (subdivision agreement, site plan or other)

10 Assumption Protocols and Performance Verification

For LID BMPs that will be assumed by a municipality, the site developer may be required to complete a Certificate of Completion that verifies LID BMP specifications and performance for approval following the post-construction period of LID BMP stabilization and vegetation establishment but prior to property transfer.

The Stormwater Management Certification Protocols for Low Impact Development (CVC, 2012) document details five (5) levels of SWM Certification Protocols (simple to complex) that can be used to verify a variety of infiltration and filtration practice designs and performance. The certification protocol 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 practices 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 owner takes over maintenance responsibilities.

Level 1 Certification - 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, an 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- 48 hours following a rainfall event)

Visual inspection alone cannot provide quantitative information about the LID performance and should be done in conjunction with qualitative monitoring and testing

Level 2 Certification – 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 is a tool that is used to measure in-situ saturated hydraulic conductivity.

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 Certification – 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. 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 Certification – 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 Certification – 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).

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 present 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 conducting 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.

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 allow estimation of loads and development of Event Mean Concentrations (EMC).

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:

1. Weather is unpredictable and can produce various runoff volumes of various durations with varying pollutant concentrations at various times.

2. 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.

3. Equipment malfunction due to rodents, electrical interferences, routine wear, storm damage/loss, or vandalism are common.

4. 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.

10.1 Conventional SWM Monitoring Programs

Compliance monitoring requirements for ECAs is discussed in **Section 7.6** of this manual. 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 quality parameters. Several key parameters and data collection methods are identified in **Table 10.1**.

Table 10.1: Conventional stormwater management monitoring parameters and collection methods

Data Type	Monitoring Parameters	Collection Methods
Water Quantity	Flow rates, long-term flow regime and total volume discharges at hydraulic structures	Loggers at facility inlet and outlet with rating curves
	Water levels within facilities and storm sewers	Loggers and/or staff gauges
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) • Total Suspended Solids (TSS) • Bacteria • Organic Compounds (Hydrocarbons, Pesticides, etc.) • Turbidity • Temperature • pH • Conductivity	Water quality probes and grab samples

Data Type	Monitoring Parameters	Collection Methods
	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) • Total Suspended Solids (TSS) • Bacteria • Organic Compounds (Hydrocarbons, Pesticides, etc.)	Automated water quality samplers calibrated for flow proportional sampling

10.2 Post-Assumption LID Monitoring Programs

Although many of the objectives of LID monitoring are consistent with conventional stormwater management practices, 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 LIDs such as bioretention facilities and bioswales to reduce runoff rates and mitigate associated pollutant loading is dependant 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 is a tool that is used to measure in-situ saturated hydraulic conductivity. After assumption protocols are meet, using this device to test infiltration rates is only necessary if prolonged ponding of water is noted.

Volume Reduction: Reducing rainfall contributions 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:

1. 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.
2. 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.
3. **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 provides valuable information on removal rates but neglects loading reductions accomplished via volume reduction. For all infiltration-based LIDs, 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.

10.2 Watershed, Subwatershed and Catchment Level Monitoring

When applied across a large geographical scale such as a subwatershed or watershed, source and conveyance controls provide a wide range of environmental benefits. To fully understand the positive impact of LID BMPs on a subwatershed or watershed, multidisciplinary monitoring should be applied as LID BMPs are being implemented across the community and continue for years after LIDs have been fully established. This approach to monitoring is especially important when LIDs are being implemented within an existing urban area as part of retrofits, infill development and re-development. Multidisciplinary monitoring will differ depending on the location and anticipated impact. Monitoring results that can indicate that LIDs 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 a healthy baseflow;
- Reductions in TSS 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.

In situations where municipalities and their partner Conservation 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 be exempt. Watershed, subwatershed and catchment level programs should be tailored to local environmental receivers and be developed in close cooperation with local conservation authorities where applicable.

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APPENDIX 1 – GLOSSARY OF TERMS

Atmospheric Deposition - Atmospheric deposition refers to the phenomenon through which pollutants, including gases and particles are deposited from the atmosphere in the form as dust or in precipitation, ultimately entering fresh water systems.

Biofilter – a bioretention stormwater best management practice featuring an impermeable liner and underdrain that prevents infiltration of runoff into the underlying native soil; provides sedimentation and filtration of urban runoff as it passes through the mulch layer, engineered filter media and vegetation root zone.

Bioretention – a stormwater filtration and infiltration practice. The practice is a shallow excavated surface depression containing a prepared soil mix, mulch, and planted with specially selected vegetation. 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 technique for incorporating shallow depressed areas into urban landscaped areas for storing and infiltrating runoff. Typically, depression storage areas are small and have limited capacity and limited duration of retention in order to address property owner concerns relating to insects, damage to structures and inconvenience of ponded water on their property.

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

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

Dry Swale – linear bioretention cells designed to convey, treat and attenuate stormwater runoff; The engineered filter media soil mixture and vegetation 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 and transpiration. For the purpose of this document, the evapotranspiration volume shall correspond to free-standing water lost to the atmosphere as well as soil and plant moisture lost to the atmosphere. Harvested rainwater which is used for irrigation and lost to the atmosphere will not be considered evapotranspiration, but rather volume retention through capture during the respective rainfall event. Irrigated volumes will instead be treated as a demand on the rainwater harvesting system which is intended to ensure sufficient capture volume is available for subsequent rainfall events to achieve the required target (see Re-use).

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

Filtration 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. Filters shall consist of an appropriate filter media per the LID Stormwater Planning and Design Guide (2010, v1.0 as amended from time to time) or a third party verified manufactured or proprietary product. Filtered runoff may be collected and returned to the conveyance system or allowed to partially infiltrate.

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 humanmade (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.

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.

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

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

Intensification – intensification of a property, site or area which results in a net increase in density, units or accommodation and can occur in the context of redevelopment and reurbanization. It includes:

a) redevelopment, including the redevelopment of brownfield sites;
b) the development of vacant or underutilized lots within previously developed areas;
c) infill development - new development on formerly vacant land;
d) the conversion or expansion of existing industrial, commercial and institutional buildings for residential use; and
e) 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.
f) **Impervious Area or Surface** are hardened surfaces which do not significant absorb rainwater and/or are not specifically designed to permit the entry of water. For the purpose of this document, impervious areas and/or surfaces shall include, but shall not be limited to, compacted urban soils and gravels, impermeable roof tops and paved surfaces (non-permeable concrete, asphalt and pavers).

Linear Projects - Construction or reconstruction of roads, trails, sidewalks, rail lines and transit infrastructure that are not part of a common plan of development or sale.

Low Impact Development (LID) is a stormwater management strategy that seeks to mitigate the impacts of increased runoff and stormwater pollution by managing runoff as close to its source as possible. LID comprises a set of site design strategies that minimize runoff 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.

New Development means the creation of a new lot, a change in land use, or the construction of buildings and structures requiring approval under the Planning Act, but does not include:

a) Activities that create or maintain infrastructure authorized under an environmental assessment process; and,
b) Works subject to the Drainage Act

Permeable pavement – is an alternative practice to traditional impervious pavement, 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 with a maximum runoff-coefficient of 0.15, whichever is most stringent.

- For Redevelopment, Reurbanization and Intensification the (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 to a maximum runoff-coefficient of 0.30, whichever is most stringent.

- For Linear Development and retrofits - the pre-development impervious condition 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 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 of new units, uses or lots on previously developed land in existing communities, including brownfield and greyfield sites. 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
- Greyfield are previously developed sites that are not contaminated.

Re-use includes storing stormwater runoff and then using it as a source of water for internal and/or external uses. Re-use is also referred to as rainwater harvesting. For the purpose of this document, the runoff collected will be treated as the retained volume 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.

Reurbanization - describes four (4) distinct types of activity, all of which serve to increase the residential or employment density on sites located within the existing urbanized area of a community. The four types of activity captured under the definition of reurbanization include:

a) infill: new development on formerly vacant land;
b) intensification: an expansion in the use of an existing structure or structures that serves to increase the density on a site
c) adaptive re-use: a change in the use of a building or structure, typically from commercial/industrial to residential, that results in greater density; and,
d) redevelopment: the wholesale change or conversion of an area, often involving some form of land assembly and/or demolition, which results in significantly higher density than existed previously (see above)

Retrofit – voluntary construction and/or reconstruction of new municipal stormwater infrastructure within an existing urban area, already serviced or inadequately serviced by stormwater infrastructure which provides a net environmental benefit. A stormwater retrofit cannot:

a) be part of a common plan of development (i.e. subdivision, site plan, plan of condominium etc.)
b) be described as new development, redevelopment, intensification and reurbanization; and
c) require approval under the Planning Act.

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

Soil amendment – the practice of adding organic material, such as mulch or compost to topsoil 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 - refers to practices which aim to recued runoff volumes, minimize the impact of polluted runoff flowing into watercourses, control the rate at which runoff is discharged, or prevent, flooding from occurring and reduces the strain that stormwater places on stormwater infrastructure.

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

Water Balance of an area over a period of time represents the way in which precipitation falling within that time period is partitioned between the processes of evaporation, transpiration, infiltration, and runoff, taking account of changes in water storage.

Vegetated filter strip – 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. 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 – subsurface water level which is defined by the level below which all the spaces in the soil are filled with water; The entire region below the water table is called the saturated zone;

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.

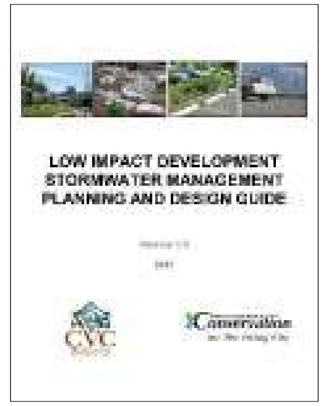
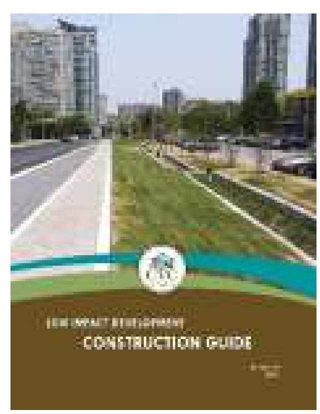
APPENDIX 2 – LIST OF ABBREVIATIONS AND ACRONYMS

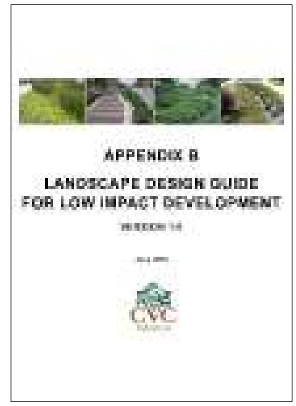
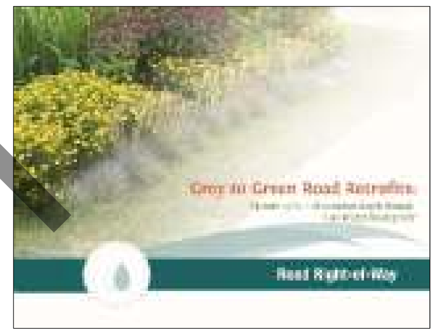
AET Actual evapotranspiration
AEM Adaptive environmental management
BMP Best management practice
CA Conservation authority
CEC Cation Exchange Capacity
CHMC Canada Mortgage and Housing Corporation
cm Centimetre
CCCMA Canadian Centre for Climate Modelling and Analysis
CofA Certificate of Approval
CWP Center for Watershed Protection
CVC Credit Valley Conservation
CSO combined sewer overflow
ESGRA Ecologically Significant Groundwater Recharge Area maps
EIS Environmental impact statement
EPA Environmental Protection Act
ECA Environmental compliance approval
EOP End-of-pipe
GI Green Infrastructure
GCM Global Circulation 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
IFA Issued for Approval
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
MTO Ministry of Transportation of Ontario
N Nitrogen
OMAFRA Ontario Ministry of Agriculture, Food, and Rural Affairs
OMMAH Ontario Ministry of Municipal Affairs and Housing
OMNRF Ontario Ministry of Natural Resources and Forestry
O&M Operation and maintenance
OWRA Ontario Water Resources Act
MOECC Ontario Ministry of the Environment and Climate Change
OPSS Ontario Provincial Standard Specification
RFS Rainfall Frequency Spectrum
ROW Right-of-way
P Phosphorus
PAH Polycyclic aromatic hydrocarbons

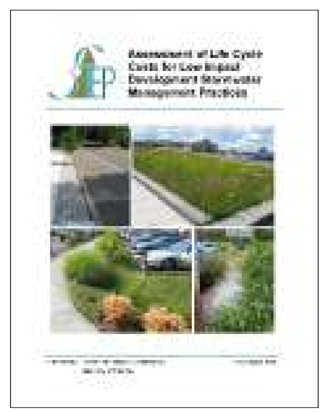
PET Potential rates of evapotranspiration
PICP permeable interlocking concrete pavers
PPS Provincial Policy Statement
PWGMN Provincial Groundwater Monitoring Network
PWQO Provincial Water Quality Objective
RVCT Runoff Volume Control Target
s Second
SGRA Significant Groundwater Recharge
SWMPDM Stormwater Management Planning and Design Manual
STEP Sustainable Technologies Evaluation Program
SWM Stormwater management
SWMGM Stormwater management guidance manual
SWMPs Stormwater management practices
TP Total phosphorus
TRCA Toronto and Region Conservation Authority
TSS Total suspended solids
U.S. EPA United States Environmental Protection Agency
WHPA Wellhead Protection Areas
WWIS Water well information system
yr Year

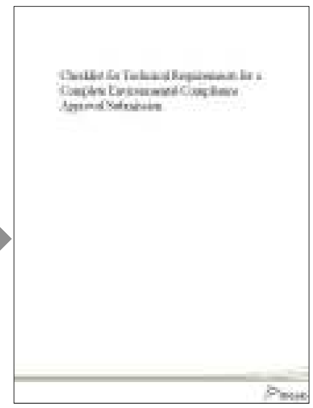
APPENDIX 3 - RESOURCE DIRECTORY

Resource Directory

Planning and Design Guide	**Low Impact Development Stormwater Management Planning and Design Guide (TRCA/CVC, 2101, Version 1.0)** http://sustainabletechnologies.ca/wp/wp-content/uploads/2013/01/LID-SWM-Guide-v1.0_2010_1_no-appendices.pdf	
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	
ECA 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	
Groundwater Mounding Analysis	**Simulation of Groundwater Mounding Beneath Hypothetical Stormwater Infiltration Basins** **USGS** https://pubs.usgs.gov/sir/2010/5102/ spreadsheet Hantush_USGS_SIR_2010-5102-1110.xlsm	
LID Performance Resources	**Sustainable Technologies Evaluation Program available** http://www.sustainabletechnologies.ca/wp/publications/ **LID BMP monitoring plans, technical reports and case studies** http://www.creditvalleyca.ca/low-impact-development/lid-maintenance-monitoring/ **International Stormwater BMP Database** http://www.bmpdatabase.org/index.htm.	

Other Resources and Reports		
	Sustainable Technologies Evaluation Program (STEP): www.sustainabletechnologies.ca/ **Resources, Studies and Reports** 1. Green Infrastructure Map 2. Stormwater Infiltration in Cold Climates Review (2009) 3. Stormwater Management and Watercourse Impacts: The Need for a Water Balance Approach 4. Preserving and Restoring Healthy Soil: Best Practices for Urban Construction 5. LID Discussion Paper 6. Urban Water Balance 7. LID “Barrier Buster” fact sheet series **Features Studies and Resources:** 8. Bioretention and Rain Gardens 9. Green Roofs 10. Soakaways, Infiltration Trenches and Chambers 11. Permeable Pavement 12. Swales and Roadside Ditches 13. Perforated Pipe Systems 14. Rainwater Harvesting 15. Residential Stormwater Landscaping 16. Water Balance for the Protection of Natural Features	

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[ii] Credit River Water Management Strategy Update (CVC, 2007)

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[v] Ferguson, B.K., 1995 Downstream Hydrographic Effects of Urban Stormwater Detention and Infiltration, in: Proceedings of the 1995 Georgia Water Resources Conference, Kathryn J. Hatcher (ed), pp. 128- 131. Athens, University of Georgia Institute of Government.

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[xiii] British Columbia (B.C.) Stormwater Planning Guidebook (2002)

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[xvii] Credit River Water Management Strategy Update (CVC, 2007)

[xviii] British Columbia (B.C.) Stormwater Planning Guidebook (2002)

[xix] British Columbia (B.C.) Stormwater Planning Guidebook (2002)

[xx] US EPA (1979) A Statistical Method for the Assessment of Urban Stormwater

[xxi] Chang, G., J. Parrish and C. Scour (1990) Structural Best Management Practices for Stormwater Quality in the Ultra-Urban Environment. In Proceedings of the Water Environment Federation 6th Annual Conference, Volume 7, Surface Water Ecology, Anaheim, CA. pp. 223-234.

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[xxiii] Center for Watershed Protection (2008) Managing Stormwater in Your Community, A Guide for Building an Effective Post-Constriction Program.

[xxiv] Issued Paper "B" Precipitation Frequency Analysis and Use (EOR and SWMP, Jan 6, 2005).

[xxv] Issued Paper "B" Precipitation Frequency Analysis and Use (EOR and SWMP, Jan 6, 2005).

[xxvi] British Columbia (B.C.) Stormwater Planning Guidebook (2002)