# INNOVATIVE STORMWATER SOURCE CONTROL POLICY FOR INDUSTRIAL, COMMERCIAL AND INSTITUTIONAL LAND USES

**DRAFT FINAL**

Submitted to:
**City of Hamilton**
Hamilton, Ontario

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# 1. INTRODUCTION

The City of Hamilton (ref. Figure 1), has established this Innovative Stormwater Source Control Policy for use in the planning and design process specifically related to Industrial, Commercial, and Institutional land uses.

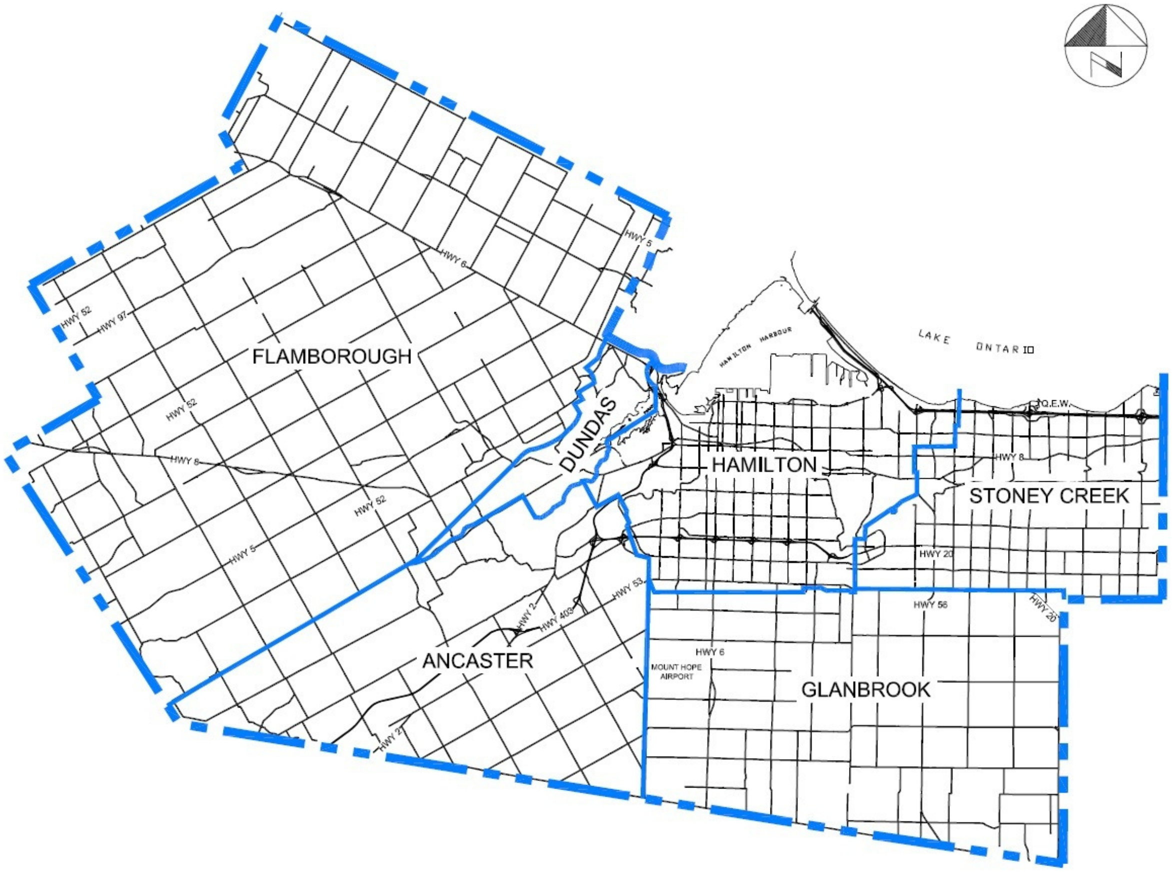


**Figure 1**

## 1.1 Description of City of Hamilton

The City of Hamilton is situated at the westerly extent of Lake Ontario. The City spans across 1120 $km^2$ (+/-), which mostly drains to Hamilton Harbour and Lake Ontario through various watercourses and viaducts.

The City's origins date back to the mid 1700's. Most of the early development within the City was located in Dundas and along the southern shore of Hamilton Harbour. Residential development within the City saw significant growth in the 1970 – 1980 era to those areas of Stoney Creek and Ancaster. Since 1990 to present times, growth has continued in the Hamilton Mountain area, as well the outlying communities. As of 2011, the population of the City of Hamilton was approximately 520,000 (source: Stats Canada, June 2012).

As identified in the companion document, City of Hamilton Storm Drainage Policy (May 2004) the City is rich in natural resources including:

- Cootes Paradise
- Hamilton Harbour
- Niagara Escarpment
- Beverly Swamp
- Eramosa Karst
- Several waterfalls, including: Grindstone, Borer's, Tews, Websters, Sherman, Tiffany, Chedoke, Buttermilk, Albion, Felker's and Devil's Punch Bowl.
- Several Conservation Areas

The 1120 km$^2$ (+/-) that comprises the City of Hamilton municipal boundary is characterized by urban and rural development and spans across four (4) conservation authorities: Hamilton Conservation Authority, Grand River Conservation Authority, Niagara Conservation Authority, and Conservation Halton.

## 1.2 Evolution of Stormwater Management Practices

### *1.2.1 Technical and Functional Criteria*

Urbanization is recognized to increase the amount of impervious surfaces within the landscape through the construction of rooftops and paved surfaces (i.e. roads, sidewalks, patios, etc.) compared to non-urban land uses. Hydrologically, this increase in impervious surface is recognized to produce a corresponding increase to both the volume (i.e. amount) and speed (i.e. rate or flow) of runoff compared to the pre-developed (i.e. rural or non-urban) land use condition. In addition, it was similarly recognized that urbanization tended to increase the concentration and mass of certain contaminants and water quality indicators, particularly heavy metals, compared to the pre-developed land use condition.

Original practices related to stormwater management system design focused upon conveyance of the additional runoff resulting from urbanization. The conveyance system typically focused upon subsurface conveyance (i.e. storm sewers or combined sewers) before the 1950's. Following the 1950's, and in the wake of Hurricane Hazel, dedicated stormwater conveyance infrastructure was further emphasized in design.

In the 1970's, it was recognized that flooding continued to occur during formative events, despite the construction of dedicated conveyance infrastructure. Consequently, stormwater management practices were revised to include the construction of stormwater management infrastructure to provide detention storage for flood control. This approach required that under the urban land use condition, peak flows would be controlled to pre-development levels, thereby mitigating any potential increase to flood risk as a result of the urban development. In many instances, these stormwater management flood control and conveyance systems were constructed off-site from development areas, and thus addressed stormwater management requirements for larger drainage areas.

In the late 1980's and 1990's there was a broadened focus on quality and erosion control for stormwater management practices and systems designs, in order to mitigate the impacts of storm runoff to the aquatic ecosystems. The stormwater management system design practices continued to include "end-of-pipe" solutions (i.e. providing the requisite stormwater management at the storm sewer outlet to the receiving system). However, the additional requirement to provide stormwater quality control recognized the benefits of a "treatment train" approach whereby stormwater quality enhancements would be provided at all points between the runoff source (i.e. the impermeable surface) and the ultimate receiver (i.e. the receiving watercourse). This approach shifted the focus from providing stormwater quality control solely at the end-of-pipe to providing stormwater quality control at all locations between the source and the receiver, and hence introduced the notion of "source controls". This notion of "source controls" extended beyond technologies and techniques to provide stormwater quality control, and included "source controls" for stormwater quantity controls.

Following the turn of the century (and millennium), stormwater management practices entered the next stage in the evolutionary process. This new focus explored opportunities to mitigate the increased runoff volume generated from the conversion of non-urban land uses to urban land use. A variety of approaches were introduced, which ranged from an interception and retention of stormwater to intercepting and detaining runoff for evaporation to intercepting and infiltrating runoff for groundwater recharge. This new approach toward managing storm runoff recognized that the space provided within the conventionally designed end-of-pipe facility was insufficient to provide any appreciable benefit toward reducing the increased runoff volume. Consequently, this new approach further emphasized the source control strategy for stormwater management system design.

### *1.2.2 Source Control Criteria and Guidelines Within Ontario*

In 1991, the Ontario Ministry of Environment and Energy and Ministry of Natural Resources formally required quality treatment of stormwater and in 1994, the MOE issued the first Stormwater Management Planning and Design Manual. This document provided practitioners with clear guidelines regarding the criteria and standards for the design of stormwater management facilities for stormwater quality control, including the design of source controls to address the new Provincial requirements for stormwater quality control. The Ministry of the Environment's planning and Design Manual was updated most recently in 2003 and it has integrated some of the advancements in stormwater management since the 1994 version.

In 2010, Credit Valley Conservation (CVC) and Toronto Region Conservation Authority (TRCA) developed the LID SWM Planning and Design Guide with funding assistance from MOE. This document has become a key source of information for designers to integrate lot level LID practices into their stormwater management designs, and includes stormwater source control practices which are not currently included within the Provincial Guidelines as established by the Ontario Ministry of the Environment. Although this document has not been developed by any Provincial Ministry, it currently represents the most encompassing document in Southern Ontario for LID source controls and has thus been referenced and applied in areas of the Province which are outside of the CVC and TRCA jurisdiction.

### *1.2.3 City of Hamilton Storm Drainage Policies and Guidelines*

The City of Hamilton current stormwater policy is provided in the Storm Drainage Policy (Philips Engineering Ltd., May 2004). The policy outlines storm drainage policy to be applied within the City of Hamilton, specifically storm drainage requirements to be applied to all new land development, re-development of existing lands, as well as the City of Hamilton Capital Works projects, where appropriate, for storm sewer system extensions and for reconstructions of existing infrastructure. Furthermore, the policy specifies requirements for storm drainage design and reporting at various stages of the land development process and provides reference and context to applicable federal, provincial, and Municipal polices and regulations which much be considered when planning or designing storm drainage systems.

Design criteria for stormwater infrastructure within the City of Hamilton is provided in the City's Criteria and Guidelines for Stormwater Infrastructure Design (Philips Engineering Ltd., September 2007). This document is a companion component to the City of Hamilton Storm Drainage Policy and is generally used by industry practitioners undertaking the detailed design or review of proposed stormwater management infrastructure.

The current stormwater management policies and guidelines for the City of Hamilton have been developed in accordance with the governing Provincial and Federal legislative requirements for the planning and design of stormwater management infrastructure. The policies and criteria were also developed to address the specific requirements and constraints across the City of Hamilton. The current policies and stormwater management guidelines within the City of Hamilton address the requirements to mitigate the increased flood risk and erosion potential resulting from urbanization, as well as the reduced quality of runoff associated with urbanization. This includes the application of source controls to achieve these objectives.

## 1.3 Innovative Source Control Concept

In general, innovative source controls are those stormwater management strategies and technologies which may be applied at source and which achieve a standard of stormwater management beyond the current Provincial and Federal legislative requirements. Specifically regarding the requirements of the City of Hamilton, these types of source controls would:

- Reduce the peak flow and/or runoff volume from proposed redevelopment areas compared to existing conditions or developments to the same land use condition in a similar hydrologic setting (i.e. similar soil infiltration rates, site slopes, etc.).
- Reduce the peak flow and/or runoff volume from proposed infill or greenfield development areas compared to developments to the same land use condition in a similar hydrologic setting.
- Provide an enhanced reduction to the erosion potential within the receiving watercourse above that which would be required based upon the governing criteria for the subject area.
- Improve the quality of storm runoff beyond that which would be required in accordance with current Provincial standards.

# 2. CITY OF HAMILTON STORMWATER MANAGEMENT POLICY

## 2.1 Storm Drainage Policy

### *2.1.1 Goals and Objectives*

The goals and objectives of the current City of Hamilton storm drainage policy are:

i) Provide present and future residents of the City of Hamilton with good engineering design that provides a high quality of living environment that protects and enhances natural features and minimizes pollution of water, air and land resources.

ii) Minimize risk of life and property from flooding and erosion.

iii) Encourage the use of stormwater as a resource such that it maintains and/or enhances:

- In-stream Water Quality
- Fisheries and Aquatic Habitat
- Hydrogeologic Function (i.e. baseflow, groundwater quality)
- Natural Channel Forming Processes (stream morphology)
- Terrestrial Linkages and Habitat

iv) Mitigate negative impacts to water resources, which would affect other riparian interests and users.

v) Provide direction for designs of stormwater infrastructure which are easily and effectively maintainable by the City's Public Works Department.

vi) Establish criteria for acceptable service levels for the hydraulic capacity of both the minor and major drainage systems to provide reasonable levels of service for the connected property owners.

### *2.1.2 Legislative Framework and Planning Process*

A detailed discussion of the current Federal, Provincial, Regional, and Municipal policies, guidelines and legislation governing stormwater management and valley systems and watercourses is provided in Section 2 of the City of Hamilton Storm Drainage Policy (Philips Engineering Ltd., May 2004). The main legislative vehicles for the planning and design of source controls and stormwater management infrastructure are:

- The Environmental Assessment Act (Municipal Class Environmental Assessment Process)
- The Planning Act
- The Ontario Water Resources Act (Stormwater Management Planning and Design Manual, MOE, March 2003)
- MOE Exemption Regulation 525-98

The current policy for the City of Hamilton encourages the preparation of Watershed/Subwatershed Studies and Master Drainage Plans in order to establish the design criteria and preferred locations for providing stormwater management for future development. These types of studies typically consider larger drainage areas and multiple land ownerships. Although these types of studies typically recommend strategic, centralized locations for providing stormwater management systems to service multiple landowners, these studies may also identify areas which would not be anticipated to drain toward centralized facilities and which would therefore be anticipated to require source controls to provide stormwater management.

In the absence of a Master Drainage Plan or Subwatershed Study, the planning, design, and approval of stormwater management infrastructure for industrial, commercial, and institutional land uses is typically completed through the submission of individual Site Plans in fulfillment of the Planning Act. For commercial and institutional land uses, the review and approval of stormwater management plans is completed by the City of Hamilton; depending upon the location and type of work proposed, additional approval may be required from other agencies (i.e. the Federal Department of Fisheries and Oceans, the Ontario Ministry of Natural Resources, the Hamilton Conservation Authority). The Ontario Water resources Act and the Ontario Regulation 525 require ministry approval for stormwater works included those works located on industrial land. This is in addition to the municipal plan/planning approval requirements outlined above for commercial and institutional land uses.

### *2.1.3 Current Policy Regarding Source Controls*

The City of Hamilton Storm Drainage Policy provides for the application of source controls to address stormwater management requirements for flooding, erosion, and stormwater quality control, in accordance with the current Provincial criteria and legislation. The planning and design of source controls for industrial, commercial, and institutional land uses are most commonly prepared as part of individual Site Plans, although these may also be recommended as part of higher studies (i.e. Master Drainage Plans or Watershed/Subwatershed Studies) depending upon the level of detailed information available for the higher level studies.

The Policy recognizes that, in certain instances, on-site measures to address requirements for stormwater quality control may not be considered feasible. In particular, the current policy at the City of Hamilton also recognizes that all future development and redevelopment within the Red Hill Creek Watershed is required to result in a zero increase to contaminant loading in Hamilton Harbour, in compliance with the Hamilton Harbour Remedial Action Plan; this standard of control cannot be achieved solely through the implementation of conventional stormwater management practices as provided in the 2003 MOE Guidelines. Consequently, the current Policy provides for the implementation of a cash-in-lieu program in order to construct off-site improvements for stormwater quality control. These cash-in-lieu programs require a long-term regional assessment (i.e. as Master Stormwater Quality Plan) in order to identify the opportunities, preferred locations, and phasing for the construction of off-site facilities for stormwater quality control, and to develop a funding formula and mechanism for the appropriate direction of the financial resources accordingly.

## 2.2 Innovative Stormwater Source Control Policy

### *2.2.1 Relation to Stormwater Drainage Policy*

This document represents a companion to the City of Hamilton Storm Drainage Policy, and provides the framework for the incorporation of stormwater source controls for the development and redevelopment of sites to provide or retain institutional, commercial or industrial land uses. It is intended that this document would be reviewed in conjunction with the current Storm Drainage Policy; as such, this policy is not considered to supercede or replace the current Storm Drainage Policy, but rather to complement the current Policy specifically with respect to developments or redevelopments to provide or retain institutional, commercial, or industrial land uses.

### *2.2.2 Goals and Objectives*

In essence, the goals and objectives outlined in the current City of Hamilton Storm Drainage Policy (May 2004) shall be met, in addition to the following list of goals and objectives:

<u>Goals</u>

(i) Provide present and future industrial, commercial and institutional businesses with good engineering design that provides a high quality of business environment that protects and enhances natural features and minimizes pollution of water, air, and land resources.

(ii) Provide the City and its businesses with sustainable stormwater management solutions.

(iii) Provide all practitioners (i.e. analysts, designers, planners, and reviewers) with guidance regarding acceptable practices, technologies, and analytical techniques related to the design of source controls for stormwater management, in order to satisfy functional requirements which are considered beyond the current standard provided in the City of Hamilton Storm Drainage Policy.

<u>Objectives</u>

(a) Commit to supporting the implementation of privatized stormwater management facilities for industrial, commercial, and institutional land uses which exceed the current Provincial criteria related to flooding, erosion, and stormwater quality control.

(b) Commit to the continuing the support, implementation, and understanding of at-source (lot-level) stormwater management techniques, including low impact development techniques.

(c) Commit to providing incentives to land developers who chose to integrate low impact development stormwater techniques/features in their development plans, for new or re-development projects to provide or retain industrial, commercial, or institutional land uses.

### 2.3 Other Policies

As part of the City's Development Charges By-Law, the City supports the implementation of LID measures. Developments under Site Plan Control that incorporate LID measures in the absence of an identified stormwater management facility may be eligible for further stormwater credits to the Development Charges (ref. City of Hamilton 2011 DC By-Law).

# 3. FUNCTIONAL BENEFITS OF INNOVATIVE SOURCE CONTROL PRACTICES

Innovative source control practices represent a suite of stormwater management practices. Some practices are currently provided in the 2003 MOE Guidelines, and of which achieve a level of stormwater management which is beyond the standards required in accordance with current legislation, policies and guidelines. The functional benefits of innovative source control practices include the following:

- Promoting groundwater recharge.
- Maintenance or enhancement of baseflow within receiving watercourses.
- Enhanced quality of runoff to receiving watercourses compared to existing levels in redevelopment areas, including reduced thermal impacts.
- Enhanced quality of runoff to receiving watercourses compared to conventional practices in infill and greenfield development areas, including reduced thermal impacts.
- Enhanced erosion protection for receiving watercourses compared to existing levels in redevelopment areas.
- Enhanced erosion protection for receiving watercourses compared to conventional practices in redevelopment areas.
- Reduced potential for surcharge or flooding of the receiving major and minor systems compared to existing levels.
- Reduced potential for on-site flooding.
- Reduce potential for combined sewer overflow for infill development or redevelopment contributing to combined sewers.

# 4. PREFERRED SOURCE CONTROL PRACTICES WITHIN CITY OF HAMILTON

Various technologies for providing stormwater source control are presented in the Stormwater Management Planning and Design Manual (MOE, March 2003), and the Low Impact Development Stormwater Management Planning and Design Manual, Version 1.0 (CVC/TRCA, 2010). These two documents represent the primary sources of information and guidance for the selection and design of stormwater source controls within the Province of Ontario.

The stormwater source control practices presented in these two documents have been reviewed in order to identify preferred stormwater source controls for industrial, commercial, and institutional land uses (including road rights-of-way within these land uses, where applicable) within the City of Hamilton. This screening has been completed with consideration for:

- Spatial constraints (i.e. land availability) associated with each land use.
- Practicality/functionality of implementing the stormwater source control practice within the given land use.
- Potential for secondary issues (i.e. spills) and implications to stormwater source control practice.
- Operation and maintenance requirements.

Preferred source control practices within the City of Hamilton for industrial, commercial, and institutional land uses are summarized in (but not limited to) Table 4.1.

**Table 4.1. Preferred Stormwater Source Control Practices Within the City of Hamilton for Industrial, Commercial, and Institutional Land Uses**

| Practice | Land Use | | | | |
|---|---|---|---|---|---|
| | Industrial | | Commercial | | Institutional |
| | Site | Road ROW | Site | Road ROW | Site |
| Rooftop Storage | X | | X | | |
| Parking Lot Storage | X | | X | | |
| Green Roofs | X | | X | | |
| Oil/Grit Separators | X | X | X | X | X |
| Rainwater Harvesting | X | | X | | |
| Downspout Disconnections | | | | | X |
| Pervious Pipes | X | X | X | X | X |
| Oversized Pipes | X | | X | | X |
| Permeable Pavement | | | X | | X |
| Soakaway Pits | X | | X | | X |
| Infiltration Trenches | X | | X | | X |
| Bumpouts | | X | | X | |
| Grassed Swales | X | X | X | X | X |
| Biofilters | X | X | X | X | X |

The foregoing list of preferred stormwater source control practices would necessarily need to be further screened at the detailed design stage in order to identify the most appropriate practices for the specific site, and recognizing the specific characteristics and constraints for the site (i.e. groundwater levels, soils, infrastructure constraints, etc.). Furthermore, while the full suite of practices presented in the MOE 2003 Guidelines and the CVC/TRCA 2010 Guidelines have not been presented, it is nevertheless recognized that there may be occasions when the other stormwater source control practices presented in each document may more appropriately be applied for a given site condition. Requirements for documenting the selection of the proposed stormwater source control practices are discussed later in this policy.

The preferred stormwater source control practices have been categorized according to the stormwater management function(s) afforded by each practice. The results of this assessment are summarized in Table 4.2.

**Table 4.2. Stormwater Management Function Provided by Preferred Stormwater Source Control Practice**

| Practice | Flood Control | Erosion Control | Quality Control | Runoff Volume Reduction | Groundwater Recharge |
|---|---|---|---|---|---|
| Rooftop Storage | X | | | | |
| Parking Lot Storage | X | | | | |
| Green Roofs | | X | X | X | |
| Oil/Grit Separators | | | X | | |
| Rainwater Harvesting | | X | | X | |
| Downspout Disconnections | | | | X | |
| Pervious Pipes | | X | X | X | X |
| Oversized Pipes | X[1.] | | | | |
| Permeable Pavement | | X | X | X | X[2.] |
| Soakaway Pits | | X | X | X | X |
| Infiltration Trenches | | X | X | X | X |
| Bumpouts | | X | X | X[3.] | X[3.] |
| Grassed Swales | | | X | | |
| Biofilters/Bioswales | | X | X | X[3.] | X[3.] |

NOTES:
1. Oversized pipes require designed outlet structure (eg. orifice plate or valve) in downstream manhole in order to provide flood control.
2. Acceptance of permeable pavement for groundwater recharge is contingent upon approval of the anticipated quality of surface runoff.
3. Runoff volume reduction/groundwater recharge function of bumpouts and biofilters/bioswales requires design of infiltration medium below subdrains.

# 5. DESIGN CRITERIA AND GUIDELINES

## 5.1 Design Criteria

The following criteria shall be applied for the planning and design of source controls for industrial, commercial, and institutional land uses.

***Flood Control***

All future Subwatershed Studies and Master Drainage Plans shall include requirements for the provision of source controls for flood control for industrial, commercial, and institutional lands.

Where a Subwatershed Study or Master Drainage Plan has been completed which includes the subject site, source controls for flood control shall be provided for all industrial, commercial, and institutional land uses in conformance with the governing Subwatershed Study or Master Drainage Plan.

Where no Subwatershed Study or Master Drainage Plan has been completed which includes the subject site, or where the governing study does not prescribe flood control requirements for the subject property and proposed development, all industrial, commercial, and institutional sites shall be designed to incorporate source controls for flood control. For infill developments and greenfield developments, the flood control for the site shall be designed to control the post-development flow to the *lesser* of the capacity of the receiving system or the pre-developed flow rate from the site, as determined in accordance with the City's Criteria and Guidelines for Stormwater Infrastructure Design (Philips Engineering Ltd., September 2007).

Where no overland flow route is provided within the receiving system, redevelopments which provide or retain industrial, commercial, or institutional land use, on-site flood control shall be designed to control the 100 year post-development flow rate to the 2 year flow rate for the existing developed condition of the site as determined by hydrologic analysis to the satisfaction of the City of Hamilton. Where an overland flow route is provided within the receiving system, redevelopments which provide or retain industrial, commercial, or institutional land use, on-site flood control shall be designed to control the 100 year post-development flow rate to the 100 year flow rate for the existing developed condition of the site.

All stormwater source controls which are recognized to provide flood control and/or a reduction in surface runoff volume (as per Table 4.2) shall be included/considered in the modelling analysis of the proposed flood control system for the site.

The design shall include of source controls to provide flood control for industrial, commercial, and institutional land uses shall include equipment and/or appurtenances for remote monitoring or for facilitating field (manual) monitoring, ease of inspection, maintenance, and clean-out.

***Erosion Control***

All future Subwatershed Studies and Master Drainage Plans shall include requirements for the provision of source controls for erosion control for industrial, commercial, and institutional lands.

Where a Subwatershed Study or Master Drainage Plan has been completed which includes the subject site, source controls for erosion control shall be provided for all industrial, commercial, and institutional land uses in conformance with the governing Subwatershed Study or Master Drainage Plan.

Where no Subwatershed Study or Master Drainage Plan has been completed which includes the subject site, or where the governing study does not prescribe the erosion control requirements for the subject property and proposed development or redevelopment, all industrial, commercial, and institutional sites shall be designed to incorporate source controls for erosion control. Due to the prolonged duration of nuisance flooding and potential structural risks, rooftop storage and/or parking lot surface storage shall not be utilized to provide erosion control.

All stormwater source controls which are recognized to provide erosion control and/or a reduction in surface runoff volume (as per Table 4.2) shall be included/considered in the modelling analysis of the proposed erosion control system for the site.

The design shall include of source controls to provide erosion control for industrial, commercial, and institutional land uses shall include equipment and/or appurtenances for remote monitoring or for facilitating field (manual) monitoring, ease of inspection, maintenance, and clean-out.

***Stormwater Quality Control***

All future Subwatershed Studies and Master Drainage Plans shall include requirements for the provision of source controls for stormwater quality control for industrial, commercial, and institutional lands.

Where a Subwatershed Study or Master Drainage Plan has been completed which includes the subject site, source controls for stormwater quality control shall be provided for all industrial, commercial, and institutional land uses in conformance with the governing Subwatershed Study or Master Drainage Plan.

Where no Subwatershed Study or Master Drainage Plan has been completed which includes the subject site, or where the governing study does not prescribe the stormwater quality control requirements for the subject property and proposed development or redevelopment, all industrial, commercial, and institutional sites shall be designed to incorporate source controls for stormwater quality control to achieve an *Enhanced* standard of stormwater quality control as a minimum. The source controls for stormwater quality control shall include measures to mitigate thermal impacts from the proposed development or redevelopment.

The Hamilton Harbour Remedial Action Plan currently provides for a zero increase in Total Suspended Solids (TSS) contaminant loading from all future development discharging toward Hamilton Harbour. All Industrial, commercial, and institutional redevelopments which are subject to the Hamilton Harbour Remedial Action Plan shall be designed to incorporate source controls for stormwater quality control and/or reductions in surface runoff volume in order to work toward achieving a zero increase in Total Suspended Solids (TSS) contaminant loading. All stormwater source controls which are recognized to provide stormwater quality control and/or a reduction in surface runoff volume (as per Table 4.2) shall be considered in the modelling analysis of the proposed stormwater quality control system for the site.

In order to accommodate anticipated monitoring requirements the design of source controls to provide stormwater quality control for industrial, commercial, and institutional land uses shall include equipment and/or appurtenances for remote monitoring or for facilitating field (manual) monitoring, ease of inspection, maintenance, and clean-out.

***Water Balance/Surface Runoff Volume***

All future Subwatershed Studies and Master Drainage Plans shall include requirements for the provision of source controls for controlling the volume of surface runoff and/or maintain water balance for industrial, commercial, and institutional lands.

Where a Subwatershed Study or Master Drainage Plan has been completed which includes the subject site, source controls for controlling the volume of surface runoff and/or maintaining water balance shall be provided for all industrial, commercial, and institutional land uses in conformance with the governing Subwatershed Study or Master Drainage Plan.

Where no Subwatershed Study or Master Drainage Plan has been completed which includes the subject site, or where the governing study does not prescribe requirements for volume control/water balance control for the subject property and proposed development, all industrial, commercial, and institutional infill developments and greenfield developments shall incorporate source controls which work toward maintaining the average annual pre-developed water balance for the site.

Where no Subwatershed Study or Master Drainage Plan has been completed which includes the subject site, or where the governing study does not prescribe requirements for volume control/water balance control for the subject property and proposed redevelopment, all industrial, commercial, and institutional redevelopments shall incorporate source controls which works toward achieving the average annual pre-developed water balance for the sites by reducing the surface runoff volume compared to the existing developed condition for the sites.

The design shall include of source controls to provide water balance for industrial, commercial, and institutional land uses shall include equipment and/or appurtenances for remote monitoring or for facilitating field (manual) monitoring, ease of inspection, maintenance, and clean-out.

### *Groundwater Recharge*

All future Subwatershed Studies and Master Drainage Plans shall include requirements for the provision of source controls for promoting groundwater recharge for industrial, commercial, and institutional lands.

Where a Subwatershed Study or Master Drainage Plan has been completed which includes the subject site, source controls for promoting groundwater recharge shall be provided for all industrial, commercial, and institutional land uses in conformance with the governing Subwatershed Study or Master Drainage Plan.

Where no Subwatershed Study or Master Drainage Plan has been completed which includes the subject site, or where the governing study does not prescribe requirements for providing groundwater recharge for the subject property and proposed development, all industrial, commercial, and institutional infill developments and greenfield developments shall incorporate source controls which work toward maintaining the average annual pre-developed groundwater recharge.

Where no Subwatershed Study or Master Drainage Plan has been completed which includes the subject site, or where the governing study does not prescribe requirements for volume control/water balance control for the subject property and proposed redevelopment, all industrial, commercial, and institutional redevelopments shall incorporate source controls for the infiltration of rooftop runoff.

Runoff from all rooftops is generally considered “clean water” which would not require stormwater quality pre-treatment for infiltration. The ultimate acceptance of rooftop runoff from industrial buildings as “clean runoff” is at the discretion of the Ministry of the Environment, and is to be determined on a case-by-case basis. All runoff from parking lots and roadways shall require stormwater quality pre-treatment for infiltration.

The design shall include of source controls to provide groundwater recharge for industrial, commercial, and institutional land uses shall include equipment and/or appurtenances for remote monitoring or for facilitating field (manual) monitoring, ease of inspection, maintenance, and clean-out.

### *Spill Protection and Containment*

All industrial land uses shall include source controls to contain spills on the subject property. Requirements to prevent spills from infiltrating into the subsurface shall be considered on a case-by-case basis, with consideration for the type of material and the extent of impact. Consultation with City of Hamilton staff shall be required in order to determine specific requirements to provide spill protection for the site. The design shall include of source controls to provide spill protection for industrial land uses shall include equipment and/or appurtenances for remote monitoring or for facilitating field (manual) monitoring, ease of inspection, maintenance, and clean-out.

### *Summary*

The criteria to be applied for the planning and design of source controls for industrial, commercial, and institutional land uses is summarized in Table 5.1.

**Table 5.1. Summary of Criteria for the Planning and Design of Stormwater Source Controls for IC&I Land Uses**

| | Sub-watershed Study or Master Drainage Plan | No Sub-watershed Study or Master Drainage Plan or Governing Study |
|---|---|---|
| **Flood Control** | Source controls for flood control shall be provided for all IC&I land uses in conformance with the Study or Plan. | All IC&I sites shall be designed to incorporate source control for flood control.<br><br><u>Infill or Greenfield Development:</u><br>Site shall be designed to control the post-development flow to the lesser of the capacity of the receiving system or the pre-developed flow rate from the site.<br><br><u>Redevelopment:</u><br>If overland flow route provided: include on-site flood control design to control 100 year post-development flow rate to the 100 year flow rate for the existing developed conditions of the site.<br><br>If no overland flow route: include on-site flood control design to control 100 year post-development flow rate to the 2 year flow rate for the existing developed conditions of the site. |
| **Erosion Control** | Source controls for erosion control shall be provided for all IC&I land uses in conformance with the Study or Plan. | All IC&I sites shall be designed to incorporate source control for erosion control. Rooftop storage or parking lot storage shall not be used to provide erosion control. |
| **SW Quality Control** | Source controls for stormwater quality control shall be provided for all IC&I land uses in conformance with the Study or Plan. | All IC&I sites shall be designed to incorporate source control for SW quality control to achieve an *Enhanced* standard as a minimum. Including measures to mitigate thermal impacts.<br><br>Development or redevelopment in the Hamilton RAP shall be designed to work toward a zero increase in TSS contaminant loading.<br><br>The design shall include remote monitoring or allow ease of field (manual) monitoring to ensure tracking for adherence to requirements. The design shall also allow ease of inspections, maintenance and clean-out. |
| **Water Balance/ Surface Runoff Volume** | Source controls for controlling volume of surface run-off or maintaining the water balance shall be provided for all IC&I land uses in conformance with the Study or Plan. | <u>Infill or Greenfield Development:</u><br>IC&I sites shall incorporate source control which works towards maintaining the average annual pre-developed water balance for the sites.<br><br><u>Redevelopment:</u><br>IC&I sites shall incorporate source control which works towards achieving the average annual pre-developed water balance for the sites by reducing the surface runoff volume compared to the existing developed condition for the sites. |
| **Groundwater Recharge** | Source controls for promoting groundwater recharge shall be provided for all IC&I land uses in conformance with the Study or Plan. | <u>Infill or Greenfield Development:</u><br>IC&I sites shall incorporate source control which works towards maintaining the average annual pre-developed groundwater recharge.<br><br><u>Redevelopment:</u><br>IC&I sites shall incorporate source control for the infiltration of rooftop run-off.<br><br>Runoff from rooftops is to be considered as clean water and would not require treatment for water quality for infiltration. |

## 5.2 Design Guidelines

Current guidelines for the detailed design of stormwater source controls, including innovative source control practices, are currently provided in the City of Hamilton *Criteria and Guidelines for Stormwater Infrastructure Design (Philips Engineering Ltd., September 2007)*, the *Low Impact Development Stormwater Management Planning and Design Manual, Version 1.0 (CVC/TRCA, 2010)* and the *Stormwater Management Planning and Design Manual (MOE, March 2003)*. These documents provide sufficient information for the detailed design of the preferred source control practices within the City of Hamilton (as per Table 4.1), including the local characteristics and constraints which should be considered in the selection and design of the source controls. The reader is referred to these documents for the detailed screening and design of source controls for industrial, commercial, and institutional sites within the City of Hamilton.

# 6. PLANNING PROCESS

Section 5 of the City of Hamilton Storm Drainage Policy provides a detailed discussion of the planning and design process for stormwater management infrastructure. The following section provides a general overview of this process, specifically related to the application of innovative source controls for industrial, commercial, and institutional land uses.

## 6.1 Stormwater Management Planning Process

***Watershed/Subwatershed Studies***

The current Provincial guidelines, as provided by the Ministry of the Environment, advocate planning water resources management an ecosystem approach to land use planning. This approach is addressed through the completion of Watershed/Subwatershed Planning Studies, which are typically completed in conjunction with the land use planning process. The recommendations advanced in these studies typically include the design criteria and preferred siting for stormwater management infrastructure, in order to address watershed/subwatershed scale requirements for flooding, erosion, and stormwater quality control in accordance with the current Provincial standards and criteria. The study areas for watershed and subwatershed studies are typically several hundred hectares in size, and thus the recommendations are applicable to a variety of urban land uses, including industrial, commercial, and institutional developments. Although detailed requirements for stormwater source controls are typically not incorporated into this level of study, the source control requirements outlined in this Policy shall be included in all subsequent watershed and subwatershed studies initiated by the City of Hamilton.

***Master Drainage Plans***

In the absence of watershed/subwatershed planning, stormwater management requirements for new development are typically established through the completion of Master Drainage Plans. These studies tend to be more scoped compared to watershed/subwatershed studies, and the recommendations advanced in these studies typically include the design criteria and preferred siting for stormwater management infrastructure in order to address local requirements for flooding, erosion, and stormwater quality control in accordance with the current Provincial standards in criteria. The study areas for Master Drainage Plans tend to be smaller in size compared to watershed/subwatershed studies, and hence generally consider fewer types of urban land uses compared to the higher level studies. Nevertheless, Master Drainage Plans generally prescribe stormwater management requirements for areas involving multiple land owners. This level of study would typically be anticipated to be completed in support of Municipal Redevelopment and Intensification Studies. As such, the source control requirements outlined in this Policy shall be included in all subsequent Master Drainage Plans within the City of Hamilton.

***Tertiary Planning and Design Studies***

This level of study may be required in areas where multiple land ownership within the subwatershed occurs, and focuses on integrating servicing and stormwater management of adjacent development to a greater level of detail than is normally achieved through the Subwatershed and Master Drainage Plan. The study areas for these studies are typically smaller than those associated with Master Drainage Plans, but also typically include more detailed information for the study area and the receiving systems than is typically associated with Master Drainage Plans. The source control requirements outlined in this Policy shall be incorporated into the analysis and design of stormwater management infrastructure through the Tertiary Planning and Design Study process.

***Site Plan Applications***

Stormwater management studies are frequently completed for industrial and commercial land uses as part of individual site plan applications. These studies are typically focused on one particular lot, and thus typically involve one development proponent as part of an infill development or redevelopment of an existing property. The stormwater management studies and analyses completed as part of this process tend to focus on constraints local to the subject property. All stormwater management plans prepared for industrial, commercial, and institutional land uses through the Site Plan process shall be completed in conformance with this Policy and all applicable planning, rezoning, and redevelopment policies of the City of Hamilton.

## 6.2 Stormwater Management Planning Principles

The following principles shall be applied for the planning of source controls to provide stormwater management for industrial, commercial, and institutional land uses.

### *6.2.1 Practices in Public Spaces*

The public road right-of-way generally represents the only public space within industrial and commercial sites. The City of Hamilton should be consulted regarding the application of innovative source controls within the public road right-of-way, as outlined in Table 4.1. Approval for the proposed source control is at the discretion of the City of Hamilton through the applicable planning process, with consideration of the local constraints within the study area and the design criteria outlined in the documents referenced in Section 5.2 of this Policy. Source controls proposed within public spaces shall be planned and designed in order to address the stormwater management requirements for the public space only, and shall not be planned and designed to address the stormwater management requirements for the adjacent private properties.

Should other public spaces be proposed within the limits of the industrial, commercial, or institutional land uses (i.e. parks, green spaces, etc.), the proponent shall pre-consult with City of Hamilton staff in order to determine requirements and acceptable source controls within these other public spaces.

#### *6.2.2 Practices on Private Properties*

Stormwater source controls shall be provided on all private properties for industrial, commercial, and institutional land uses. The source controls shall be planned and designed in order to address the stormwater management requirements for the individual industrial, commercial, or institutional land use as per the requirements and criteria outlined in this Policy.

# 7. METHODS FOR EVALUATING REQUIREMENTS AND EFFECTIVENESS

## 7.1 Analytical Methods

Various analytical methods and techniques for the evaluation of source control requirements and effectiveness are outlined in the *Low Impact Development Stormwater Management Planning and Design Manual, Version 1.0 (CVC/TRCA, 2010)* and the *Stormwater Management Planning and Design Manual (MOE, March 2003)*. These analytical methods typically require a high level of planning detail (i.e. specific size, type, and location for stormwater source control), hence they are considered more applicable to the detailed design stage for source controls, and are less applicable to the planning stage for the siting of stormwater source controls. Consequently, it is recognized that the development of analytical techniques to support both the planning and design of source controls represents an emerging and evolutionary field of practice. Such methods have been developed to apply more conceptual systems for higher level studies (ref. Appendix A), whereas various hydrologic models (i.e. PCSWMM/EPA SWMM) continue to be updated in order to include commands and routines for the evaluation of specific stormwater source controls. The appropriate methods for the analysis of source control requirements and effectiveness shall be determined consultatively between the practitioner undertaking the design and the City of Hamilton.

While the approaches provided in the foregoing documents are considered to represent the preferred approaches for analyzing the spatial requirements and effectiveness of source controls, pre-consultation with City of Hamilton staff is recommended in order to establish the approved methods and techniques for the subject property.

## 7.2 Monitoring

The effective of stormwater management practices for achieving flood protection, erosion protection, stormwater quality control, water balance, and groundwater recharge are frequently verified through the implementation of monitoring programs. These programs are typically implemented as a condition of approval by the Ministry of the Environment, and often focus upon verifying the performance of stormwater management practices for providing stormwater quality control. In order to accommodate anticipated monitoring requirements the design of source controls for industrial, commercial, and institutional land uses shall include equipment and/or appurtenances for remote monitoring or for facilitating field (manual) monitoring, ease of inspection, maintenance, and clean-out.

# 8. ECONOMIC CONSIDERATIONS

The preceding sections have outlined the functional and legislative basis for requiring innovative source controls for industrial, commercial, and institutional land uses, as well as the processes for the planning and design of these systems. This section provides the economic considerations which are to be applied in the selection of the source control practices to be implemented.

## 8.1 Construction Cost Estimates

The alternatives for providing source control for industrial, commercial, and institutional land uses shall be evaluated and screened on the basis of costs for the implementation. Research conducted by the USEPA suggests that the construction costs for Low Impact Development Best Management Practices, which are included among the preferred innovative source control practices within the City of Hamilton, would be comparable to or less than the costs for constructing end-of-pipe facilities to provide the equivalent function. Construction costs to be considered in the evaluation shall include:

- Earthworks for excavation.
- Material costs for infiltration medium, where required.
- Additional material costs for infrastructure which are beyond that which would be required for conventional design for conveyance (i.e. larger sized pipes, outlet controls, perforated pipes, tanks, subdrains, etc.).
- Landscaping costs.

## 8.2 Operation and Maintenance Cost Estimates

The selection of specific source controls for industrial, commercial, and institutional land uses shall consider the full life cycle costs for the source controls. Consequently, cost estimates for the long-term operation and maintenance over the design life of the infrastructure shall be included in the economic assessment of the proposed infrastructure.

## 8.3 Potential Development Charge Credits

As noted in Section 2 regarding existing City Policy, there is currently a potential development charge stormwater credit available. However, in the current (2011) DC By-Law, the City has removed the non-residential charge for stormwater management facilities. Therefore, IC&I lands are responsible for their own stormwater management controls, and there are no DC credits currently on offer. This potential credit will be reviewed each time the DC By-Law is up for renewal.

# 9. REQUIREMENTS FOR REVIEW OF ENGINEERING SUBMISSIONS

Supporting studies and analyses for innovative source controls shall be completed in support of planning applications for the proposed development, and at the detailed design stage for the proposed development. This section outlines the submission requirements for the planning and design process for innovative source controls.

## 9.1 Submission Requirements at Planning Stage

Tertiary Plans and Site Plan Applications shall be accompanied by a Functional Stormwater Management Study for the proposed development. These Functional Studies shall include, but not be limited to:

- A characterization of the study area (i.e. soil types, infiltration rates, local infrastructure constraints, existing land use conditions).
- A description of the proposed redevelopment.
- An assessment and screening of alternative source control practices on the basis of functional requirements, local constraints, potential social implications, and economic constraints.
- Identification of preferred source control practices to be implemented at the detailed design stage.
- Preliminary sizing and siting of source controls, including a site plan depicting the proposed development/redevelopment and source control footprints.
- Supporting analyses to demonstrate the performance of the proposed source controls, specifically with respect to the functional criteria outlined in Section 5 of this Policy.
- Any supplemental requirements (i.e. contributions toward a cash-in-lieu program) which may be required in order for the proposed development to satisfy the criteria outlined in Section 5 of this Policy.

The proposed source controls for the site as provided in the engineering submission which accompanies the Tertiary Plan or Site Plan Application shall be reviewed by the City of Hamilton. Subject to the approval of the City of Hamilton, the detailed design of the proposed source controls may then proceed.

## 9.2 Submission Requirements at Detailed Design Stage

The following shall be submitted to the City of Hamilton for the review and approval of the detailed design of the stormwater source controls:

- Detailed design drawings for the construction of the proposed stormwater source control.
- For rooftop storage or green roofs, a supporting study shall be prepared and submitted by a qualified Structural Engineer to prescribe any requirements for the structure in order to support the additional load associated with the proposed source control practice.
- A Design Brief completed by a qualified Engineer demonstrating that the proposed stormwater source control design would satisfy the functional criteria outlined in Section 5 of this Policy.
- A detailed outline of the operation and maintenance requirements for the proposed source controls, including the maintenance program to be implemented over the design life of the source control and associated costs.
- Recommendations for a monitoring program for the proposed source controls.
- Opportunities to implement adaptive management over the lifecycle of the source control.

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# APPENDIX A

## Assessment of Using LID for Infiltrating Urban Runoff (Farrell/Scheckenberger, November 2009)

**SUBWATERSHED-SCALE ASSESSMENT TECHNIQUE OF**

**LOW IMPACT DEVELOPMENT BEST MANAGEMENT PRACTICES**

**FOR INFILTRATING URBAN RUNOFF**

**(A LID BMP ANALYTICAL TECHNIQUE FOR SUBWATERSHEDS)**

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Low Impact Development (LID) Best Management Practices (BMP's) for urban runoff are typically applied at source or at a local scale. Current planning for stormwater management is focussed on LID BMP's being a complementary measure to more traditional forms of stormwater management such as end-of-pipe wetlands or wet ponds. The advantages of LID BMP's have been widely published and it is generally accepted that LID BMP's improve the ability of an urban watershed to meet water balance targets, address water quality targets, and, to a lesser degree, assist in meeting erosion and flooding targets.

The current design/assessment approach for establishing the use, type, and rate of application of LID BMP's in urban settings is generally at a site-specific or local-scale; for Employment lands this would constitute the Site Plan stage and for Residential lands the Plan of Subdivision stage. However, stormwater management planning begins at a broader spatial-scale such as the watershed or subwatershed unit. The problem arises as to how best to plan and design the application of LID BMP's at these larger spatial scales, in order to provide direction to the subsequent local scale assessments. Analytical and assessment tools and methodologies have generally not addressed these needs, which are critical to demonstrate the potential benefit of LID BMP's, as well as the intended rate of application and spatial distribution in the subwatershed unit (based soils, topography, groundwater levels, and other considerations such as land use).

The approach outlined in this paper provides an analytical procedure to assess LID BMP's by identifying the active mechanisms in LID BMP's in general (i.e. infiltration, and extended detention storage at source). The procedure is used in a case study involving a continuous modelling assessment of an urbanizing watershed in Southern Ontario (City of Brampton). The USEPA HSP-F program provides a means of assessing and comparing the effectiveness of stormwater management practices in Traditional (Business-as-usual) and Traditional with LID BMP's approaches. The differences in performance and end-of-pipe facility sizing are rationalized and offered for consideration in future stormwater management planning and design.

**Subwatershed, Low Impact Development, Infiltration, Modelling**

## Introduction/Purpose

Stormwater management practices in the Province of Ontario have been evolving over the past thirty years. Current Provincial standards for stormwater management formally require that all new development implement stormwater quality and quantity control practices in order to reduce (among others) total suspended solids (TSS) loadings to receiving watercourses and to provide flood protection for downstream properties, as well as erosion control to protect sensitive downstream watercourses. These objectives are commonly achieved through the planning, construction, and design of end-of-pipe stormwater management facilities (i.e. wet pond, wetland, or hybrid facility) in accordance with the standards provided in the Stormwater Management Planning Practices and Design Guidelines (Ontario Ministry of the Environment, March 2003). End-of-pipe facilities tend to be favoured by practitioners due to their proven effectiveness to satisfy current Provincial stormwater management criteria when designed in accordance with current standards, as well as their ability to serve larger drainage areas (i.e. 5 ha to 125 ha).

Over the past fifteen years, various Conservation Authorities and Municipalities across Ontario have required that stormwater management systems address additional criteria beyond the current Provincial standards. Typically, this has been in the form of higher removal rates for pollutants and other chemical species in storm runoff (i.e. phosphorus or metals), mitigation of thermal impacts from storm runoff, and promoting infiltration, in order to maintain pre-development rates of groundwater recharge. Given that the application of LID BMP's is at the local scale, actual planning and design of these measures has typically been deferred to the final stages of developing a stormwater management plan for Plans of Subdivision or Site Plans (ref. CVC, TRCA, 2009 Draft). The problem with this design approach is that the cumulative benefit of multiple LID BMP's is not well defined nor is the direction available to properly or effectively design these practices to meet subwatershed scale targets and objectives.

## Low Impact Development Best Management Practices

Low Impact Development Best Management Practices are currently being promoted in numerous jurisdictions as a preferred approach toward providing stormwater management for new developments. Unlike the more conventional practice of providing end-of-pipe facilities, Low Impact Development BMP's consist of a suite of at-source stormwater management techniques, distributed throughout the development area. These practices emphasize the treatment train approach toward stormwater management, and promote maintaining the water balance at existing levels through enhanced and distributed infiltration, as illustrated in Figure 1.

LID BMP's for stormwater management fundamentally serve the following three functions:

- Interception/detention of stormwater
- Conveyance of stormwater
- Infiltration of stormwater

Commonly applied Low Impact Development BMP's, as well as their functions and benefits for stormwater management are summarized in Table 1.

| TABLE 1. Summary of common LID BMP's (ref. CVC/TRCA, 2009 Draft; City of Calgary 2007) | | |
|---|---|---|
| **LID Practice** | **Function** | **Stormwater Management Benefit** |
| Rain Barrels | Stormwater Interception and Detention | Runoff Volume Reduction; Informal Stormwater Quality |
| Cisterns | Stormwater Interception and Detention | Runoff Volume Reduction; Informal Stormwater Quality |
| Green Rooftops | Stormwater Interception and Detention | Runoff Volume Reduction |
| Rooftop Disconnects | Stormwater Conveyance and Partial Infiltration | Runoff Volume Reduction; Informal Contribution Toward Maintaining Water Balance |
| Soakaway Pits | Stormwater Infiltration | Runoff Volume Reduction; Maintaining Water Balance |
| Soil Amendments | Stormwater Infiltration | Runoff Volume Reduction, Maintaining Water Balance; Partial Stormwater Quality Control |
| Tree Clusters | Stormwater Interception and Partial Infiltration | Partial Runoff Volume Reduction |
| Filter Strips | Stormwater Conveyance | Stormwater Quality Control |
| Permeable Pavers | Stormwater Infiltration | Runoff Volume Reduction, Maintaining Water Balance; Partial Stormwater Quality Control |
| Bio-Retention | Stormwater Filtration/Infiltration | Runoff Volume Reduction; Maintaining Water Balance; Stormwater Quality Control |
| Rain Gardens | Stormwater Infiltration | Runoff Volume Reduction; Maintaining Water Balance; Stormwater Quality Control |
| Pervious Pipes | Stormwater Infiltration | Runoff Volume Reduction; Maintaining Water Balance; Stormwater Quality Control |
| Enhanced Grassed Swales | Stormwater Conveyance | Stormwater Quality Control |
| Dry Swales | Stormwater Conveyance and Filtration/Infiltration | Runoff Volume Reduction; Maintaining Water Balance; Stormwater Quality Control |

## The Stormwater Management Planning and Design Process

### Subwatershed Studies

Stormwater management planning for future development typically begins with Subwatershed Studies, which are completed for major Watersheds and/or their tributaries. These studies evaluate the environmental systems and their function for relatively large study areas (typically larger than 10 $km^2$). Due to the scale of these study areas, the focus of Subwatershed Studies often relates to the function and impacts (from development) to key systems which are connected and integrated throughout the study area (i.e. watercourses and terrestrial systems). The analyses at the Subwatershed Study scale are conducted on a catchment basis, whereby the catchments represent the local contributing areas to key environmental systems within the study area. The catchments are typically established based upon local drainage boundaries for the respective areas, and, due to the systems-based approach, tend to be relatively large (i.e. 25 ha to 100 ha).

Future land use information which supports subwatershed studies is often in the form of Regional Official Plans and Secondary Plans. Conventional practice for the analyses to establish stormwater management requirements for the future development areas within the subwatershed involve assigning a model routing element (i.e. reservoir) at the outlet of the subcatchment unit in order to represent the cumulative effects of the stormwater management facilities which may be distributed within the subcatchment. Although the specific locations of stormwater management facilities are typically unknown at this point, this approach nevertheless incorporated the effects of stormwater management facilities with respect to peak flow reduction and lagging, and hence provides sufficient guidance with respect to stormwater management planning and design to satisfy the Provincial standards (i.e. stormwater quality, erosion, and quantity control) (ref. Farrell et al, 2008).

Due to the scale of the subwatershed study area and the limited resolution, associated with future land use conditions, the purpose of Subwatershed Studies is primarily to define the criteria and requirements to manage stormwater and impacts to environmental resources, and to outline a strategy (i.e. comprised set of management techniques) to mitigate and prevent these impacts, rather than to define the specific technologies which are to be used. This latter step is defined as part of tertiary planning and subdivision development.

**Environmental Management Plans**

Environmental Management Plans (EMP's) (also known as Environmental Impact Reports, Environmental Area Plans, Master Environmental Servicing Plans, Functional Stormwater and Environmental Management Strategies and others), are completed in support of local development areas, after the Secondary Planning Process has been completed. The analyses represent a local refinement to the parent Subwatershed Study, whereby the limits of the environmental systems and features identified within the Subwatershed Study are more resolutely defined within the limits of the EMP Study Area, and local features of significance within the EMP Study Area are further detailed. Nevertheless, the intent of these studies is to "build upon" the information provided within the parent Subwatershed Study, in order to maintain a linkage between the environmental constraints and criteria established at the Subwatershed scale and those established at the more local scale for the EMP Study Area.

Clearly the EMP and the Secondary Planning direction is integrated, hence the analyses completed to establish stormwater management requirements under the EMP process need to integrate constraints associated with existing and future infrastructure (i.e. roads, bridges, etc.). Hence, the sub-basins which are developed under the EMP process tend to incorporate a more physical basis, which includes the anticipated drainage boundaries associated with the proposed limits of grading within the various development areas within the Study Area, and hence are more refined than those established under the parent Subwatershed Study (i.e. often at a scale of 10 ha to 100 ha). This process also affords an opportunity to more resolutely define the location of future end-of-pipe stormwater management facilities for the future development areas within the Secondary Planning and EMP Study Areas. Consistent with the approach applied at the Subwatershed Study scale, common practice for the analyses completed to establish stormwater management requirements consists of assigning a model routing element (i.e. reservoir) at the outlet of the subcatchment or sub-basin. However, due to the detail associated with the siting of stormwater management facilities at the EMP stage, the contributing subcatchment represents the specific drainage area which would be serviced by the specific stormwater management facility, thus affording a more physical relationship between drainage area, the facility, and the receiving system.

The information and guidance provided from these studies is similarly a refinement to that which is provided from the parent Subwatershed Study. Specifically with respect to stormwater management requirements, EMP's can provide information regarding the acceptable technologies (i.e. types) of systems which can be applied for the stormwater management strategy. Due to the scale of the assessment, the specifics most often have been limited to the stormwater management facility location and size (i.e. end-of-pipe facility).

**Stormwater Management Plans**

The final stage in the stormwater management planning and design process is the preparation of Stormwater Management Plans, which are completed in support of Draft Plans or Site Plans. At this stage, the study area is defined by the specific development property, and the land use plan for the subject property is fully defined to include all internal roads, property boundaries, and buildings, as well as the detailed grading and drainage paths for the site.

These plans represent the most detailed stage of the stormwater management planning and design process, and include an inventory of physical and environmental constraints intrinsic to the subject development property, and the assessment of stormwater management requirements (i.e. storage volumes and controlled discharge rates) are prescribed based upon the specific needs associated with the development of the site. Nevertheless, they are intended to further build upon the constraints and criteria advanced in the governing Subwatershed Study and EMP.

At this stage in the stormwater management planning process, the study area typically represents a sub-element of one of the catchments which were developed at the EMP stage. Hence, the catchments which are developed for Stormwater Management Plans essentially represent sub-elements of the parent catchment within the EMP, and sub-elements of the drainage area to the end-of-pipe facility. This level of discretization is necessarily completed only at this stage in the planning process, since it is only at this stage that the physical constraints which are unique to the site, under both existing (and particularly under future land use conditions), are defined. Hence, while the EMP may provide direction regarding the servicing and environmental management requirements, outside of or at the limits of the subject property, it is only at the

Draft Plan or Site Plan Approval stage that the detailed servicing requirements *within* the subject property (i.e. within the sub-element of the EMP catchment) can be reasonably defined.

## Analytical Approach for LID BMP's

### *Conventional Approach at Site Plan Level*

The most commonly applied approach for the hydrologic analysis and design of LID BMP's involves conducting the analyses as part of the detailed Stormwater Management Plan in support of the Site Plan or Draft Plan Approval Process. The hydrologic analyses thus involve a detailed discretization of the study area (i.e. the subject property) to reflect the different physical features and structured elements of the site (i.e. roofs, driveways, parking areas, open spaces, roads) which drain to the specific LID BMP's, and incorporate the overall connectivity of the treatment train proposed for the local stormwater management system. This analytical approach is consistent with the design standards associated with the LID BMP's (ref. TRCA/CVC, 2009 Draft), which emphasise the application of at-source controls whereby the specific stormwater management technologies are intended to serve relatively small drainage areas (i.e. typically 2 ha or less). Moreover, this process for the design of LID BMP's is consistent with the overall LID perspective, as the stormwater management practices are intended to be more integrated with, and within the fabric of the site plan pr draft plan. General guidance regarding the analytical methods and techniques for at-source controls are provided in various guidelines, and generally focus on the appropriate methods and techniques for conducting water balance and peak flow (i.e. flood risk) analyses. The specific technique applied generally depends upon their function (i.e. interception/detention, conveyance, infiltration). The relationship between function and modelling technique is summarized in Table 2.

| TABLE 2. Summary of conventional modelling techniques (ref. MOE, 2003) | | |
|---|---|---|
| **LID Function** | **Representative LID Practice** | **Modelling Technique** |
| Interception/Detention | Rain Barrels<br>Cisterns<br>Green Rooftops<br>Tree Clusters | Storage element disconnected from the overall system or modified Initial Abstraction |
| Conveyance | Filter Strips<br>Enhanced Grassed Swales | Reservoir Routing Element |
| Infiltration | Rooftop Disconnects<br>Soakaway Pits<br>Permeable Pavers<br>Bio-Retention<br>Dry Swales<br>Pervious Pipes | Reservoir Routing Element with two outlets (one representing groundwater recharge and one representing overflow) |

The foregoing modelling techniques are applied for various hydrologic modelling methodologies (i.e. event methodology, continuous simulation, annual water balance), depending upon the capabilities of the specific hydrologic model. The results of these analyses are used to determine the water balance for the site under existing and proposed conditions, as well as to define the relative change in peak flow rates from the site, as a result of the proposed development and stormwater management practice.

As indicated in the previous section, the detailed design for the stormwater management system, as part of the Draft Plan or Site Plan Approval process, represents the final stage in the stormwater management planning process, and tends to focus on the requirements associated with the specific development area. As such, the current process associated with analyzing LID BMP's, while providing a means of assessing the impacts associated with the specific development area of interest, does not incorporate broader targets and objectives into analyses completed under the governing higher-level studies (i.e. the Subwatershed Study and the EMS), and hence does not evaluate the subwatershed-scale performance of these practices with respect to the overall environmental systems.

**Subwatershed-scale Modelling Approaches**

The hydrologic benefits of LID BMP's as related to the maintenance of the water balance and potential reductions to the sizing of end-of-pipe stormwater management facilities are of particular interest and significance at the Subwatershed scale. Given the objectives and techniques which are applied for Subwatershed-scale analyses of stormwater management systems, hydrologic modelling for LID BMP's as part of Subwatershed Studies is required to:

- Apply continuous simulation methodology using long-term meteorological data (i.e. minimum 20 years) since this methodology is considered to be more representative of meteorological conditions compared to the event methodology (ref. Farrell et al, 2001)
- Generate instantaneous peak flow rates at discrete timesteps (i.e. hourly or finer)
- Maintain consistency with current standards of practice for discretizing the study area for hydrologic analyses (i.e. apply subcatchment-scale discretization as opposed to lot-level discretization) in order to avoid modelling bias through the application of different levels of discretization and modelling practices/conventions
- Minimize time requirements for simulation in order to allow for efficient assessments of stormwater management requirements and performance (i.e. accommodate conventional iterative approach toward sizing and evaluating stormwater management requirements for development scenarios and alternatives)
- Incorporate the hydrologic impacts of various LID BMP's (i.e. interception/detention of rainwater, conveyance, and infiltration)
- Account for infiltration capacity of native soils within the study area and associated limitations to performance and function of LID BMP's which promote infiltration as well as the impacts to antecedent moisture conditions within the surrounding pervious land areas (i.e. potentially prolonged period of saturation due to infiltration practices)

In recent years, various studies and initiatives have attempted to evaluate the broader scale hydrologic impacts/benefits of LID BMP's at the Subwatershed and/or Subcatchment Scale; each has have applied different modelling techniques in order to represent the effects of LID BMP's at the Subwatershed scale.

***The Toronto Wet Weather Flow Study***

In Ontario, the one of the first attempts to conduct such analyses was completed as part of the Toronto Wet Weather Flow Study (City of Toronto, 2003), which employed a modified application of the USEPA Hydrologic Simulation Program – Fortran (HSP-F) methodology for a continuous simulation using 4 years of meteorological data. Under that initiative, a series of "micro models" was developed for "generic land use" conditions, representing a 1 hectare development of a specific land use condition with a corresponding soil type, topography slope, connectivity to the minor system, and stormwater management practice (i.e. with or without LID); consistent with current practice for completing hydrologic analyses of LID, the models developed for the generic land uses were highly discretized. An example of the model schematic for the residential land use with LID is presented in Figure 2.

The Wet Weather Flow Study Model was used in order to generate the surface runoff and groundwater recharge responses (i.e. hydrographs) for each generic land use. These hydrographs, termed Unit Response Functions (URF's) provided the basis for assessing the impacts at the subwatershed scale. Under this approach, each URF was multiplied by that areal composition of the respective generic land use within the parent catchment of the Subwatershed Scale assessment, and provided an initial approach toward quantifying the impacts to groundwater recharge associated with LID practices, as well as qualifying, in general, the impacts to peak flow response and flood risk resulting from the proposed land use change. Although this process provided an initial basis for evaluating the cumulative impacts of LID practices at the subwatershed scale, the process required significant computational effort in order to generate the URF's (i.e. several hours required to execute one simulation). Moreover the limited time period for the simulation (i.e. 4 years), while providing a qualitative means of assessing the impacts to peak flow response, was insufficient for completing frequency analyses to quantify flood risk, which, under current standards of practice, requires a minimum continuous simulation period of 20 years.

***The Credit River Flow Management Study***

In 2007, Credit Valley Conservation completed the Flow Management Study (FMS) (Philips Engineering Ltd., 2007), which adopted a watershed-wide assessment approach to recommend stormwater management practices for flood control for the main branch Flood Damage Centres. This process applied continuous simulation for forty (40) years of meteorological data using the HSP-F methodology in order to generate instantaneous peak flow rates at key locations along the Credit River, and proceeded concurrently with a Water Quality Study, which applied a version of the Wet Weather Flow Study HSP-F model. In order to maintain consistency between the two initiatives, the HSP-F methodology was also adopted for the FMS, however the model was applied using the more conventional application of the tool involving larger catchments of mixed use with hybrid parameterization.

As part of the FMS process, an approach toward simulating LID practices at the Subcatchment Scale was developed. The techniques applied for the assessment were predicated upon the methods incorporated into the Water Quality Model, which applied the techniques summarized in Table 2 for the specific LID practices. The simulation techniques which were applied at the catchment level for the watershed-scale assessment are summarized in Table 3.

**TABLE 3. Summary of simulation techniques applied for Credit River Flow Management Study for watershed-scale assessment of LID practices (ref. Farrell et al, 2008)**

| Technology | Simulation Technique |
|---|---|
| Roof Storage/Ponds | Increase interception storage for impervious land uses. The additional depth of interception storage would be determined based upon the storage volume contributing drainage area in the Water Quality Model, and weighted according to the amount of the overall impervious area draining to these systems. |
| Pervious Pipes | Modify the subcatchment schematics such that the impervious areas would be routed through a split-flow element, which would separate the portion contributing to the pervious pipe from the overflow/excess flow; the portion draining to the pervious pipe would be simulated as an external infiltration to the pervious segment of the subcatchment (ref. Figure 3). |
| Infiltration Trenches | Apply the same simulation technique as for the pervious pipes. |
| Pervious Pavements | Reduce impervious area to account for pervious pavements. The reduction in impervious area would be based upon the paved area provided in the and accounting for 30% "void" space afforded by pervious pavements (ref. Bean, Hunt, Bidelspach, 2005). |

When compared with the techniques listed in Table 2 for more conventional modelling techniques of at-source controls, the most notable distinction is that the infiltration technologies were simulated by routing the infiltratable discharge from the infiltration facility through the lower storage zone of the pervious land segment. This technique was considered to provide a benefit compared to the more common approach of using a routing element (reservoir) alone, since it would account for the higher antecedent moisture conditions within the pervious land segment resulting from the prolonged release of water from the infiltration facility, and the associated increase in runoff potential. A schematic representing this analytical technique is presented in Figure 3.

Through the Flow Management Study, it was determined that the simulation techniques specified in Table 3 would adequately simulate the hydrologic effects of the LID BMP's specifically related to reductions in runoff volumes, through the various interception storages and infiltration techniques (ref. Pitt et. al. 2005); the FMS incorporated LID BMP's into the hydrologic model at the subcatchment scale, and thus maintained consistency with current standards of practice for study area discretization. Furthermore, while the approach did not evaluate the cumulative impacts of the individual LID practices, the approach was considered consistent with current practice of representing the cumulative hydrologic impacts of stormwater management systems using a single routing element at the subcatchment outlet (ref. Farrell et al, 2008). The foregoing approach though was predicated upon first establishing "acceptable" or approved LID technologies and techniques for the various land uses, as well as appropriate parameters associated with the "typical" application of these techniques (i.e. storage volumes for interception/detention storage elements, storage-discharge relationships for infiltration technologies). Thus, while the foregoing approach provided a modelling technique using the HSP-F methodology which could be applied for hydrologic analyses at the subwatershed scale, it nonetheless required specific information regarding the types of LID practices to be applied for the future land use condition, in order to generate the storage-discharge relationship for the model routing element. As stated previously, these details are typically not known until the detailed Draft Plan or Site Plan stage, and frequently vary among Municipalities and different developments of the same type, due to local physical constraints. Consequently, it was considered necessary to develop an approach for generating a "generic" storage routing element to represent infiltration techniques, which could be applied at the Subwatershed Study stage.

**Simplified Approach for Parameterizing LID Infiltration Practices at Subcatchment Scale**

In the absence of detailed information regarding the preferred, approved, or even acceptable LID BMP's which are to be applied for new developments, a simplified approach has been developed based upon the fundamental functions of LID stormwater management practices. As indicated previously, LID BMP's perform one or more of three basic functions: storage and detention of runoff, conveyance of storm runoff, and/or infiltration of storm runoff. Of the three functions, it is only the infiltration function which affects water balance by promoting groundwater recharge; therefore the simplified approach described herein pertains specifically to those technologies which promote infiltration of urban runoff.

As indicated in Table 2 above, various LID practices promote infiltration practices. Design criteria for each of these practices are available from various sources (ref. MOE, 2003; CVC/TRCA, 2009; City of Calgary, 2007). The information provided in these design drawings indicates that the specific details and dimensions of the LID practice vary among the specific technology applied; nevertheless, this review of the background information has indicated that the constructed infiltration technologies (i.e. soakaway pits, permeable pavers, bio-retention, dry swales, pervious pipes) include a granular matrix which temporarily stores the runoff to be infiltrated into the surrounding soil.

A design concept for a generic infiltration technology has been developed based upon this review of the available design standards for the various infiltration technologies, which reflects the minimum anticipated depth of the granular medium. This generic concept, as presented in Figure 4, is described as follows:

- Infiltration facility consists of a granular matrix embedded within the native soil.

- Runoff from the contributing drainage areas is stored within the voids of the granular matrix.

- The available storage volume within the infiltration facility is calculated as:

$$V = n \times d \times A \qquad \text{(Equation 1)}$$

where

V = storage volume within the infiltration facility ($m^3$)

n = void ratio of the granular matrix (unitless)

d = depth of the granular matrix (m)

A = surface area of the granular matrix ($m^2$)

- Infiltration facility is constructed above the water table in order to avoid groundwater interaction; hence, the infiltrated discharge rate for the infiltration facility is calculated as:

$$Q = (i \times A)/3600000 \qquad \text{(Equation 2)}$$

where

Q = infiltrated discharge rate from the infiltration facility ($m^3/s$)

i = infiltration capacity of the native soil surrounding the infiltration facility (mm/hr)

A = surface area of the granular matrix ($m^2$)

Based upon a review of available design standards for various infiltration technologies, a depth of 0.4 m was assumed as the appropriate depth of the granular matrix since this was noted to represent the minimum depth of the granular matrix of all the infiltration technologies. As well, a void ratio of 0.3 has been assumed, which is representative of the voids associated with the application of a granular medium.

In many jurisdictions, the storage volume of infiltration facilities is determined based upon a prescribed volume of runoff which is to be captured within the storage matrix and infiltrated into the surrounding soil. This capture volume is typically defined as a depth of water (in mm or inches); hence, the requisite capture volume is the product of this target depth and the size (area) of the contributing drainage area. Recognizing that volume is a prescribed target, Equation 1 can be rearranged to calculate the surface area of the granular matrix based upon the remaining known variables as follows:

$$A = V/(n \times d) \qquad \text{(Equation 3)}$$

When Equation 3 is substituted for A in Equation 2, then the discharge rate from the infiltration facility can be calculated as a function of the target volume and dimensions of the generic infiltration facility (i.e. n and d) as follows:

$$Q = (i \times V)/(n \times d \times 3600000) \qquad \text{(Equation 4)}$$

The foregoing approach toward determining the storage-discharge relationship for the generic infiltration facility, in combination with the modelling technique developed under the Flow Management Study for simulating LID practices at the Subwatershed scale, provides a means for efficiently assessing a broader suite of hydrologic impacts associated with generic LID practices (i.e. water balance, erosion, flood risk) at the Subwatershed Study level. This approach then provides guidance for subsequent studies with respect to specific requirements for LID BMP's in order to meet Subwatershed scale targets and objectives for environmental systems management.

## Case Study

In order to demonstrate the function and performance of the proposed approach for simulating LID infiltration functions at the Subwatershed Scale, the methodology described earlier has been applied to a conceptual development area within the Huttonville Creek Subwatershed of the Credit River Watershed (ref. Figure 5). The Huttonville Creek Subwatershed measures some 12.6 $km^2$, and the conceptual development area measures some 7.0 $km^2$. Soils within the study area are prominently fractured Halton Till, which exhibits relatively high runoff volume and response, particularly under saturated conditions. In general, these soils exhibit a relatively low infiltration capacity. The land use conditions within the study area are currently predominantly agricultural, with some isolated areas of forest cover scattered throughout the proposed development area.

Hydrologic analyses for the Huttonville Creek Subwatershed have been completed using the HSP-F hydrologic model which was originally developed for the Credit River Flow Management Study. The original FMS model was refined within the limits of the Subwatershed to include 35 catchments ranging from 5.74 ha to 206.5 ha in size, as well as 29 channel routing elements, and calibrated using local meteorological and flow data. The calibration of the original model included calibration of snow accumulation and melt parameters; the model refinements thus included a validation of the simulated results for snow accumulation and melt within the original parent HSP-F model.

In addition to the foregoing, the development of the HSP-F hydrologic model for the study area included the validation and integration of simulated groundwater recharge values with calibrated values obtained using a FEFLOW groundwater model of the study area. The development of the HSP-F hydrologic model thus incorporated a more rigorous calibration process for the simulation of the subsurface regime, and hence represents a more reliable tool for evaluating the associated impacts resulting from proposed changes in land use conditions and the application of various stormwater management processes.

The hydrologic analyses for the study area were completed using a 40 year continuous simulation using hourly precipitation, temperature and dew point data, and daily evaporation, solar radiation and wind movement data. Flow rates to the receiving surface water system were generated at 15 minute timesteps. In addition, the HSP-F model was executed in order to generate groundwater recharge rates at 15 minute timesteps for the same period of record, for the water balance assessment.

**Development of LID Routing Elements**

The methodology described in the previous section has been used in order to develop the routing elements to represent the associated infiltration technologies. The infiltration targets were established based upon consultation with the Technical Steering Committee for the project. Initial target rates were established recognizing the limited infiltration capacity of the soils, and primarily predicated upon maintaining the existing water balance to the extent possible; these rates were subsequently modified to account for the anticipated loss of efficiency which would occur over time, as a result of lack of maintenance. Through this consultation, effective capture rates for the given soils conditions ranged from capture volumes of 1 mm/impervious hectare to 4 mm/impervious hectare, depending upon the contributing land use condition. Hence the storage values for the LID routing elements for the respective subcatchments were calculated using the following equation:

$$V_s = \Sigma(V_i \text{ x } A_{s,i}) \qquad \text{(Equation 5)}$$

where

$V_s$ = total storage volume available within generic LID infiltration facilities for Subcatchment s ($m^3$)

$V_i$ = storage volume available within generic LID infiltration facility for Land Use i, as calculated using Equation 1 above and the target rates established by the Technical Steering Committee ($m^3$/ha)

$A_{s,i}$ = total area of Land Use i within Subcatchment s (ha)

Once the value of $V_s$ was determined for each subcatchment, the corresponding discharge rate for the generic LID facility for the respective subcatchment was calculated using the calibrated infiltration rate for the soils, and Equation 4 above.

The discharge rates for the respective subcatchments were determined using Equation 4, using the storage values calculated as described in the foregoing, and using the calibrated infiltration rates for the subcatchment.

**Simulated Water Balance**

A water balance assessment was completed for the calibrated HSP-F hydrologic model for existing land use conditions, future land use conditions with conventional end-of-pipe stormwater management, and future land use conditions with LID BMP's. The hydrologic model for future land use conditions with conventional stormwater management was modified in accordance with the methodology described above as follows:

- Model schematic was modified so that the operation sequence for each catchment representing sites of future development corresponded to the schematic provided in Figure 3 (i.e. within the OPN SEQUENCE and NETWORK blocks).

- Storage-discharge relationships for the routing elements representing the LID infiltration systems were incorporated into the model (i.e. within the FTABLES block)

A water balance was calculated for each of the three land use and management scenarios in order to determine the relative effectiveness of LID practices with respect to promoting groundwater recharge and maintaining water balance within the Huttonville Creek Subwatershed. The Water Balance Assessment was completed using the following approach:

- Simulated surface runoff volume for all three scenarios was generated as the sum of the direct surface runoff component and the interflow component for the pervious land segments (i.e. groundwater outflow to the surface water systems was not included as surface runoff).

- Simulated groundwater recharge was generated as a separate simulation for all three land use scenarios.

- Evapotranspiration was calculated for each of the three scenarios using the empirical relationship

  [Total Precipitation] = [Surface Runoff Volume] + [Groundwater Recharge Volume] + [Evapotranspiration Volume]

  and applying an average annual total precipitation of 780 mm based upon the 40 year record.

The results of this assessment are presented graphically in Figure 6.

The results of the water balance assessment, using the methodology described herein, indicate that the application of LID practices would increase the recharge to the groundwater regime compared to conventional stormwater management practices. This is consistent with anticipated results for these systems. The results, however, also indicate that the application of LID practices would result in higher evapotranspiration rates compared to the application of conventional stormwater management practices, and that the majority of the surface runoff which would be captured by the infiltration facilities through the application of LID practices would be lost to evapotranspiration as opposed to infiltrating into the underlying soil. This is considered plausible, given the relatively low infiltration rates associated with the fractured Halton Till, as well as the potential for water to evaporate from the granular matrix within the infiltration facility.

**Erosion Assessment**

Conventional practice for providing erosion control for future development areas consists of increasing the storage volume and drawdown time for the extended detention storage component of the stormwater management facility, in order to reduce the duration of flows above a pre-determined threshold flow rate within the receiving water course. The threshold flow rate represents the minimum erosive flow rate within at the critical (i.e. most erosion prone) site, and is determined through detailed fluvial geomorphological assessments of the watercourse. This value is used to establish a target unitary discharge rate for erosion control using the following relationship:

$$Q_{unitary} = Q_{erosive}/A \qquad \text{(Equation 6)}$$

where

$Q_{unitary}$ = target unitary discharge rate for erosion control ($m^3/s/ha$)

$Q_{erosive}$ = threshold flow rate for erosion at critical site ($m^3/s$)

A = total drainage area to the critical site for erosion (ha)

The target unitary discharge rate is in turn used to calculate the extended detention discharge rate for the stormwater management facilities, as the product of the target unitary discharge rate for erosion control and the size of the contributing drainage area to the facility. The requisite extended detention storage volume is then determined by iteratively adjusting the volumes for the facilities until the duration of flows above the threshold flow rate at the critical site under the future land use condition with stormwater management, effectively matches the duration for existing conditions (within a reasonable tolerance).

The above approach toward determining erosion control requirements within end-of-pipe facilities has been applied for the conceptual development area in order to determine whether or not LID infiltration practices within the subject study area may afford efficiencies (i.e. reductions) to end-of-pipe facility requirements for erosion control. The results of this assessment have indicated that, through the application of LID infiltration practices within the upstream conceptual development area, erosion control requirements within the end-of-pipe facility for that area could be reduced by as much as 36 %.

## Summary

The foregoing has outlined an approach whereby LID BMP's which promote infiltration for future development areas can be incorporated into conventional Subwatershed-scale modelling in order to evaluate the long-term effectiveness of these practices at a larger scale in order to provide direction related to maintaining the water balance within the study area, as well as determining efficiencies for the sizing of end-of-pipe facilities. The methodology utilizes a conceptual routing element to determine the storage-discharge relationship for the conceptual infiltration facilities within the contributing catchment, and applies the infiltration capacity of the native soils to determine the effective discharge from the facility, based upon a generic configuration of the conceptual infiltration facility.

The approach has been applied to a Case Study which utilized the HSP-F hydrologic model and long-term continuous simulation methodology. The approach was further tailored to the HSP-F methodology, by utilizing the opportunities to link the infiltration discharge from the conceptual routing element to the lower storage zone within the pervious land segment of the contributing drainage area, as a lateral input to the lower zone, which thereby accounts for the increased antecedent moisture conditions within the pervious land segment which may result from the application of the LID practices. The approach affords a more efficient means of evaluating the hydrologic benefits of applying LID practices at discrete timesteps and for longer simulation periods, compared to other approaches which have been applied, and also affords the opportunity to assess potential reductions to end-of-pipe facility requirements to address Subwatershed-scale targets.

Future research and development of this approach includes validation against other tools and techniques which may also applied at the Subwatershed scale, as well as assessments in other jurisdictions with soil conditions exhibiting higher infiltration capacities. Further research includes testing the application of this approach for establishing LID application requirements to satisfy Subwatershed-scale hydrologic targets (i.e. water balance and erosion control).

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## Tables

TABLE 1: Summary of common LID BMP's

TABLE 2: Summary of conventional modelling techniques

TABLE 3: Summary of simulation techniques applied for Credit River Flow Management Study for watershed-scale assessment of LID practices

## Figures

FIGURE 1: Conceptual application of LID BMP's on residential lot

FIGURE 2: Modelling schematic for conventional lot-level assessment of LID

FIGURE 3: Modelling schematic for subcatchment-scale assessment of LID

FIGURE 4: Design concept for generic LID infiltration facility

FIGURE 5: Case Study Area Location Plan

FIGURE 6: Summary of water balance for Huttonville Creek subwatershed

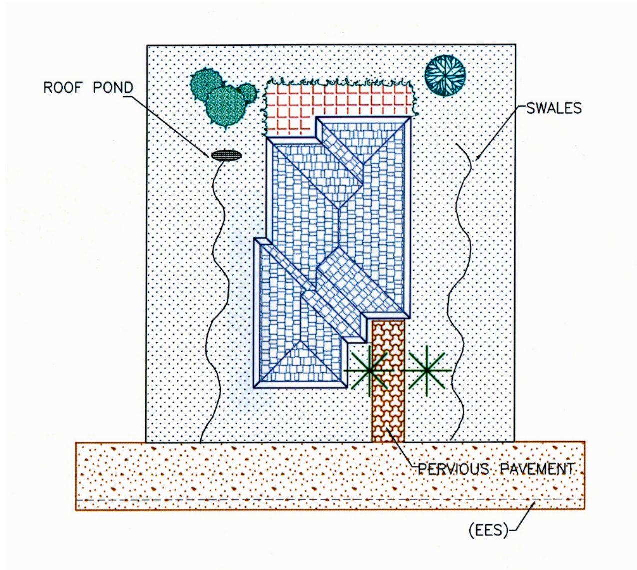


FIGURE 1: Conceptual application of LID BMP's on residential lot

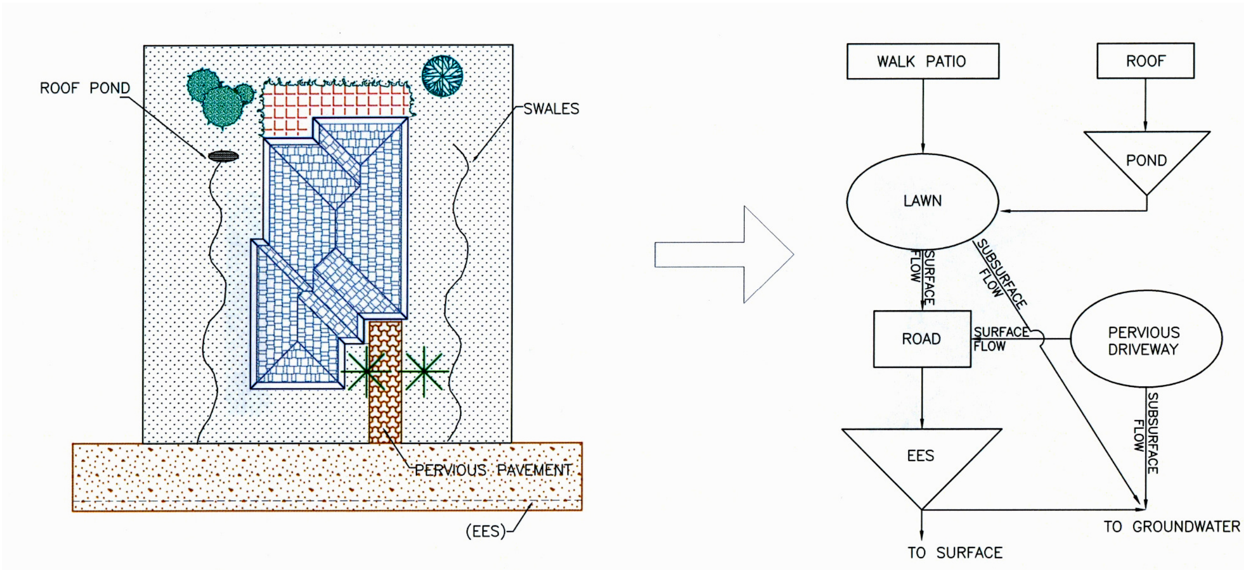


FIGURE 2: Modelling schematic for conventional lot-level assessment of LID

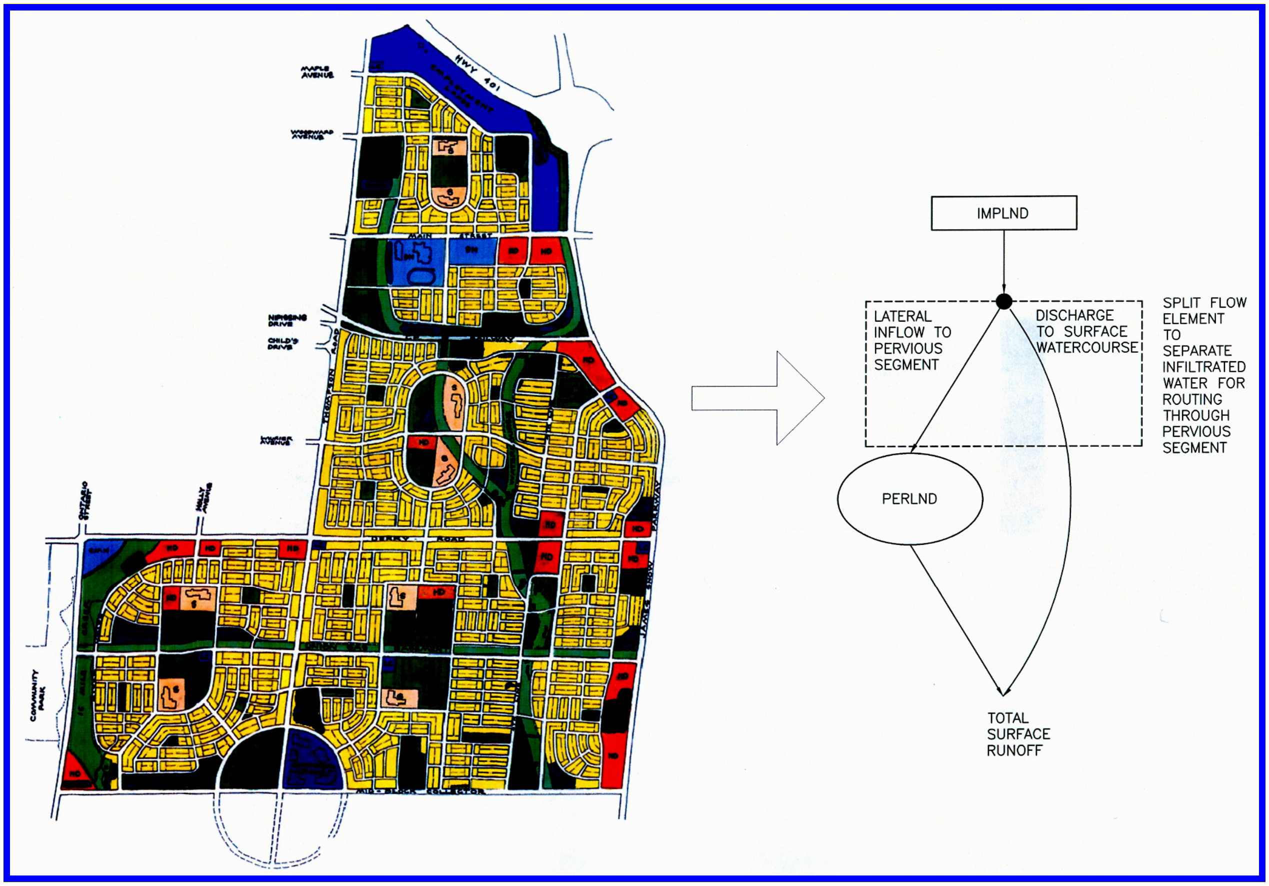


FIGURE 3: Modelling schematic for subcatchment-scale assessment of LID

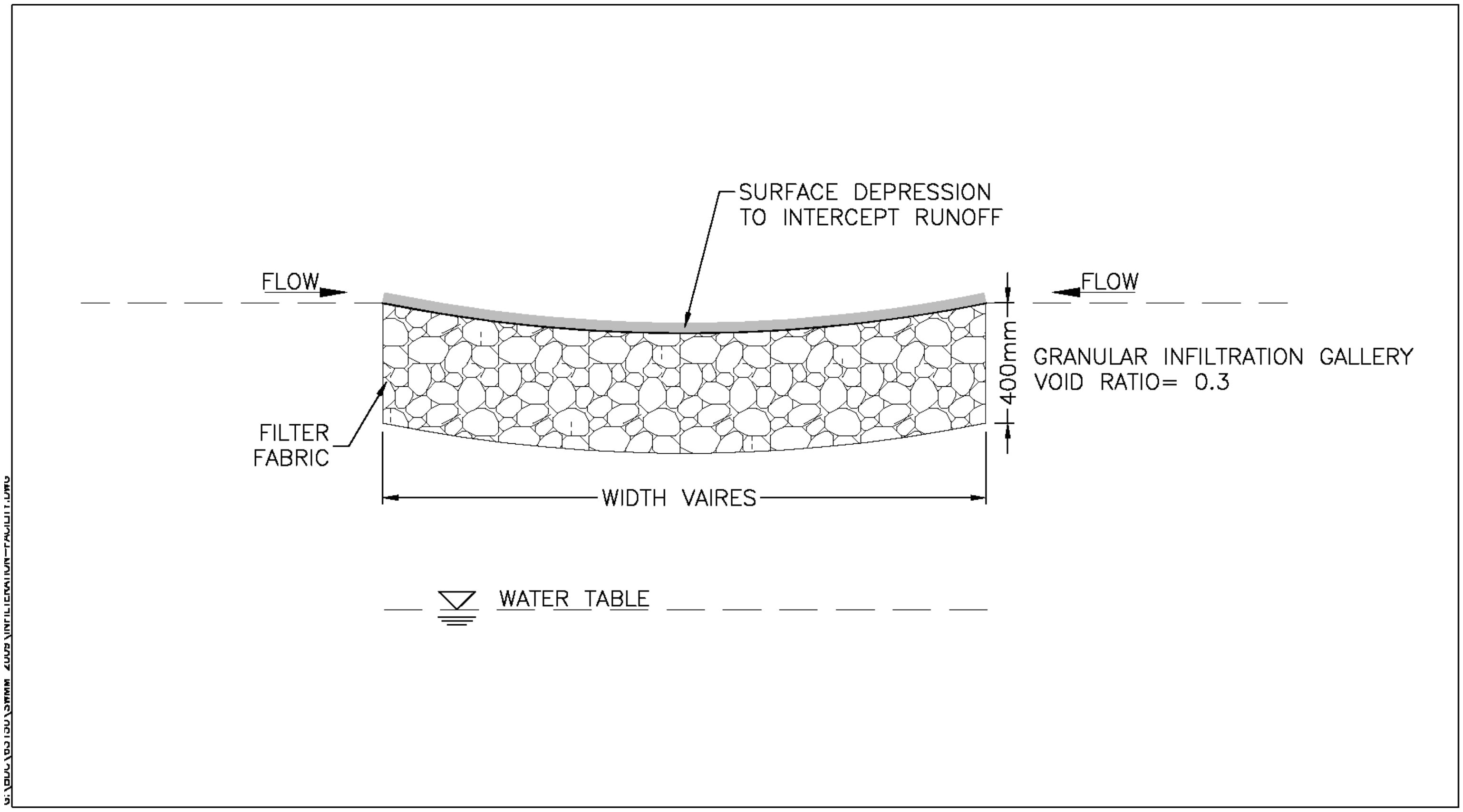


FIGURE 4: Design concept for generic LID infiltration facility

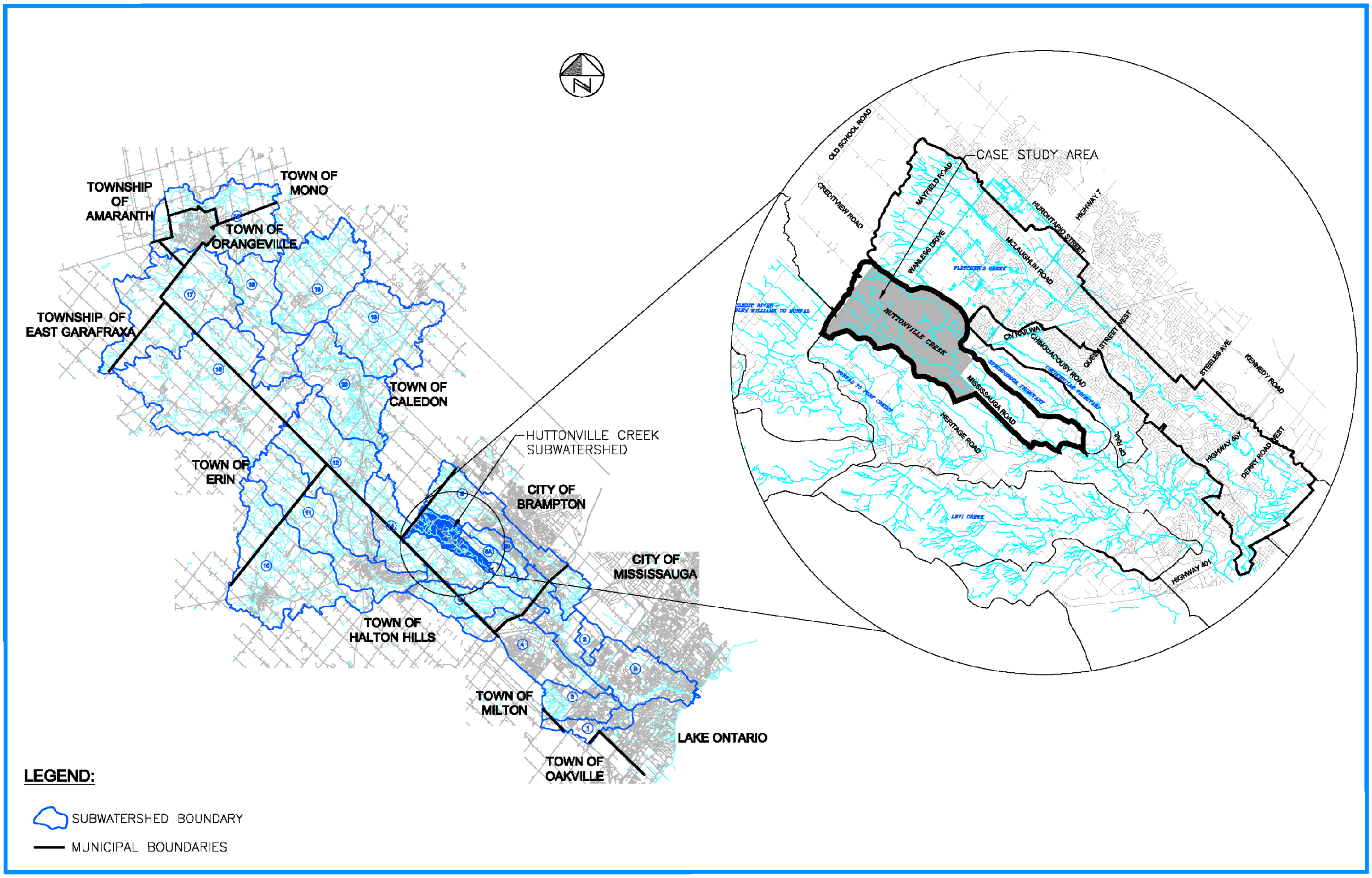


FIGURE 5: Case Study Area Location Plan

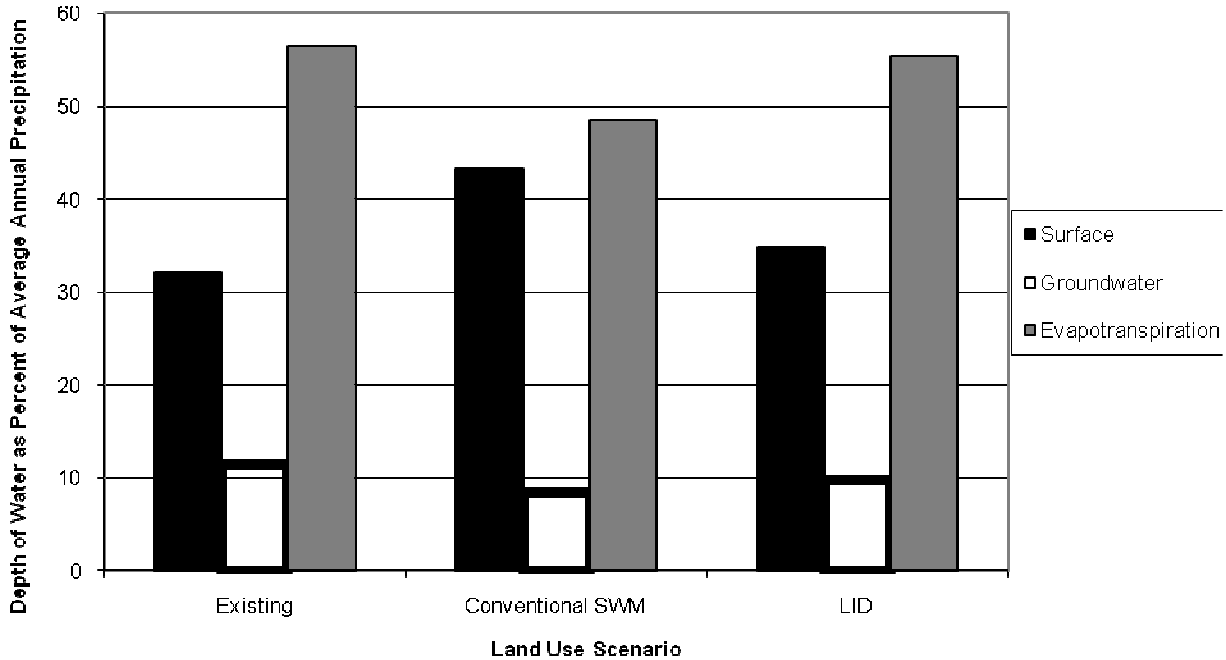


FIGURE 6: Summary of water balance for Huttonville Creek subwatershed