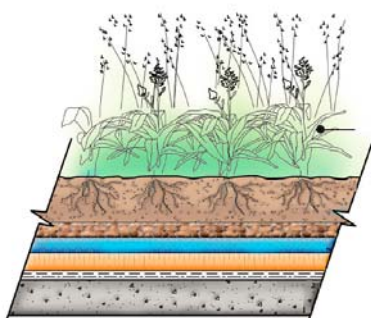


Low Impact Development Best Management Practices Design Guide Edition 1.0

November 2011

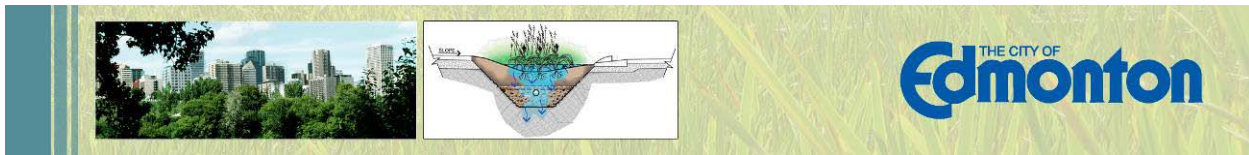


**CITY OF EDMONTON
LOW IMPACT DEVELOPMENT –
BEST MANAGEMENT PRACTICES
DESIGN GUIDE**

Edition 1.0

City of Edmonton
Edmonton, Alberta

November 2011



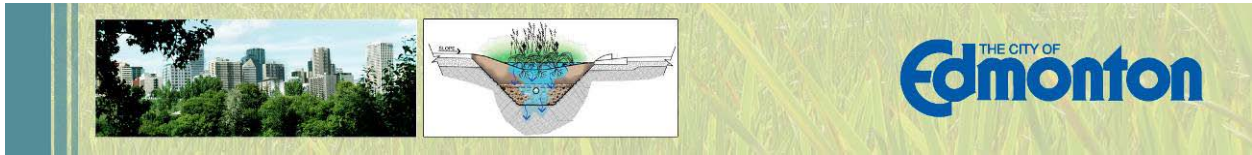
PREFACE

This document – the *Low Impact Development - Best Management Practices Design Guide* (Design Guide) - was developed by the City of Edmonton (City) to provide guidance for the application of low impact development best management practices (LID-BMPs). It provides an overview of LID-BMPs and design guidelines that planners, engineers, developers, and designers can use to integrate LID-BMPs into land development, redevelopment, or retrofit projects. Development of the Design Guide supports the City's vision of sustainable growth and forwards the environmental goals laid out in *The Way We Green*, the City's environmental strategic plan.

The Design Guide consists of 14 chapters. Chapter 1 introduces why LID is necessary and what it entails. Chapter 2 briefly describes the federal, provincial and municipal legal documents that are most likely to have an impact on implementation of LID-BMPs. Chapter 3 describes soil and climate characteristics typical of the City of Edmonton. Chapter 4 describes LID site planning level details. Chapter 5 provides an overview of seven LID features identified to be most applicable to the City of Edmonton. Chapter 6 provides a LID facility design process and identifies cold weather adaptations recommended for Edmonton applications. Chapters 7 to 13 describe design considerations for each of the seven LID facilities. Chapters 14 and 15 contain a glossary and list references cited in this document. There are also five appendices that provide LID sizing, modeling tools and examples.

As LID is an evolving field and new to the City, this Design Guide is a living document and will be updated through continuing engineering experience and research studies in the City's local context. This Design Guide is not a design standard but rather provides high-level information about LID-BMPs to assist those interested in LID oriented development. Each site considered for development is unique. Consequently, the design of the LID-BMP facilities will also be unique and must be based on sound engineering principles that account for the soils, vegetation, topography, hydrology and management requirements for the site. Qualified professionals should be consulted for advice specific to each development. In addition, the relevant requirements for stormwater management as set out in City drainage bylaws, Design and Construction Standards and other pertinent legislation remain applicable to LID. It is strongly recommended that discussions with applicable City of Edmonton departments be started early in the process to facilitate the design and approvals process and ensure mutual understanding of the development objectives and methodology.

This document was drafted in June 2011 by AMEC Earth & Environmental with assistance from Armin A. Preiksaitis & Associates Ltd. and Progressive Engineering Ltd. The Drainage Planning section of the City's Drainage Services Branch made further revisions to the draft Design Guide. The Design Guide development fully incorporated stakeholder inputs from advocacy and technical roundtable sessions. The authors acknowledge the contributions and participation of key stakeholders including Parks, Community Services, Sustainable Development, Development Services, Buildings and Landscape Services and Transportation Services.



Comments and questions regarding this Design Guide should be directed to:

General Supervisor, Environmental Planning group, Drainage Services, 6th floor Century Place, 9803-102A Avenue, Edmonton, Alberta T5J 3A3. Phone: 780-496-3006

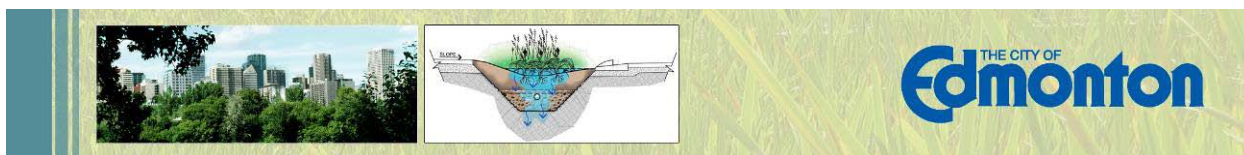
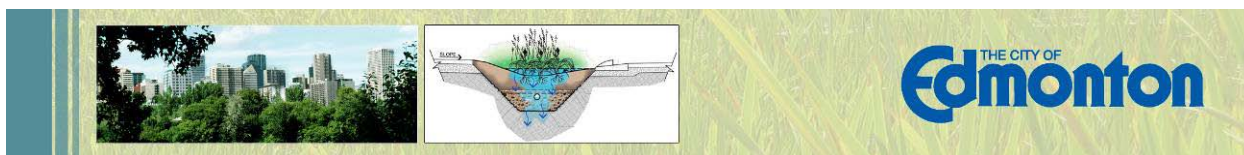
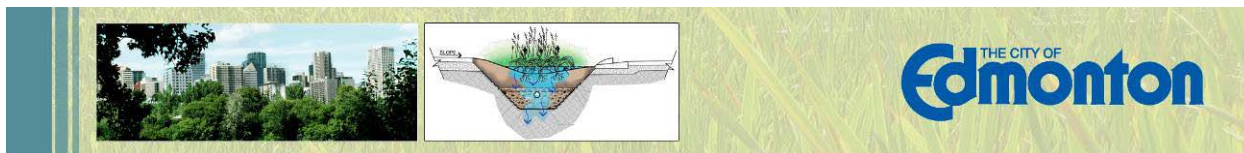


TABLE OF CONTENTS

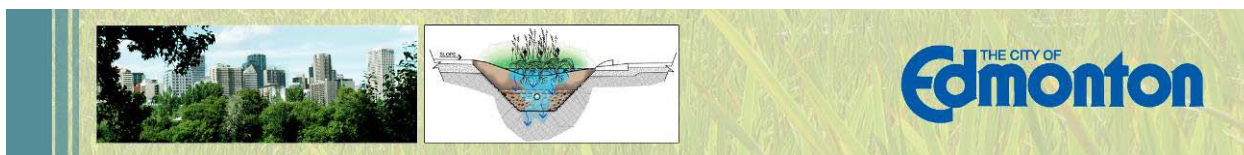
	PAGE
1.0 INTRODUCTION.....	1
1.1 Stormwater Management Practices	1
1.1.1 Impact of Urbanization	1
1.1.2 Conventional Stormwater Management	1
1.2 Low Impact Development	2
1.2.1 What is LID?	2
1.2.2 Benefits of LID-BMP Based Development.....	3
1.3 LID-BMP Design Considerations	4
1.4 Regulatory Involvement and Approvals.....	5
2.0 STORM DRAINAGE REGULATIONS & GUIDELINES.....	6
2.1 Federal Regulations.....	7
2.1.1 Navigable Waters Protection Act	7
2.1.2 Federal Fisheries Act.....	7
2.1.3 Edmonton Garrison Zoning Regulations	7
2.2 Provincial Regulations	8
2.2.1 Alberta Water Act	8
2.2.2 Alberta Environmental Protection and Enhancement Act (EPEA)	8
2.2.3 Restricted Development Area Regulation	9
2.2.4 Alberta Building Code	9
2.2.5 Alberta Public Lands Act.....	10
2.2.6 EPEA Approval to Operate	10
2.2.7 Municipal Policies and Procedures Manual	10
2.3 Municipal Guidelines, By-laws and Regulations	11
2.3.1 City of Edmonton Design and Construction Standards, Part 3 Drainage	11
2.3.2 City of Edmonton Sewers Use Bylaw No. 9675.....	11
2.3.3 City of Edmonton Sewers Bylaw No. 9425.....	11
2.3.4 City of Edmonton Surface Drainage Bylaw No. 11501	12
2.3.5 City of Edmonton Zoning Bylaw No. 12800.....	12
2.3.6 City of Edmonton North Saskatchewan River Valley Area Redevelopment Plan Bylaw No. 7188	12
2.3.7 City of Edmonton Winter Road Maintenance Policy – C409F	12
3.0 LOCAL CHARACTERISTICS	14
3.1 Physical and Climatic Conditions	14
3.2 Hydrology	16
3.2.1 Precipitation	16
3.2.2 Evaporation.....	17
4.0 LID SITE PLANNING AND DESIGN	21



4.1	Conventional vs. LID Neighbourhood Design.....	21
4.2	LID Site Design Process / Sequence	27
4.2.1	Site Assessment	28
4.2.2	Identification of Applicable Zoning, Land Use, Subdivision and Other Relevant Legislation.....	31
4.2.3	Delineation of the Development	31
4.2.4	Reduction of Impervious Surfaces within the Development.....	33
4.2.5	Development of Preliminary Integrated Site Plan	34
4.2.6	Hydrology Comparison	35
4.2.7	Construction Management.....	35
4.2.8	Completion of the LID Site Plan	37
5.0	LID BMPS OVERVIEW	38
5.1	LID Facility Features and Description	38
5.1.1	Bioretention / Rain Gardens.....	38
5.1.2	Bioswales.....	40
5.1.3	Green Roofs	41
5.1.4	Permeable Pavement	43
5.1.5	Box Planters	44
5.1.6	Naturalized Drainage Ways	47
5.1.7	Rainwater Harvesting for Re-use	48
5.2	Performance of LID-BMPs	49
5.3	LID Benefits, Costs and Limitations	50
5.3.1	LID Benefits	50
5.3.2	Life Cycle Costs.....	54
5.3.3	Limitations of LID	59
6.0	LID BMPs FACILITY DESIGN	62
6.1	Vegetation Selection and Planting	62
6.2	Soil Management and Amendment.....	63
6.2.1	Soil Management.....	63
6.2.2	Soil Amendments.....	64
6.3	Cold Climate Considerations.....	67
6.3.1	Managing and Designing for Road Salt Applications.....	68
6.3.2	Managing and Designing for Sand and Gravel Applications.....	69
6.3.3	Recommendations for Edmonton.....	69
6.4	LID Facility Design Process	72
6.4.1	Facility Selection.....	73
6.5	Hydrological Analysis.....	77
6.6	Site Monitoring.....	80
6.6.1	Precipitation	80
6.6.2	Flows	80
6.6.3	Water Quality.....	80
6.6.4	Optional Parameters	81



7.0	BIORETENTION / RAIN GARDENS	82
7.1	Description.....	82
7.2	Application	82
7.3	Design Considerations.....	83
7.4	Operation and Maintenance.....	85
8.0	BIOSWALES.....	90
8.1	Description.....	90
8.2	Application	90
8.3	Design Considerations.....	91
8.4	Operation and Maintenance.....	97
9.0	GREEN ROOFS.....	99
9.1	Description.....	99
9.2	Application	101
9.3	Design Considerations.....	102
9.4	Operation and Maintenance.....	106
10.0	PERMEABLE PAVEMENT	108
10.1	Description.....	108
10.2	Application	108
10.3	Design Considerations.....	108
10.4	Operation and Maintenance.....	112
11.0	BOX PLANTERS	115
11.1	Description.....	115
11.2	Application	115
11.3	Design Considerations.....	116
11.4	Maintenance Schedule	120
12.0	NATURALIZED DRAINAGE WAY	123
12.1	Descriptions.....	123
12.2	Applications	123
12.3	Design Considerations.....	124
12.2	Operation and Maintenance.....	127
13.0	RAINWATER HARVESTING FOR RE-USE.....	129
13.1	Description.....	129
13.2	Application	129



13.3 Design Considerations.....	130
13.4 Operation and Maintenance.....	132
14.0 GLOSSARY	137
15.0 REFERENCES.....	141

LIST OF TABLES

Table 2.1	Regulations and Guidelines Applicable to LID-BMPs in the City of Edmonton	6
Table 3.1	Edmonton Climate Statistics	15
Table 3.2	Soil Characteristics for the Edmonton Region.....	16
Table 3.3	Monthly Average High and Low Temperature and Precipitation (1971-2000) at Edmonton City Centre.....	17
Table 4.1	Site Assessment Requirements.....	30
Table 4.2	Long Term Average Infiltration Rates for Compacted Soils.....	36
Table 5.1	Observed Removal Efficiencies (%) in LID-BMP Facilities in the USA and Canada	50
Table 5.2	Benefits of LID BMPs.....	52
Table 5.3	Summary of Cost Comparisons of Conventional and LID Approaches	57
Table 5.4	Life Cycle Costs of LID-BMP Facilities.....	58
Table 6.1	Amended Topsoil Characteristics	66
Table 6.2	Challenges to Design of LID-BMP Facilities in Cold Climates	68
Table 6.3	LID Facility Selection Matrix.....	74
Table 6.4	LID Facility Site Constraint Matrix	75
Table 6.5	Non-Point Sources of Pollution in Developed Areas	77
Table 7.1	Bioretention Parameters and Guidelines.....	86
Table 7.2	Bioretention Drawing Details.....	88
Table 7.3	Bioretention Operation, Maintenance and Replacement Schedule	89
Table 8.1	Bioswale Design Parameters and Guidelines	95
Table 8.2	Bioswale Drawing Details.....	96
Table 8.3	Bioswale Operation, Maintenance and Replacement Schedule	98
Table 9.1	Function of Green Roof Layers.....	100
Table 9.2	Green Roof Characteristics – Extensive and Intensive	102
Table 9.3	Guidelines for Green Roof Physical and Performance Parameters.....	104
Table 9.4	Details and Considerations for Green Roof Selection and Design	105
Table 9.5	Green Roof Drawing and Reporting Details	106
Table 9.6	Green Roof Operation, Maintenance and Replacement Schedule	107
Table 10.1	Permeable Pavement Parameters and Guidelines.....	111
Table 10.2	Permeable Pavement Drawing Details.....	112
Table 10.3	Permeable Pavement Operation, Maintenance and Replacement Schedule.....	114
Table 11.1	Box Planter Parameters and Guidelines	119
Table 11.2	Box Planter Drawing Details	120
Table 11.3	Box Planter Operation, Maintenance and Replacement Schedule	121
Table 12.1	Naturalized Drainage Way Parameters and Guidelines	126
Table 12.2	Naturalized Drainage Way Drawing Details	127

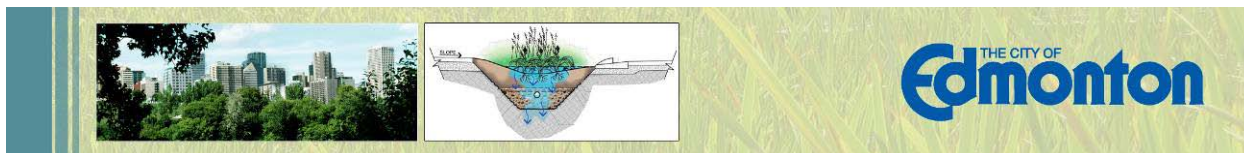
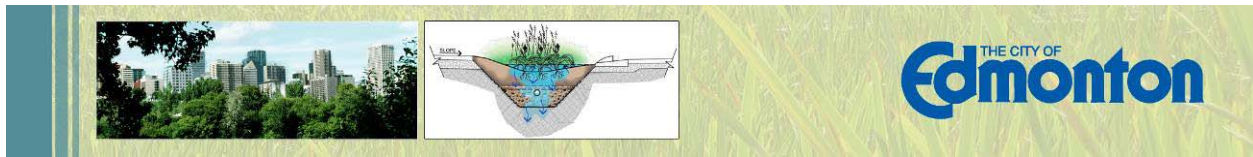


Table 12.3	Naturalized Drainage Way Operation, Maintenance and Replacement Schedule.....	128
Table 13.1	Rainwater Harvesting System Components.....	134
Table 13.2	Rainwater Harvesting System Design Parameters and Guidelines	135
Table 13.3	Cistern Operation, Maintenance and Replacement Schedule	136

LIST OF FIGURES

Figure 1.1	The Natural Hydrologic Cycle	3
Figure 3.1	Natural Regions and Subregions of Alberta	18
Figure 3.2	Current City of Edmonton Boundary and Historical Soil Survey Map	19
Figure 3.3	Rain Point Diagram for Edmonton Area Rainfall	20
Figure 4.1	Conventional Neighbourhood Concept Plan	25
Figure 4.2	LID-BMP Neighbourhood Concept Plan.....	26
Figure 4.3	Steps to Designing a LID Site	27
Figure 4.4	Street Layout Options According to Pavement Length.....	34
Figure 5.1	Bioretention Installations in Western Canada	39
Figure 5.2	Bioretention Area Components	40
Figure 5.3	Bioswale Installation Examples	41
Figure 5.4	Intensive and Extensive Green Roofs	42
Figure 5.5	Layers of a Green Roof	42
Figure 5.6	Permeable Pavement Installation Examples	43
Figure 5.7	Components of Permeable Pavement Facilities.....	44
Figure 5.8	Examples of Box Planter Installations	45
Figure 5.9	Tree Trench Box Planter with Cell Structure	45
Figure 5.10	Stormwater Management Mechanisms in a Box Planter	46
Figure 5.11	Naturalized Drainage Ways in Medium and Low Density Developments	47
Figure 5.12	Stormwater Management Mechanisms in a Naturalized Drainage Way	48
Figure 5.13	Types of Rainwater Storage Tanks.....	49
Figure 6.1	Compost Amendment Ratios for Topsoil and Subsoil Types.....	66
Figure 6.2	Water Holding Capacity by Soil Type.....	67
Figure 6.3	Distribution of Total Rainfall at Edmonton City Centre Gauge.....	79
Figure 7.1	Bioretention Installations in Residential, Commercial and Park Settings.....	83
Figure 7.2	Cross Section of a Basic Bioretention Area	87
Figure 7.3	Cross Section of a Deep Infiltration Bioretention Area	87
Figure 8.1	Local Bioswale Installations in Residential and Commercial Settings.....	91
Figure 8.2	Cross-Section of a Bioswale	93
Figure 8.3	Longitudinal Profile of a Bioswale with Check Dams.....	93
Figure 8.4	Plan View of a Bioswale.....	94
Figure 9.1	Cross-Section of Typical Green Roof Layers	100
Figure 10.1	Cross-Section of Permeable Pavement Installation	110
Figure 11.1	Tree Trench Box Planter with Structural Cells.....	116
Figure 11.2	Cross-Section of Flow-Through Box Planter	118
Figure 11.3	Cross-Section of Infiltration Box Planter.....	118
Figure 12.1	Longitudinal View of Naturalized Drainage Way with Check Dams	125
Figure 13.1	Rainwater Harvesting System Schematics (adapted from Rupp, 1998)	133



APPENDICES

- Appendix A: Recommended Vegetation for LID-BMP Facilities in Edmonton
- Appendix B: Soil Amendment Tools
- Appendix C: Cold Climate Facility Sizing Example
- Appendix D: Road Salt Application Examples
- Appendix E: Comparative Modelling Study

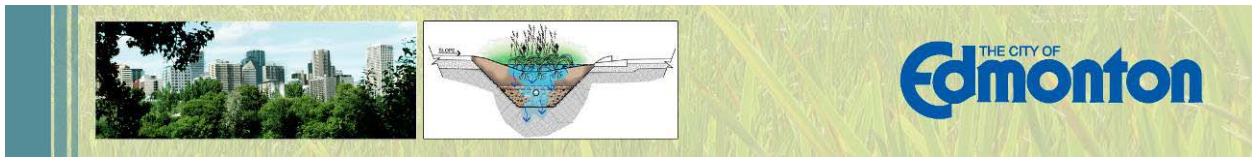
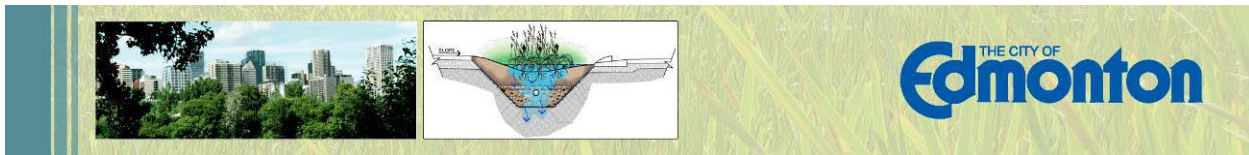


TABLE OF MEASUREMENTS AND TECHNICAL ABBREVIATIONS

Abbreviation	Definition
cm	centimetre
g	gram
hr	hour
L	litre
m	metre
mg	milligram
mm	millimetre
Q₂	Edmonton's 2 year precipitation event (95% of storms)
Q₅	Edmonton's 5 year precipitation event
Q₁₀	Edmonton's 10 year precipitation event
Q₂₅	Edmonton's 25 year precipitation event
Q₁₀₀	Edmonton's 100 year precipitation event
WSE	Water Surface Elevation



Stormwater – water that runs off land and developed surfaces during a rain or snowmelt event.

Impervious Area – areas covered with surface material that prevents water from passing through or penetrating to the sub-soils.

Urban Heat Island – an area, such as a city or industrial site, having consistently higher temperatures than surrounding areas because of a greater retention of heat, as by buildings, concrete, and asphalt.

Storm Sewers – concrete or PVC pipes, buried below the frost line, designed to convey stormwater runoff from the surface to the receiving waterbody or an end-of-pipe facility such as a stormwater pond

1.0 INTRODUCTION

1.1 Stormwater Management Practices

1.1.1 Impact of Urbanization

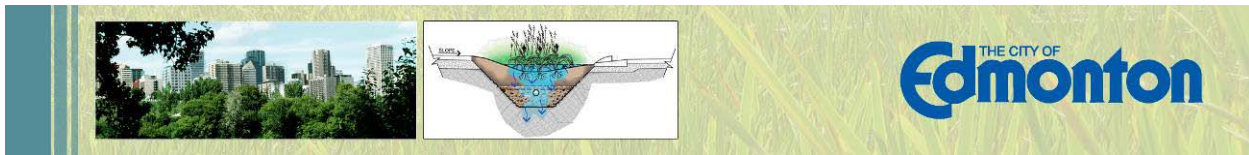
As the City of Edmonton grows and more land is developed both within the city and in surrounding areas, hydrologic functions of the natural water cycle are altered. Urbanization creates impervious areas that negatively impact stormwater runoff characteristics. These changes to the natural hydrologic cycle result in:

- increased flooding;
- decreased groundwater recharge;
- decreased evaporation from soil to the atmosphere;
- decreased transpiration from plants to the atmosphere; and
- increased urban heat island effects.

1.1.2 Conventional Stormwater Management

Current stormwater management practices in Edmonton and other urban centres direct stormwater runoff from pervious and impervious areas to storm sewers and then either directly to the receiving water body or to stormwater ponds. These stormwater ponds are used to reduce release rates during major storm events. Stormwater runoff reaching surface water bodies through the storm sewer system are characterized by increased volumes, duration and flow rates, especially during small storm events. These inputs to the receiving surface water body eventually result in:

- erosion and sedimentation in receiving waters due to increased sediment loading and flow rates during small storm events;
- water quality degradation due to increased sediment and pollutant loadings;
- stream channel degradation due to erosion and sedimentation;
- alterations to water temperature patterns within receiving waters due to the input of warmer runoff water;
- degradation of high-quality fish habitat due to erosion and sedimentation; and
- loss of recreation opportunities due to water quality degradation and bank erosion.



Stormwater Management Facilities – manage stormwater runoff to provide controlled release into receiving streams

LID-BMP – ecosystem-based approach to managing and treating stormwater runoff

Infiltration – process by which water penetrates into soil from the surface or upper soil layers.

Transpiration – the process of absorption of water by plants, usually through the roots, the movement of water through the plants, and the release of water vapour through small openings on the underside of leaves.

Rainwater – drops of fresh water that fall as precipitation from clouds.

1.2 Low Impact Development

1.2.1 What is LID?

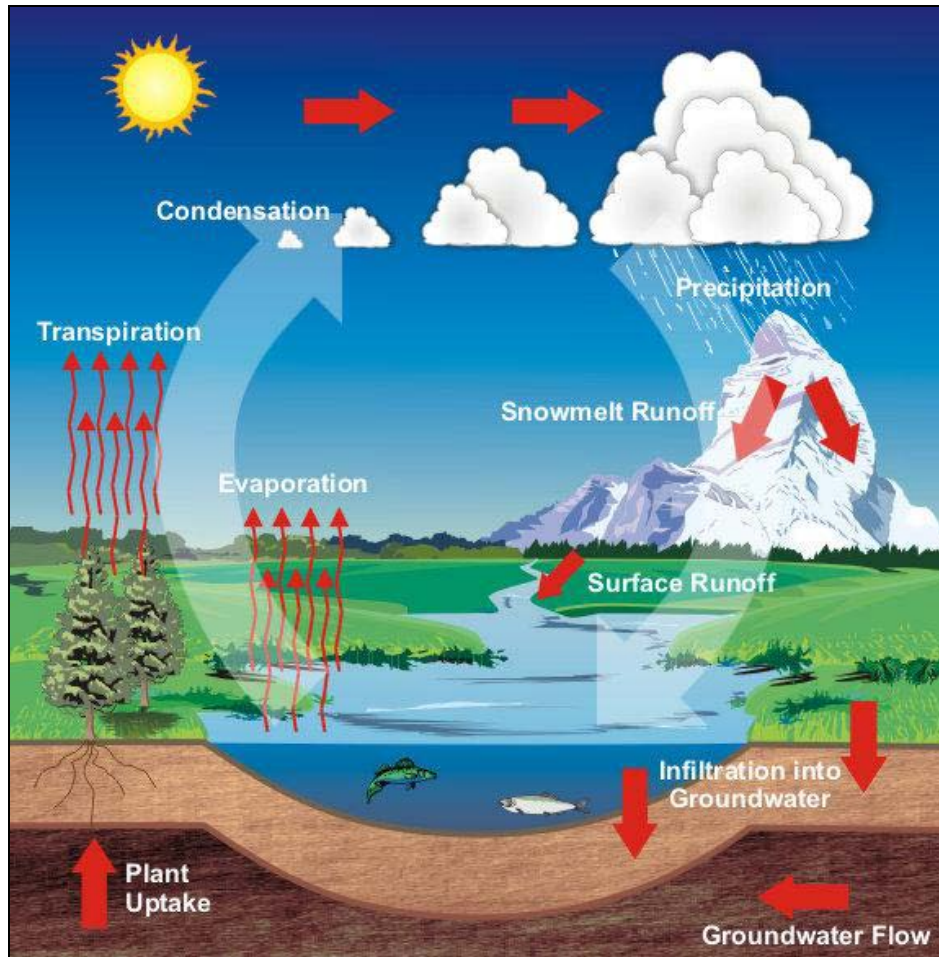
The U.S. Environmental Protection Agency (USEPA) defines low impact development (LID) as “an approach to land development (or re-development) that works with nature to manage stormwater as close to its source as possible” (US EPA, 2010). This approach focuses on maintaining or restoring the natural hydrological processes of a site, providing opportunities for natural processes to take place. Key principles in LID include:

- Preserving natural site features;
- Small scale, integrated stormwater management controls dispersed throughout the site;
- Minimizing and disconnecting impervious areas;
- Controlling stormwater as close to its source as possible;
- Prolonging stormwater runoff flow paths and times; and
- Creating multi-functional landscapes.

LID best management practices (BMPs) are techniques that rely on natural processes to manage water quantity and quality, including:

- absorption;
- infiltration;
- evaporation;
- evapo-transpiration;
- filtration through standing plant material and soil layers;
- potential pollutant uptake by select vegetation; and
- biodegradation of pollutants by soil microbial communities.

LID-BMPs promote maintenance of the hydrologic cycle, shown for a natural environment in **Figure 1.1**, where rainwater is able to provide soil moisture for plants, infiltrate to recharge groundwater aquifers and allow for evaporation and transpiration of water back into the atmosphere. The properties of natural materials such as soil, gravel, vegetation and mulch reduce the volume and peak flow rates of runoff reaching receiving streams and enhance the quality of stormwater entering our receiving water bodies. As a landscape becomes more developed, many of the functions of the hydrologic cycle shown in **Figure 1.1** are impaired. LID-BMPs seek to restore these natural processes to the urbanized landscape.



(www.solcomhouse.com/images/hydrowealth.jpg)

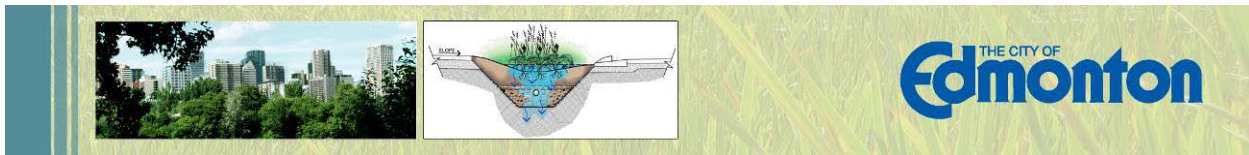
Figure 1.1 The Natural Hydrologic Cycle

1.2.2 Benefits of LID-BMP Based Development

There are three primary stormwater management objectives that typically drive LID-BMP applications. These are:

- stormwater volume control;
- stormwater peak flow control; and
- stormwater water quality enhancement

LID-BMP facilities often address all three of these stormwater management objectives at some level. Facilities may also be



designed to work in series within a development to meet the regulatory requirements driving these objectives.

Applications of LID-BMPs provide many benefits to stormwater management, the environment and communities. Some of these benefits can be assigned monetary value while others are more intangible environmental or social benefits that are difficult to assign a quantitative value. These benefits are further discussed in Section 4.3 LID Benefits, Costs and Limitations.

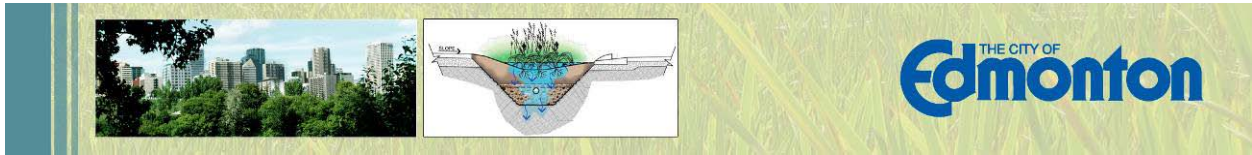
1.3 LID-BMP Design Considerations

The application of LID-BMPs uses existing natural systems, where feasible, and practical engineered systems that use natural materials. These applications are based on the individual requirements and design of the development or site. Application ranges from lot level to site level to regional level, and facilities are often combined to meet the requirements of the site. Unique characteristics (site location, climate, vegetation, regulations) may affect the performance of LID-BMP facilities and must be accounted for in the design. These include:

Greywater – untreated used domestic water that does not include sewage (e.g. laundry, dishwashing, bath waters)

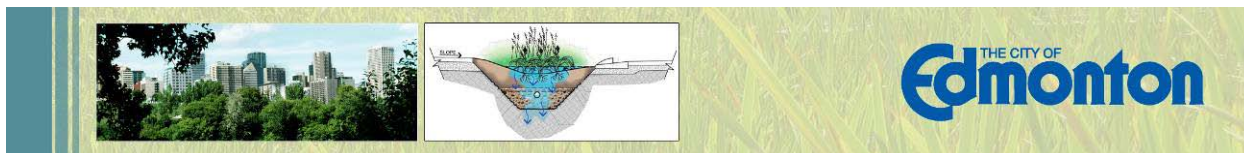
- tight soils;
- frost depth;
- local precipitation and hydrology;
- vegetation suitability to precipitation characteristics;
- winter maintenance materials including sand, gravel and salt;
- maintenance responsibilities and commitments;
- regulatory conflicts or resistance;
- regulation gaps (e.g. greywater re-use code); and
- objectives or drivers for implementation.

Some sites may have unique challenges or constraints to the application of LID-BMPs that must be addressed by a qualified engineer/designer on a case by case basis. There is no universal prescriptive guide for LID-BMPs that applies to all sites. One unique challenge facing designers of LID-BMP facilities in the Edmonton area relates to cold climate considerations. These considerations are discussed in Chapter 6.



1.4 Regulatory Involvement and Approvals

Regulations at all levels of government (federal, provincial and municipal) are likely to have an impact on the implementation of LID-BMPs for stormwater management. The most relevant regulations from the various levels of government are discussed in Chapter 2. LID-BMP designs may require additional input on approvals from City Departments outside of the Infrastructure Services Department. The level of involvement from other departments will depend on the City's plans for an appropriate approval process for LID-BMP implementation. Implementation plans and any related approval requirements specific to LID-BMP were not in place at the time of this publication (November 2011).

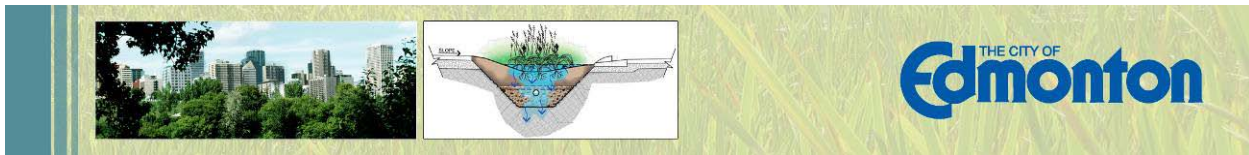


2.0 STORM DRAINAGE REGULATIONS & GUIDELINES

There are regulations and guidelines, at the federal, provincial and municipal levels, that govern stormwater management. This section provides an overview of the regulations and guidelines that impact the development of LID-BMPs in the City of Edmonton. The bylaws, acts, regulations, plans and manuals reviewed in this chapter are listed in **Table 2.1** for each regulatory level on the application of LID-BMPs in the City of Edmonton.

Table 2.1
Regulations and Guidelines Applicable to LID-BMPs
in the City of Edmonton

Regulation	Impact on LID-BMP Practices				
	Location	Design	Const.	Operation	WQ Treatment
Federal					
Navigable Waters Protection Act, R.S.C. 1985	x		x		
Federal Fisheries Act, R.S.C. 1985			x		
Edmonton Garrison Zoning Regulations	x			x	
Provincial					
Alberta Water Act, R.S.A. 2000				x	
Alberta Environmental Protection and Enhancement Act, R.S.A. 2000			x	x	
Restricted Development Area Regulation	x				
Alberta Building Code		x		x	
Alberta Public Lands Act, R.S.A. 2000	x			x	
City of Edmonton EPEA Approval to Operate				x	x
Municipal Policies and Procedures Manual					x
Municipal					
City of Edmonton Design and Construction Standards, Part 3 Drainage	x	x		x	
Sewer Use Bylaw No. 9675				x	
Sewers Bylaw No. 9425	x	x		x	
Surface Drainage Bylaw No. 11501				x	
Edmonton Zoning Bylaw No. 12800		x			
North Saskatchewan River Valley Area Redevelopment Plan Bylaw No. 7188	x				
Winter Road Maintenance Policy C-409E	x	x			



The following sections provide details regarding the impact of each regulation or guideline for the implementation of LID-BMP practices within the City of Edmonton. Discussions with various regulatory bodies regarding the design and construction of LID-BMP facilities may be required to confirm their applicability.

2.1 Federal Regulations

2.1.1 Navigable Waters Protection Act

The Navigable Waters Protection Act (2010, Transport Canada) requires that (Section 5(1)):

Section 5

- (1) No work shall be built or placed in, on, over, under, through or across any navigable water without the Minister's prior approval of the work, its site and the plans for it.

LID-BMP facilities are typically sited to ensure they do not compromise the environment and habitat. It is unlikely that LID-BMP facilities would be located where this Act would be invoked. If an LID-BMP facility does invoke the Act it will not be given special consideration but will be treated in the same manner as conventional stormwater management facilities.

2.1.2 Federal Fisheries Act

The Federal Fisheries Act (2010, Department of Fisheries and Oceans) requires that:

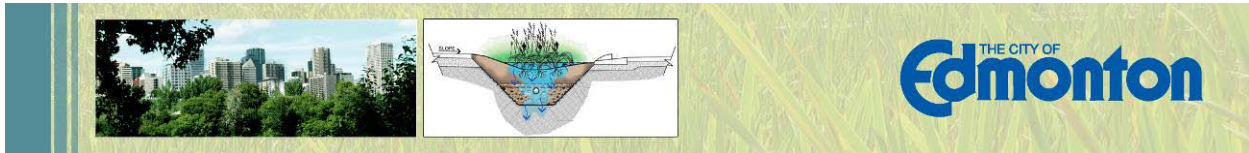
Section 35

- (1) No person shall carry on any work or undertaking that results in the harmful alteration, disruption or destruction of fish habitat.

LID-BMP facilities will be treated similarly to conventional stormwater management facilities and will not be given special consideration under the Act.

2.1.3 Edmonton Garrison Zoning Regulations

Regulations for height restrictions, bird hazard mitigation and noise attenuation that impact areas adjacent to and under the flight paths for the Edmonton Garrison are in the Department of National



Defence (DND) Edmonton Garrison Zoning Regulations.

The regulations dealing with bird hazard migration may have an impact on the ability to implement certain LID-BMP facilities in certain locations as the creation and enhancement of wildlife habitat is one of the desirable benefits of many of these techniques.

2.2 Provincial Regulations

2.2.1 Alberta Water Act

The Alberta Water Act (Alberta Environment, 2009) allows the designated Director of the Act to require an approval for any activities that involve:

Section 1(1)

- (b) placing, constructing, operating, maintaining, removing or disturbing of ground, vegetation or other material

and have the potential to impact the water body, aquatic environment or adjacent areas. In addition, activities involving outfall structures discharging into a water body must be carried out in accordance with the Code of Practice for Outfall Structures on Water Bodies (2007, Alberta Environment)

LID-BMP facilities that discharge water to a watercourse require the same approval and follow the same approval process as conventional stormwater management structures.

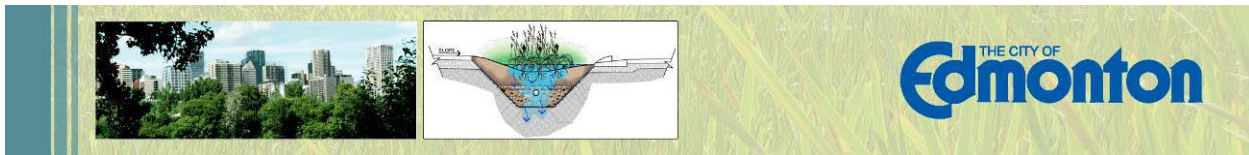
2.2.2 Alberta Environmental Protection and Enhancement Act (EPEA)

Environmental Protection and Enhancement Act (EPEA) Wastewater and Storm Drainage (Regulation 119 / 93), administered by Alberta Environment (AENV), states (Section 6.1(1)):

Section 6.1

- (1) No person shall commence construction of an additional storm drainage treatment facility or a modification of a storm drainage treatment facility except in accordance with a written authorization from the Director.

LID-BMP facilities that discharge to a natural watercourse fall into



the category of “special features” and therefore a Letter of Acknowledgement is required from AENV prior to construction. It is recommended that discussions with AENV are started during the planning or preliminary design stage to ensure that everyone involved has a complete understanding of the purpose of, and restrictions on, the planned LID-BMP facility. It is the responsibility of the developer to obtain the Letter of Acknowledgement.

Re-use of domestic wastewater is acceptable for irrigation or other purposes when approved by AENV or governed by a code of practice.

2.2.3 Restricted Development Area Regulation

The Edmonton-Devon Restricted Development Area Regulation (Alberta Regulation 286 / 1974, Alberta Environment), states:

Section 5

- (2) No person shall, without the written consent of the Minister, commence, continue or recommence any operation or activity that causes, will cause or is likely to cause any surface disturbance of land in the Area or to construct or erect any buildings on any land in the Area.

LID-BMP facilities must be handled in the same way as conventional stormwater management systems with respect to the Restricted Development Area.

2.2.4 Alberta Building Code

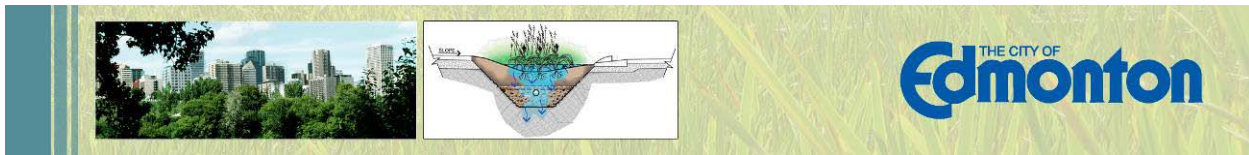
The Alberta Building Code (2006, revised 2009) states:

Section 7.2.1.2 Plumbing Systems and Fixtures

- (8) Non-potable water shall not be connected to plumbing fixtures that provide water for human consumption, cooking, cleaning, showering or bathing.

Water collected through rainwater harvesting systems, and not provided further treatment, is considered non-potable and must comply with the Alberta Building Code.

Green roof systems must comply with the structural loading and moisture protection requirements detailed in the Alberta Building Code.



2.2.5 Alberta Public Lands Act

The Public Lands Act (2010) is administered by Alberta Sustainable Resources Development (SRD). Where a proposed facility (including a stormwater outfall discharging to a major watercourse) may encroach on Crown lands, a License of Occupation would be required under the Public Lands Act.

An LID-BMP facility which discharges directly to a major watercourse requires a License of Occupation through the Public Lands Act.

2.2.6 EPEA Approval to Operate

The City of Edmonton Environmental Protection and Enhancement Act (EPEA) Approval to Operate (No. 639-02-07) is the governing document for the City of Edmonton's drainage system and requires specific water quality objectives be met prior to the release of water into receiving water bodies.

Further, the EPEA Approval to Operate stipulates that "...the approval holder shall develop a comprehensive Storm Water Quality Control Strategy and a plan for implementing the strategy."

Edmonton's Stormwater Quality Control Strategy and Action Plan, developed in 2008, recommends the application of green infrastructure and innovative design. LID-BMPs fall within these recommended approaches.

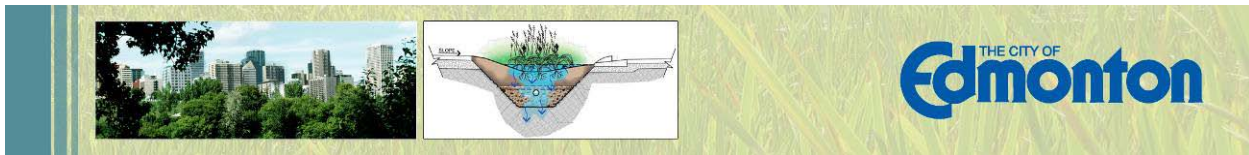
2.2.7 Municipal Policies and Procedures Manual

The Alberta Environment Municipal Policies and Procedures Manual (2001) stipulates:

Minimum Quality Standards – Storm outfalls without due consideration for water quality improvements shall not be allowed. Stormwater management techniques to improve water quality shall be included to effect a minimum of 85% removal of sediments of particle size 75 µm or greater. Additional quality management measures shall be required, based on site-specific conditions.

And,

[Alberta Environment] will work with the municipalities to develop a Master Drainage Plan, and this process shall be integrated into the Drainage System Approval for the municipalities.



Minor System – the roadside drainage, underground pipes and lot drainage systems that collect, store and convey stormwater runoff from more frequent storm events up to and including the minor design event storm (5 year return period)

Major system – overland portion of the overall stormwater drainage system that controls flows greater than those controlled by the minor system and up to and including flows from the major design event storm (100 year return period)

LID-BMP facilities often provide enhanced water quality treatment which can further enable the City of Edmonton to meet the sediment reduction requirements set by AENV.

2.3 Municipal Guidelines, By-laws and Regulations

2.3.1 City of Edmonton Design and Construction Standards, Part 3 Drainage

The drainage system is made up of a minor system and a major system. The minor system should provide flood protection for a 1:5 year design rainfall event and the major system able to convey and store a 1:100 year design rainfall event without flooding.

The Drainage Design and Construction Standards will have differing impacts on implementation of LID-BMP practices. These standards must be considered during the planning stage. Consultation with the City of Edmonton is recommended at this stage to ensure that the impacts of these standards on the ability to implement LID-BMPs are fully understood by both the developer and the approving department.

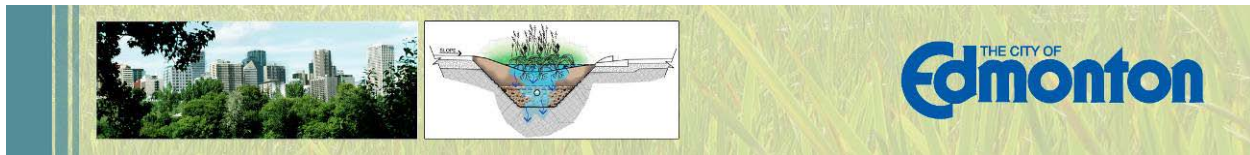
2.3.2 City of Edmonton Sewers Use Bylaw No. 9675

Bylaw 9675 prohibits the direct and indirect discharge of storm water from private property into the North Saskatchewan River, within a section from the upstream City limits to 125 meters downstream of the E.L. Smith Water Treatment Plant water supply intake (section 12). LID-BMP facilities may qualify for exemption under this bylaw, provided certain conditions are met.

2.3.3 City of Edmonton Sewers Bylaw No. 9425

Based on Bylaw 9425 (section 15), LID-BMP facilities are prohibited from crossing private property boundaries. This restriction may prevent the design of surface drainage swales or other conveyance methods. However, this bylaw does not preclude the development of such facilities in common title properties such as condominiums.

Any LID-BMP facilities implemented on private property must be operated and maintained by the owner (section 21).



2.3.4 City of Edmonton Surface Drainage Bylaw No. 11501

The Edmonton Surface Drainage Bylaw provides the City Manager with the authority to specify where and at what rate surface drainage may be discharged to any stormwater management facility, including public sewers, ditches or surface drainage features.

LID-BMP facilities are required to comply with the drainage restrictions of the site as determined by the City Manager.

2.3.5 City of Edmonton Zoning Bylaw No. 12800

Current residential yard requirements may hinder the reduction of imperviousness by requiring minimum setback distances. However, Section 56.4 details hardsurfacing and curbing requirements for parking and loading spaces in residential properties that may allow for driveways to be less impervious:

Section 56.4.2.b

For an on-site driveway in any Residential Zone, the area required to be hardsurfaced may be constructed on the basis of separated tire tracks, with natural soil, grass, or gravel between the tracks, but shall be constructed so that the tires of a parked or oncoming vehicle will normally remain upon the hardsurface.

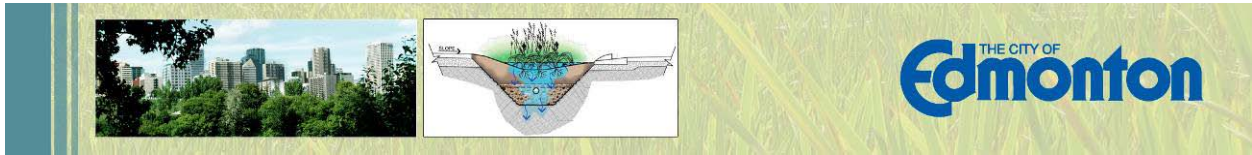
2.3.6 City of Edmonton North Saskatchewan River Valley Area Redevelopment Plan Bylaw No. 7188

A boundary for the North Saskatchewan River valley and ravine system within Edmonton is identified in City of Edmonton Bylaw No. 7188. The bylaw requires assessment and review of development or construction that would impact designated areas within this valley and ravine system against a set of policies and development approval procedures. The goal of the bylaw is the preservation of the natural character and environment of the North Saskatchewan River valley and ravine system.

LID-BMP facilities planned within this area are required to comply with the policies and procedures set out in this bylaw.

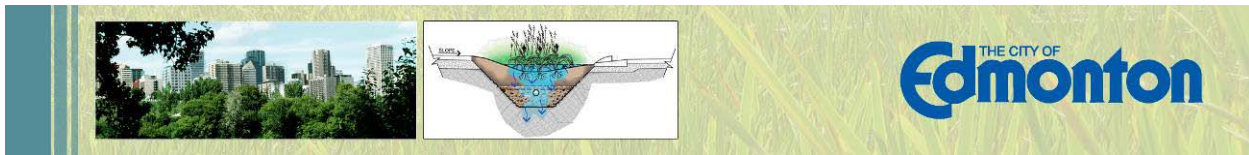
2.3.7 City of Edmonton Winter Road Maintenance Policy – C409F

The City of Edmonton Winter Road Maintenance Program Policy (Policy Number C409F, 2010) does not directly impact the design,



construction or function of LID-BMP facilities. However, it has indirect implications on the long-term function and maintenance of the facility due to de-icing activities.

The Winter Road Maintenance Program Policy must be considered during planning stages to ensure that LID-BMP facilities selected for the site and location do not conflict with Policy C409F.



3.0 LOCAL CHARACTERISTICS

Since LID BMPs are site specific, a full understanding of the characteristics of the local environment, such as climate, hydrology, soil and vegetation conditions, is instrumental in LID BMP planning design, construction and maintenance.

3.1 Physical and Climatic Conditions

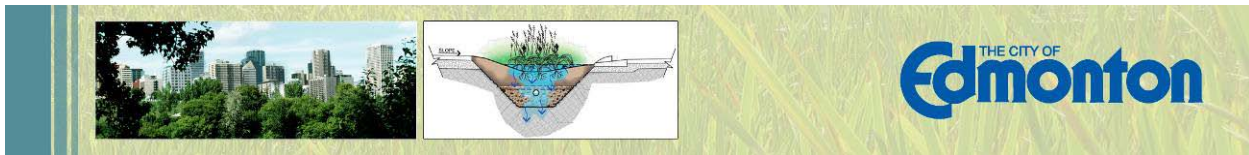
Edmonton is located in the Alberta Capital Region, at a latitude and longitude of 53°340"N, 113°31'0"W, respectively. The population of the City is 782,439 (2009). The average elevation of the city is 686 metres above sea level. The total land area is 71,000 hectares (ha), with about 34,000 ha of urban footprint.

Edmonton is in a semi-arid, continental climate region. The average maximum temperature is 24°C (July) and average minimum temperature is -19°C (January). There are about 100 to 120 frost free days in Edmonton, or a growing season of 138 days.

Table 3.1 shows climate data for the Edmonton region.

Ecologically, the City of Edmonton lies within the Central Parkland Natural Sub-region of Alberta (**Figure 3.1**), with prairie to the south and boreal forest to the north. Based on the sub-region's soil fertility, the area is dominated by cultivated land with only 5% native vegetation, primarily aspen and prairie mosaics, and 10% wetland (Natural Regions Committee, 2006). The soil survey of the Edmonton region (Alberta Soil Survey, 1962) is the main source of information regarding native soil types within the City of Edmonton (**Figure 3.2**). However, Edmonton city limits have grown nearly five times in areal extent from 1959 to 2010, indicating that the majority of native soils in the area have been disturbed.

Bedrock underlying the City of Edmonton includes part of the Upper Cretaceous Wapiti Formation (Andriashek, 1988). This formation is composed of bentonitic sandstones, sandy shales, bentonitic clays, and coal seams. Within most of the area of the City of Edmonton, this is directly overlain by clay and silty clay deposits of Glacial Lake Edmonton. Quaternary sands, stratified deposits of the Empress Formation and glacial till occur between the Wapiti Formation and the glacial clays in some places. Till of variable thickness makes up the surficial deposit in parts of east



Edmonton. The till predominately has a clay loam texture and is slow to very slowly permeable with 1-3% diffused calcium and magnesium carbonate content (Alberta Soil Survey, 1962; Andriashek, 1988). Soils within the Edmonton area predominately belong to the Malmo soil series, with two phases:

- silt loam (Mo.SiL); and
- silty clay loam (Mo.SiCL).

Table 3.2 details some of the characteristics of soils native to the Edmonton region.

Table 3.1
Edmonton Climate Statistics

Climate Parameter	Value
Average Annual Mean Temperature ¹	3.9°C
Average Daily Temperature, January ¹	-11.7°C
Average Daily Temperature, July	18 °C
Frost Free Days ²	100-120
Typical Frost Depth ³	2.3 m
Mean Monthly Snowfall ¹	1.2 m
Average Annual Precipitation ¹	477 mm

¹ Canadian Climate Normals 1971-2000, Edmonton City Centre A (Environment Canada, 2010)

² Frost-Free Period (Energy, Mines and Resources Canada, 1981)

³ Maisonneuve, 2011.

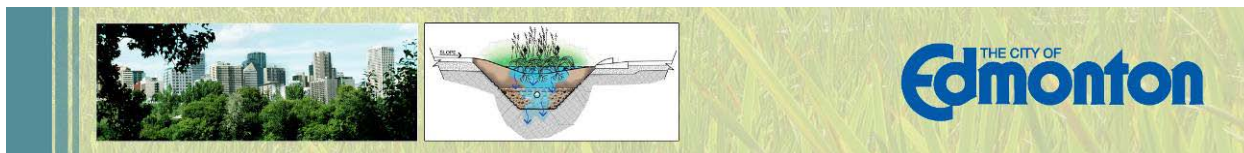


Table 3.2
Soil Characteristics for the Edmonton Region

Soil Characteristics	
Map Symbol	Mo.SiL; Mo.SiCL
Water Storage	> 12 cm of water per 30 cm of soil (High)
Topsoil (A horizon)	10 mm to 100 mm/hr saturated hydraulic conductivity (Medium)
Subsoil (B horizon)	3 mm to 10 mm/hr saturated hydraulic conductivity (Low to Medium)
Underlying soil (C horizon)	≤3 mm/hr saturated hydraulic conductivity (Low)
Topsoil thickness (cm)	Organic enriched topsoil horizon; Commonly 15-25 cm, can be up to 50 cm or more in places; Slightly acidic
Natural Drainage	Water is removed from the soil readily (Well)
Organic Matter in Topsoil	> 7% organic matter (High)
Salinity of Subsoil	< 2% soluble salt (Low) > 8% soluble salt (Medium)
Stoniness	Relatively no stones
Topography	Relatively level; very little non-arable land

(Alberta Soil Information Centre, 2001).

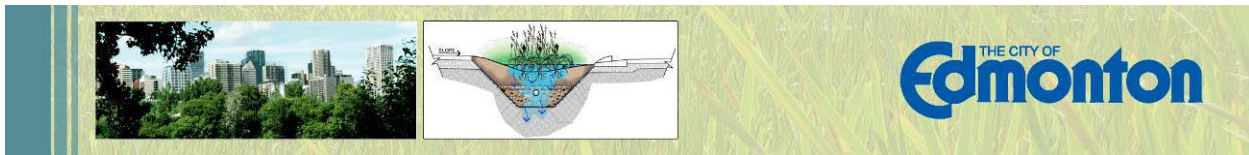
Precipitation – any form of water that falls from the clouds including rain, snow, hail, sleet or mist.

3.2 Hydrology

3.2.1 Precipitation

Average annual precipitation measured for Edmonton is 477 mm (1971 – 2000) of which 364 mm are rainfall and 113 mm are melt from snowfall (123.5 cm). On average, there are 122 days annually in which greater than 0.1 mm of precipitation (rain, sleet, snow or hail) occurs. The driest month is March, when on average 16.6 mm of precipitation occurs. The wettest month is July, with an average rainfall of 91.7 mm. **Table 3.3** shows monthly average precipitation as measured at Environment Canada's Edmonton City Centre Airport station.

A rainfall analysis based on Environment Canada's 1960-2008 data shows that most rainfall events (~90%) in Edmonton are less than



25 mm in depth and have durations of 5 hours or less. **Figure 3.3** presents a summary of the distribution of rainfall events corresponding to three Environment Canada rain stations in Edmonton (Namaso, City Center Airport, and International Airport).

3.2.2 Evaporation

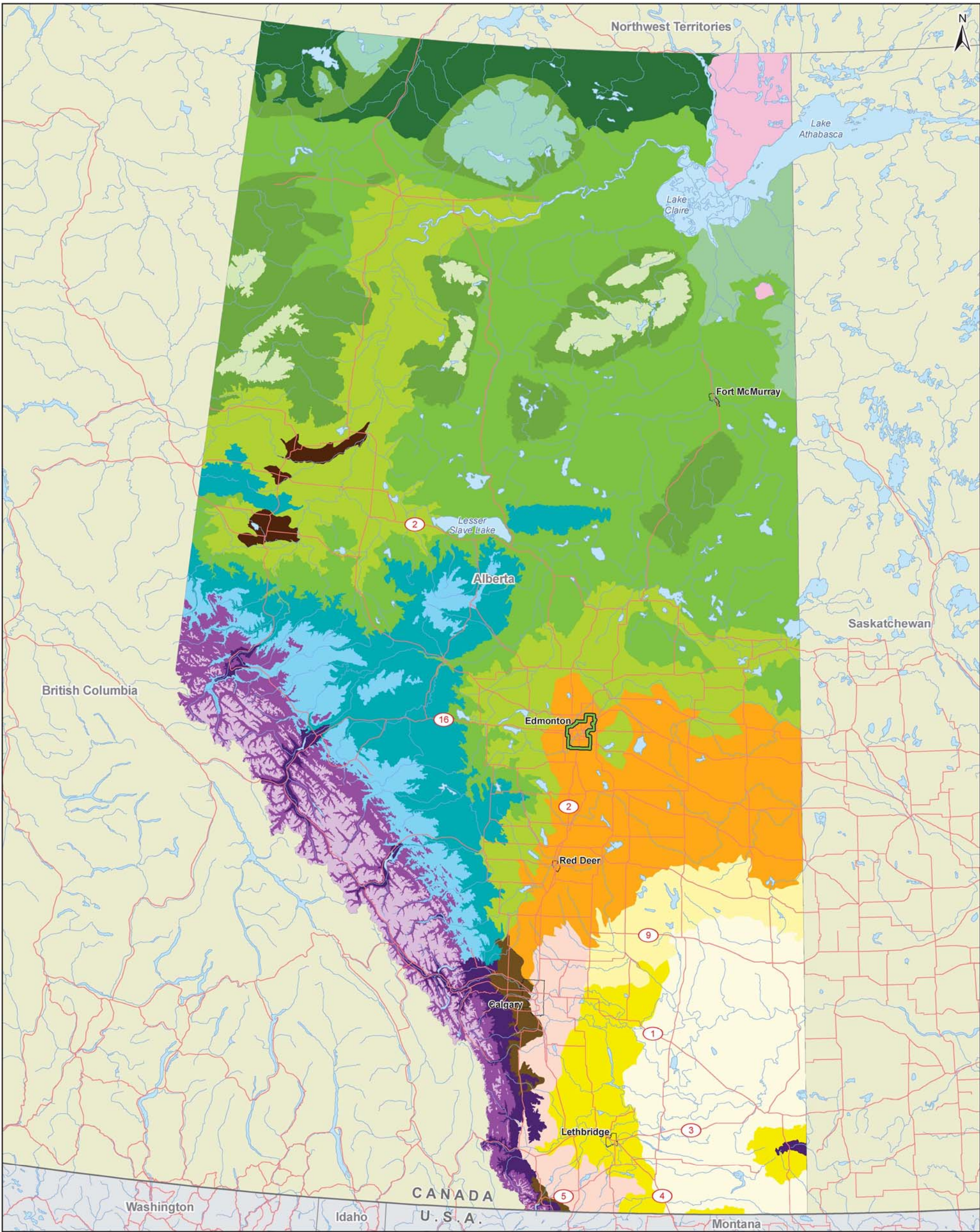
Evaporation – process by which liquid water converts to water vapour by energy from heat or air movement

The average annual lake evaporation (the water that evaporates from water bodies) is 665 mm in Edmonton (Alberta Environment, 2010). Annual evaporation is greater than annual precipitation. With lower precipitation in winter, the soil moisture is not always restored to capacity in an average year.

Table 3.3
Monthly Average High and Low Temperature and Precipitation (1971-2000) at Edmonton City Centre

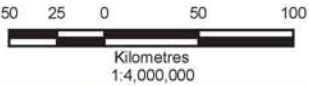
Month	High Temperature Mean Value	Low Temperature Mean Value	Rainfall (mm)	Snowfall (cm)	Precipitation (mm)
January	-8.2	-17	1.3	24.5	22.5
February	-4.2	-13.7	0.9	15.8	14.6
March	1.1	-8.4	2.1	16.8	16.6
April	10.5	-0.7	13.1	13.4	26.0
May	17.5	5.7	45.1	3.5	49.0
June	21.3	9.9	87.1	0.0	87.1
July	23	12	91.7	0.0	91.7
August	22.1	11	68.9	0.0	69.0
September	16.6	5.6	42.3	1.5	43.7
October	11.3	0.6	10.5	7.8	17.9
November	-0.1	-8.4	1.9	17.9	17.9
December	-6.3	-14.8	0.8	22.3	20.9
Total			365.7	123.5	476.9

(EC, 2010)



- Legend**
- Study Area - City of Edmonton (Current Boundary)
- Natural Regions and Sub-regions of Alberta**
- | | |
|--------------------------------------|---------------------------------------|
| Boreal Forest Natural Region | Foothills Natural Region |
| Central Mixedwood | Upper Foothills |
| Dry Mixedwood | Lower Foothills |
| Northern Mixedwood | |
| Boreal Subarctic | Canadian Shield Natural Region |
| Peace-Athabasca Delta | Kazan Uplands |
| Lower Boreal Highlands | Parkland Natural Region |
| Upper Boreal Highlands | Foothills Parkland |
| Athabasca Plain | Peace River Parkland |
| Rocky Mountain Natural Region | Central Parkland |
| Alpine | Grassland Natural Region |
| Subalpine | Dry Mixedgrass |
| Montane | Foothills Fescue |
| | Northern Fescue |
| | Mixedgrass |

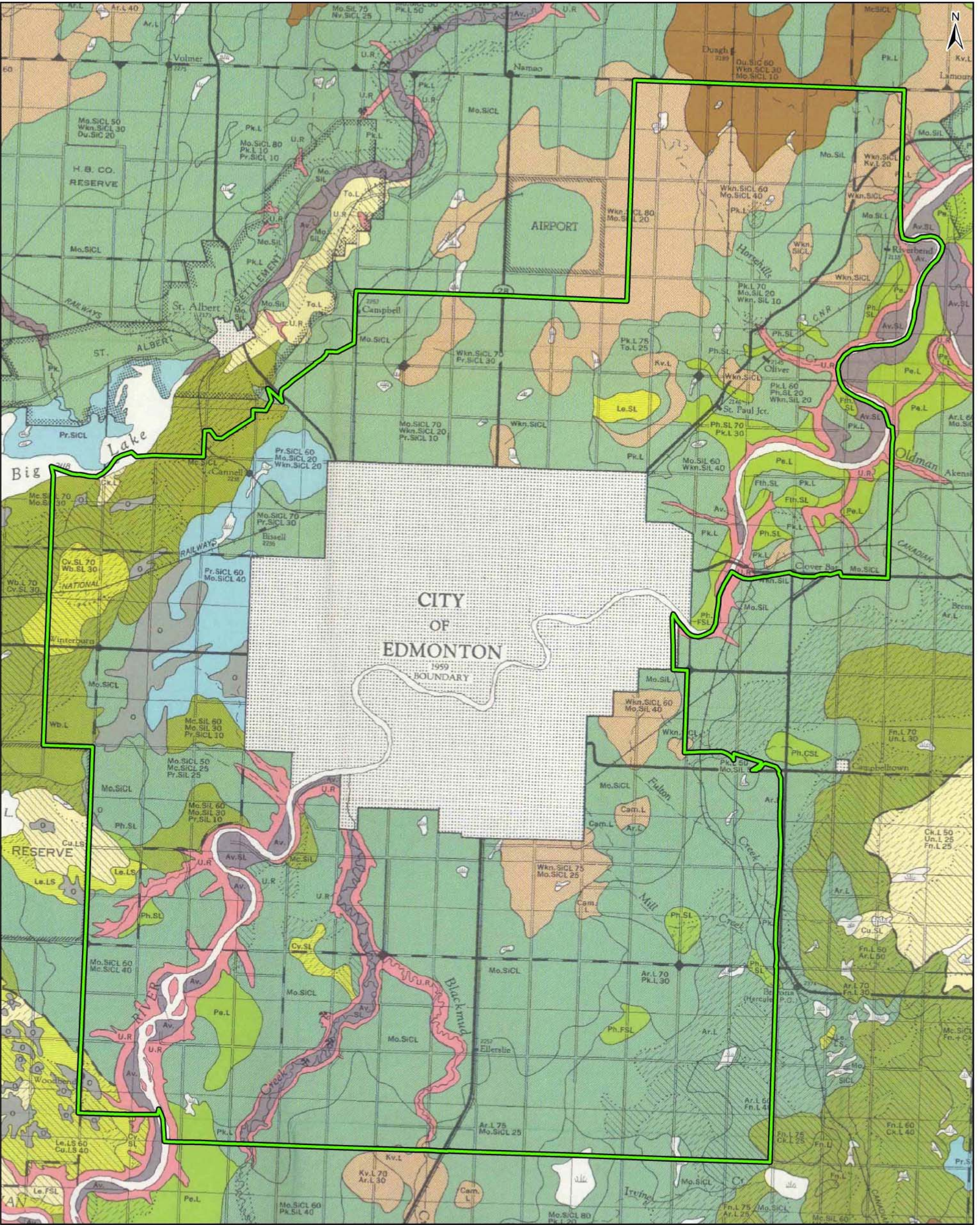
Sources: AB TPR, DMTI Spatial Inc., ESRI, Spatial Data Warehouse Ltd.



Edmonton LID/BMP Design Criteria

Natural Regions and Sub-regions of Alberta

DATE: January 2011	Figure 3.1
PROJECT: EW1022	Fig 3.1 Natural Regions 11-01-21
ANALYST: CP	QA/QC: TR KR KR
PROJECTION/DATUM: UTM Zone 12 NAD83	



Legend


Study Area - City of Edmonton (Current Boundary)

Soil Survey		Solonchetsic Soils		Podzolic Soils		Regosolic Soils		Gleysolic Soils		Organic Soils		Soil Complexes	
Chernozemic Soils													
Ds. L	Ar. L	Wf. L	Ck. L	Bi. C	Cn. L	O.	U. R						
Bh. L	Mo. SiL	Du. SiL	Bn. L	Av.	Pr. SiL								
Pe. L	Mo. SiCL	Du. SiCL	Mw. CL	D. S	Pr. SiCL								
Nv. SiL	Pk. LL	Du. SiC	Mw. SiCL	B. S	Nv. M								
Nv. SiCL	Pk. L		To. L		P. G								
Ph. FSL	Pk. SiL	Cam. L	To. SL		Dy. L								
Ph. SL		Wkn. SiL	Gd. L										
Ph. CSL	Fn. L	Wkn. SiCL	Md. L										
Ph. LFS	Wb. L	Wkn. SiC	Cu. SL										
Ph. LS	Wb. LL	Am. L	Cu. LS										
Ph. CLS	Wb. FSL	Kv. L											
Fth. L	Wb. SL	Ki. L	Un. L										
Fth. SL	Rb. L	Kn. SiCL	Ml. CL										
Fth. CSL	Mc. SiL	Gd. SiL	Cv. L										
El. L	Mc. SiCL		Cv. SL										
I. CSL			Le. SL										
			Le. FSL										
			Le. LS										
			Hi. SL										



Edmonton LID/BMP Design Criteria

Current City of Edmonton Boundary and Historical Soil Survey Map

DATE: January 2011		Figure 3.2	
PROJECT: EW1022		Fig 3.2 Soil Survey 11-01-21	
ANALYST: CP	QA/QC: TR KG KR		
PROJECTION/DATUM: UTM Zone 12 NAD83			

Note: Adapted from soil survey map drawn and published by the Soil Research Institute, Research Branch, Canada Department of Agriculture, Ottawa, 1962
Sources: DMTI Spatial Inc., Agriculture and Agri-Food Canada.

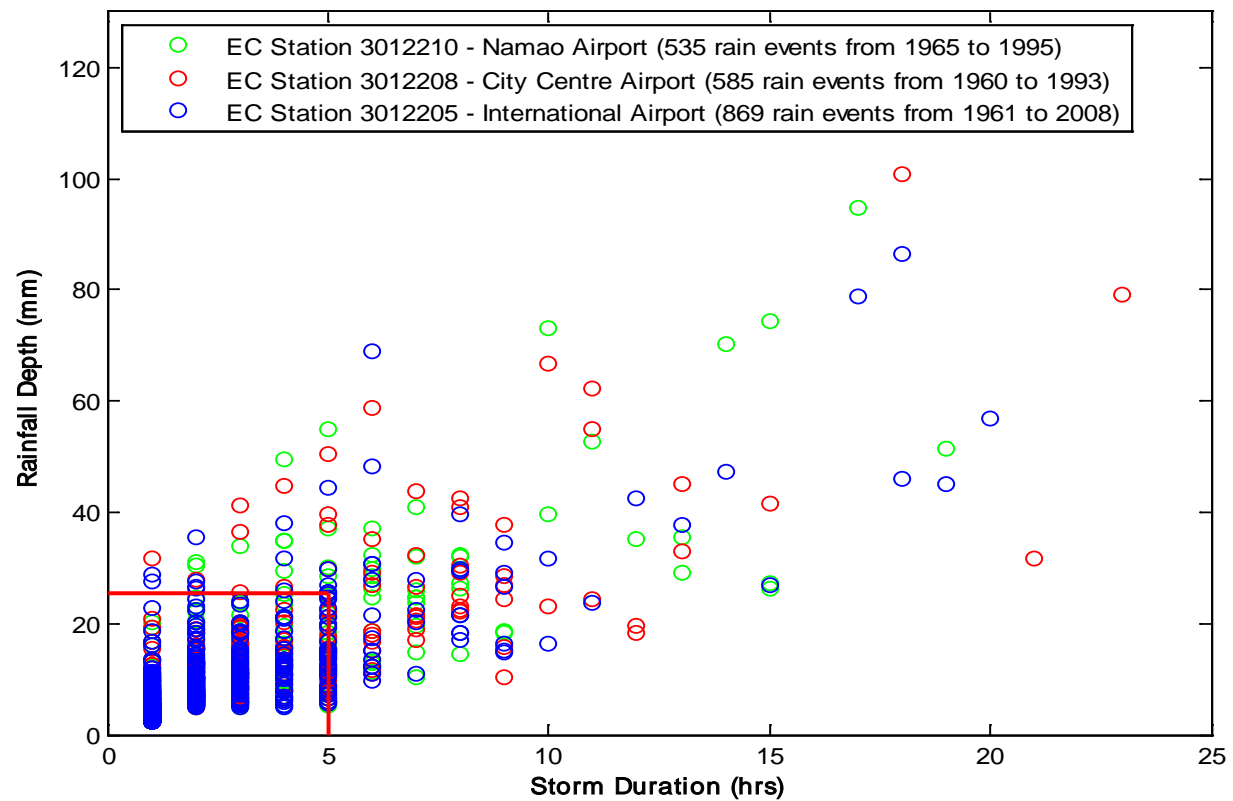
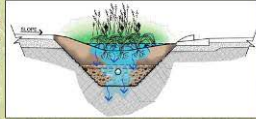
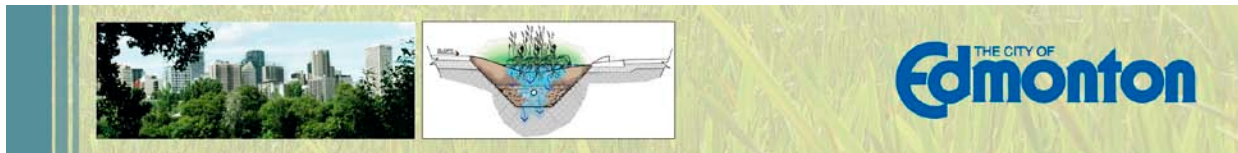


Figure 3.3 Rain Point Diagram for Edmonton Area Rainfall



4.0 LID SITE PLANNING AND DESIGN

LID site design seeks to:

- minimize land and vegetation disturbance;
- capitalize on the natural hydrology of the site when locating roads, buildings and drainage features;
- utilize, or accommodate, the natural topsoil, subsoil and vegetation within individual LID facilities;
- reduce the impacts of development by minimizing soil compaction and impervious area;
- reduce or prevent stormwater runoff during small storm events;
- provide treatment for stormwater runoff as close to the source as possible; and
- incorporate multi-purpose landscapes that treat water as a resource rather than a nuisance.

Brownfield – *abandoned or underused commercial or industrial land available for re-development*

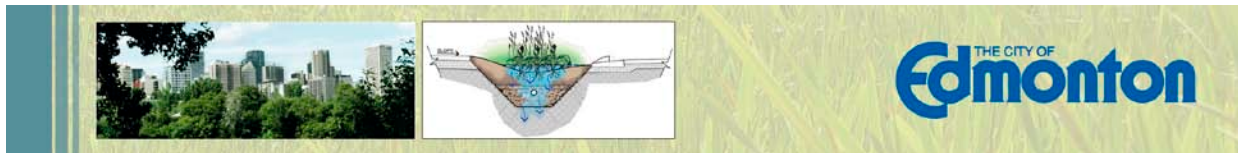
The focus of Chapter 4 is primarily on site level greenfield and brownfield development. However, LID retrofit opportunities at the lot level are abundant and may provide solutions for stormwater management, flooding and erosion issues being experienced in established communities.

4.1 Conventional vs. LID Neighbourhood Design

The benefits of LID are illustrated through comparison of conceptual plans for conventional and LID neighbourhood developments (**Figures 4.1 and 4.2**). A more detailed description and assessment of the two development designs is contained in Appendix E - Comparative Modelling Study.

The site design follows the development objectives outlined in the City of Edmonton's Municipal Development Plan, "The Way We Grow". Both site plans have been developed to mimic a realistic greenfield suburban development in the Edmonton context including the following features:

- lot building pocket, housing stock, population density and mixing of use are consistent with others offered in the Edmonton housing context;
- mixed dwelling types provides for a variety of housing options;



Holistic – consideration of the importance of the whole system and the interdependence of its parts, including: ecology; biology; hydrology; sustainability; economics; growth; etc.

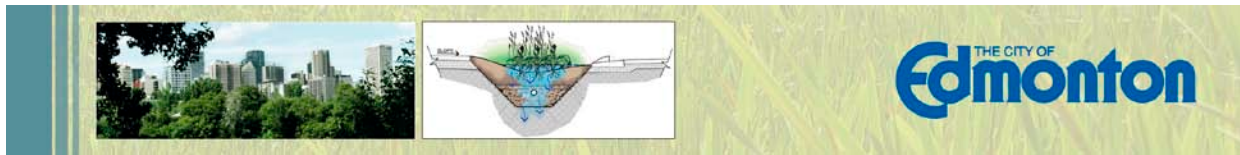
- residential densities taper down to protect interfaces between properties, minimize shadows cast, preserve privacy and maintain view corridors of community significance;
- commercial areas are laid out as focal points for neighbourhoods where a major commercial anchor is surrounded by residential development; and
- collector roads direct traffic from peripheral arterial roads into the neighbourhood, providing immediate access to a school site, commercial areas and surrounding residential local roads and lanes.

The standard site development process was followed for both neighbourhood plans. However, the LID Neighbourhood Plan incorporated additional sustainable development considerations including:

- holistically based site assessments prior to site delineation;
- identification of natural vegetation and soil preservation zones;
- development delineation based on soil and hydrologic features;
- minimal impervious areas wherever possible;
- preservation of natural hydrologic processes to the extent possible; and
- up front planning to minimize the impacts of construction activities.

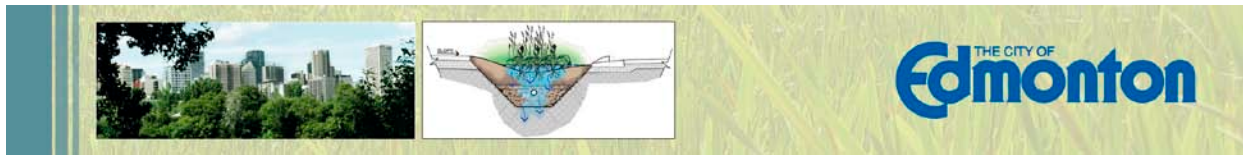
Figure 4.2 is an example of a site layout designed to minimize impervious area by minimizing street lengths. Site layouts should be designed to minimize impervious area as much as possible while still meeting design objectives of the development, such as walkability or densification. When a cul-de-sac based layout is used (**Figure 4.2**), pedestrian pathways should be provided to connect streets with other pathways, transit or open spaces (PSAT, 2005). The LID Neighbourhood Plan illustrated in **Figure 4.2**, maintains the same housing and commercial density as the Conventional Neighbourhood Plan (**Figure 4.1**) while providing the following additional unique characteristics:

- minimized site grading and preservation of existing drainage paths by locating roadways to avoid significant changes to the site topography;
- reduced runoff from impervious areas by minimizing road lengths and widths as much as possible while staying within



Edmonton's development guidelines;

- road layout designed to reduce traffic through residential zones and maintain easy access to institutional and commercial areas;
- connected green spaces throughout the site, allowing for stormwater capture and conveyance, wildlife movement and easy pedestrian access to commercial and institutional areas;
- reduced imperviousness in institutional and commercial zones through use of green roofs, permeable pavements and parking lot bioretention areas;
- rainwater captured for re-use;
- reduced building setbacks to shorten driveways and reduce impervious area;
- stormwater runoff directed toward natural depressions and wetlands; and
- stormwater runoff conveyed through bioswales along a central boulevard.



4.2 Model Construction

This section describes major components of the models for the Conventional and LID-BMP development scenarios.

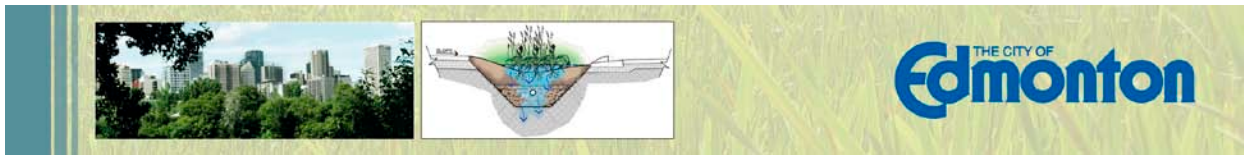
Figure 4.3 and **Figure 4.4** provide model conceptual site layouts illustrating catchment areas and key stormwater management facilities represented in the Conventional and LID-BMP models, respectively. These correspond to screen shots of the models as viewed in the SWMM5 interface. A description of key elements of the model construction is provided below.



Figure 4.1 Conventional Neighbourhood Concept Plan



Figure 4.2 LID-BMP Neighbourhood Concept Plan



4.3 LID Site Design Process / Sequence

The LID site design process builds on the conventional site design process with key modifications to capitalize on natural characteristics of the site. The LID site design process seeks to minimize detrimental hydrological impacts of development (**Figure 4.3**) by reducing impervious surfaces and using soil, vegetation and topography to maintain the hydrologic cycle.

The LID site planner has an extensive tool kit at their disposal to mitigate negative impacts on receiving waters by managing volume, discharge frequency, peak flow rates and water quality. Beginning at the assessment stage, involvement of a multi-disciplinary LID design team, including qualified and experienced professionals in landscape architecture, vegetation ecology, geotechnical engineering, soils science, and water resources engineering, is recommended to ensure long term success of LID site designs.

The comparison of LID Neighbourhood planning with Conventional Neighbourhood planning is referenced throughout this section for illustration purposes.

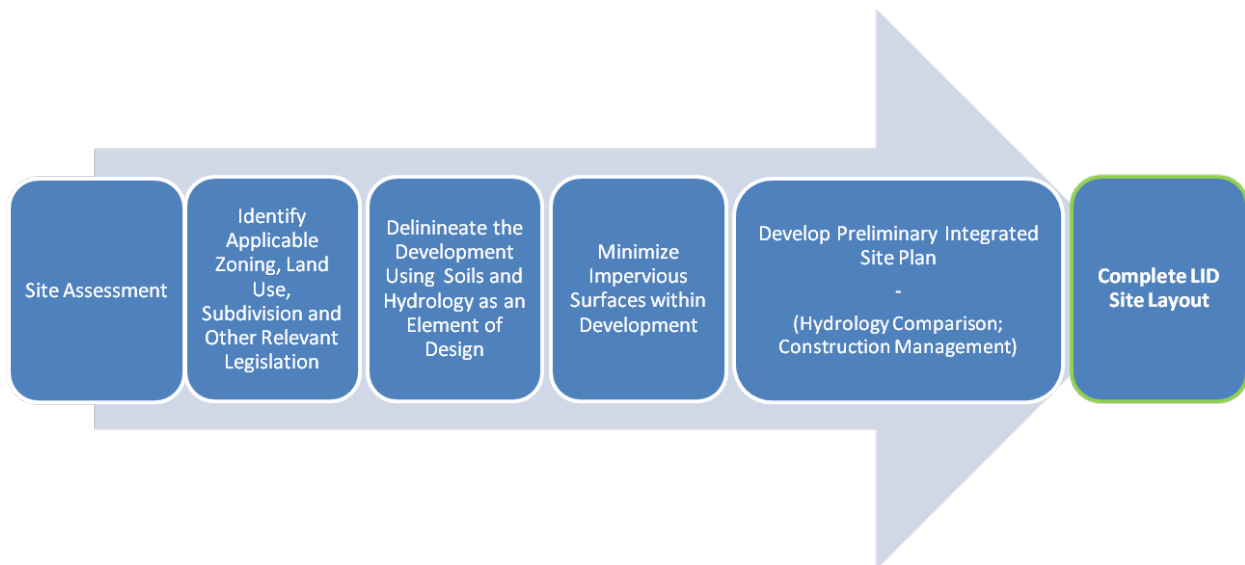
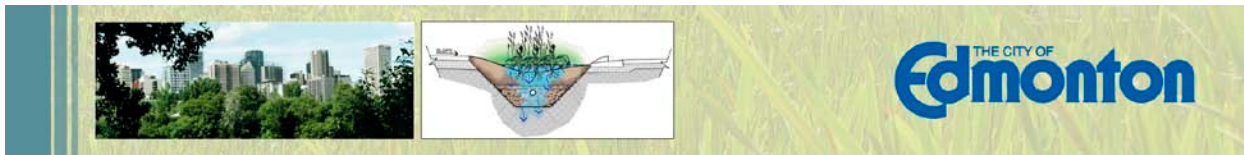


Figure 4.3 Steps to Designing a LID Site



4.3.1 Site Assessment

A holistic approach is required for characterising key aspects of the pre-development condition, including soils, geotechnical vegetation and hydrologic conditions. A thorough understanding of these aspects enables development of designs that work to preserve the natural hydrologic response of the developed watershed.

Site assessments provide the information needed to fully understand unique aspects of a potential development area. **Table 4.1** provides an overview of recommended parameters to be captured in each of the assessments and at what stage of planning these assessments are recommended.

4.3.1.1 Soils and Geotechnical Assessment

Soils and geotechnical assessments are required, as outlined in **Table 4.1**, to determine pre-development soil and sub-surface conditions (PSAT, 2005). The following planning decisions are directly based on results of the soils and geotechnical assessment:

- soil preservation zones in areas of more permeability;
- suitable LID facility locations;
- recommended soil amendments; and
- required soil protection measures during construction.

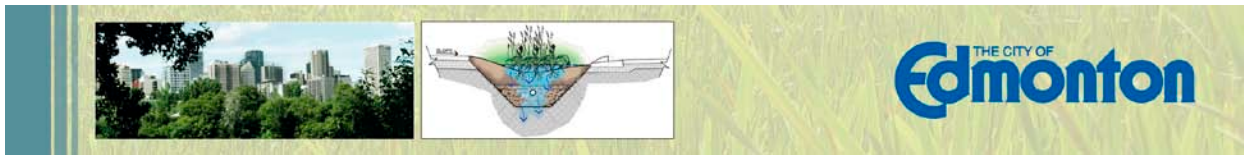
Facility failures such as flooding, ponding and clogging can occur if infiltration based LID facilities are located in tight soil zones caused by soil compaction or the presence of bedrock or clay sub-soils. High native soil permeability increases the potential for groundwater contamination in the presence of elevated pollutant concentrations. Slope stability may be compromised when infiltration based LID facilities are located in an unsuitable area.

4.3.1.2 Vegetation Assessment

A vegetation assessment is necessary to identify any areas requiring protection during the construction process (PSAT, 2005). These protected areas may be selected to:

- maintain a contiguous riparian or wildlife corridor;
- preserve rare plants;

***Riparian** – related to or located on the banks of a natural water course.*



- maintain mature tree stands; or
- maintain slope stability during construction.

The vegetation assessment may also provide a natural plant palate for the landscape designer.

4.3.1.3 Hydrologic Assessment

Hydrology is a function of the vegetation, soils and topography of the site, as well as precipitation patterns. An assessment of precipitation and meteorological conditions of the site must be combined with a detailed survey to determine the hydrologic patterns of the site (**Table 4.1**). Peak discharge rates from storm events depend on the hydrologic response of the site during precipitation events, and these rates are used to determine the impact of the site on the receiving stream or downstream stormwater management facilities. This assessment must be carried out by a qualified stormwater engineer.

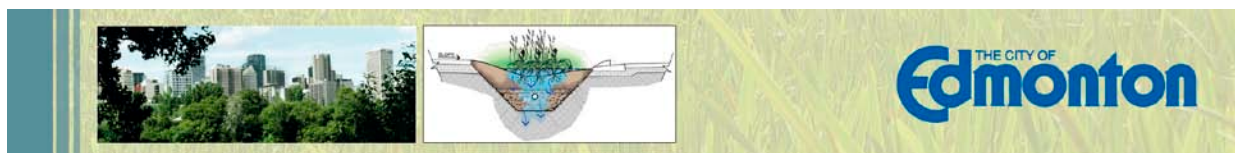
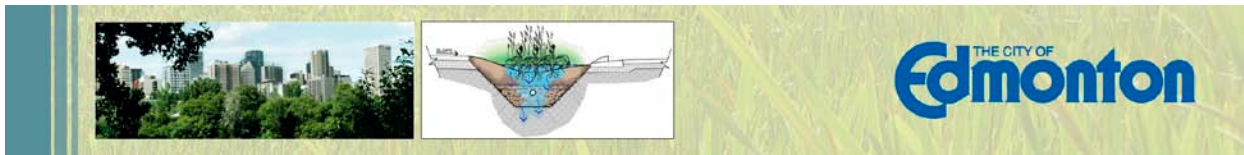


Table 4.1
Site Assessment Requirements

Assessment	Parameter	Location	Timing
Soils			
Field Investigation	Structure Texture Colour Predevelopment saturation condition Particle distribution Bulk density Nutrient content Cation exchange capacity (CEC) pH	Across Site	Prior to Development Delineation
Geotechnical			
Assessment of existing information			Ongoing
Field Testing	Soil types Soil layer depths Depth to bedrock Groundwater elevation Groundwater quality Hydraulic conductivity	Across Site	Prior to Development Delineation
Infiltration Testing ¹	Saturated hydraulic conductivity at elevation of facility base	Below designed base at facility locations	Following PISP²
Vegetation			
Field Investigation	Rare plants survey Protection area delineation	Across Site	Prior to Development Delineation
Hydrologic			
Site Survey	(Existing or surveyed topography) Surface flow paths	Across Site	Prior to Development Delineation
Meteorologic Investigation	Precipitation Temperature Humidity Wind		

¹ Infiltration tests must be conducted using published procedures

² Preliminary Integrated Site Plan (*Section 3.2.5*)
(USEPA, 1999b; SEMCOG, 2008; PSAT, 2005)



4.3.2 Identification of Applicable Zoning, Land Use, Subdivision and Other Relevant Legislation

Some common land use regulations impacting LID implementation are listed in Chapter 2.0. Discussions with the City of Edmonton Sustainable Development department should be initiated at this point in the process for clarity on constraints due to zoning, land use and other legislation. Potential constraints that may impact the implementation of LID facilities include:

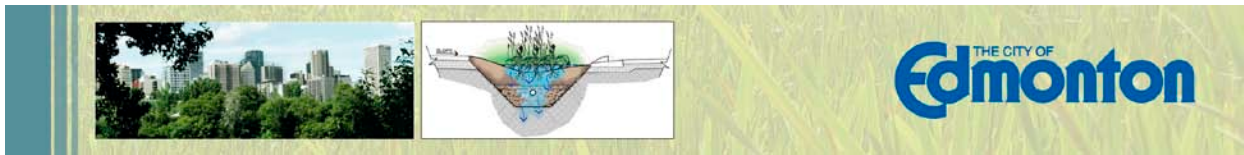
- restrictions on the size and application of LID facilities within right-of-ways due to width limitations; and
- limitations on road width reductions due to requirements to provide access for the largest servicing vehicles, regardless of whether these vehicles would need to access the area (i.e. access for large ladder trucks where only two storey homes are present).

In most cases, developable land is subject to a hierarchy of overarching policies to which appropriate land uses must conform through the subdivision of land. The corresponding Area Structure Plan (ASP) or Area Redevelopment Plan (ARP) is the linkage between zoning and high level statutory documents. The ASP / ARP provides a conceptual layout of major city sectors by locating roads and other servicing corridors, open spaces and general land uses. The Edmonton Zoning Bylaw controls the use and development of all land in the City of Edmonton and provides an essential link between policies and subdivision and development control.

4.3.3 Delineation of the Development

Development delineation and subdivision design is the result of a series of comprehensive considerations based on hydrology, topography, soils variability, land and legal encumbrances, surrounding land uses, environmental contamination and impacts and servicing constraints. Involvement of a multi-disciplinary design team is critical at this stage to account for unique site challenges and constraints impacting the implementation of LID designs.

The first step in both conventional and LID development planning is to identify 'primary' and 'secondary' conservation areas. Primary



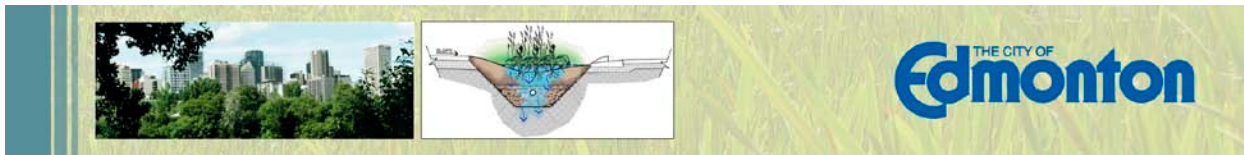
Passive Recreation – emphasizes the open space aspect of a park and involves a low level of development, including picnic areas and trails.

conservation areas typically consist of non-developable lands adjacent to water bodies and water courses, wetlands and steep slopes as identified by analysis of the site's topography and / or environmental and geotechnical studies. Depending on the context of the site, secondary conservation areas may include less significant natural areas such as existing tree stands, historically and culturally significant sites, sites with exceptional views of surrounding land and high quality agricultural lands. Development is designed to avoid primary conservation areas and preserve secondary conservation areas wherever feasible.

Remaining land is referred to as the potential development area. Careful preservation of primary conservation areas and minimized development on secondary conservation areas often yields higher lot value. In accordance with the Municipal Government Act, 10% of developable land, which includes secondary conservation areas, must be dedicated to municipal reserve (MR). No development may take place on land deemed environmental reserve (ER). However, passive recreation uses are permitted.

During the LID planning process, the following additional considerations will help to delineate the development area to protect hydrologic and ecological features, and allow for incorporation of LID facilities:

- identify protected areas (riparian habitat, stream buffers and wetlands, among others), easements, setbacks, existing drainage, topographic features, and natural drainage features;
- locate development in areas with lower infiltration potential such as barren clayey soils and preserve higher infiltration soils for LID facilities, where practical;
- delineate development envelope so that it respects natural features and conforms to existing site topography and hydrology;
- utilize slopes to naturally direct flows to bioswales;
- keep building footprints small to minimize grading and clearing of land;
- avoid soil compaction and preserve natural vegetation where possible;
- situate roadways in parallel with existing topographic ridges to avoid unnecessary soil disturbance;
- where feasible, apply zoning consistent with LID design



objectives. For example, replacing RF1 Zoning (6 metre minimum front yard setbacks) with a combination of Residential Small Lot Zones (RSL) and Planned Lot Residential Zones (RPL) (5.5 metre and 4.5 metre front yard setbacks, respectively) will reduce site imperviousness by permitting shorter driveways and more lot green space; and

- continue or initiate dialogue with appropriate City departments to ensure that expectations of both parties are understood and incorporated.

4.3.4 Reduction of Impervious Surfaces within the Development

Edmonton's Subdivision Control and Servicing Agreements dictate the level of flexibility a site planner has when designing a neighbourhood layout. Widths of roads, sidewalks, alleyways and driveways are often fixed to accommodate municipal servicing and emergency services response. The increase in the total impervious area causes an increase in total runoff volumes and peak runoff rates. The layout of the road network has a bearing on the total impervious area. **Figure 4.4** provides a schematic comparing the length of paved surface for various layouts. Many of the more recent conventional neighbourhood plans in Edmonton are characterized by a warped parallel layout.

LID sites use a variety of methods to minimize impervious areas. These strategies include the use of:

- narrower road widths that reduce site imperviousness while decreasing requirements for clearing and grading;
- flat curbs and roadside bioswales in place of traditional curb and gutter, resulting in a substantial reduction in construction costs;
- single sidewalks limited to one side of primary roads (where it will not negatively affect the social objectives of the neighbourhood);
- one sided on-street parking;
- 'green' laneways using pervious materials and surfaces;
- minimized building footprints may be achieved by building taller, narrower dwellings rather than sprawling ranch style homes;
- green roofs on multi-family and commercial sites to reduce urban heat island effects;
- limited width (2.75 metres) shared driveways and two track

- driveways to reduce impervious area;
- zoning changes to RSL and RPL zones to reduce the overall length of driveways, due to reduced lot setbacks; and
- alternate street layouts designed to maximize the number of lots with the minimum amount of pavement as shown in **Figure 4.4**.

After minimizing impervious areas, portions of the remaining impervious area may be routed to vegetated areas throughout the neighbourhood to derive further hydrologic benefits. This can be accomplished in an LID context by:

- disconnecting roof drains from weeping tile or storm sewers and routing flows to vegetated areas;
- preventing compaction of pervious areas during construction;
- fostering sheet flow through vegetated areas. Concentrated runoff can be converted to sheet flow by incorporating level spreader stormwater outlets; and
- locating impervious areas to drain to LID facilities.

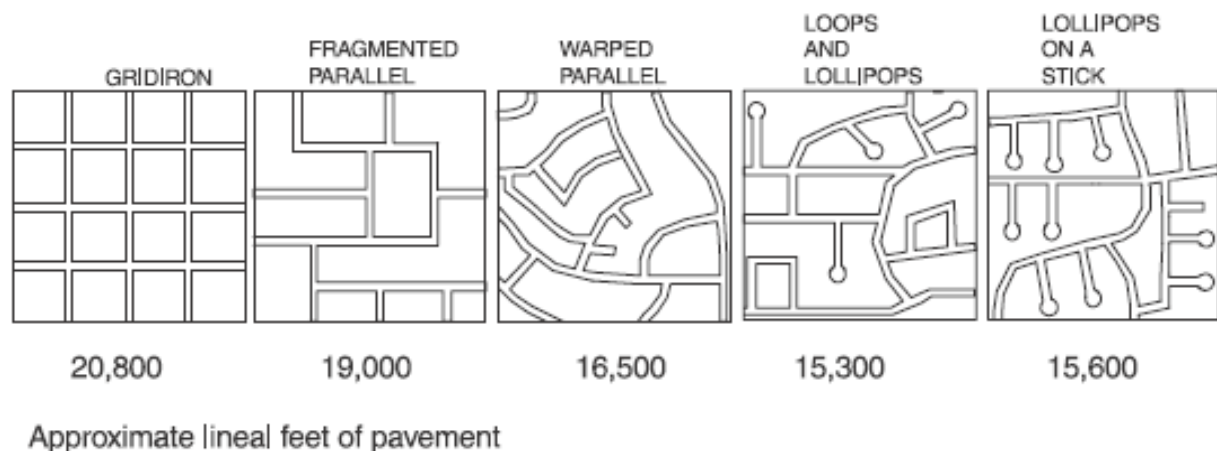
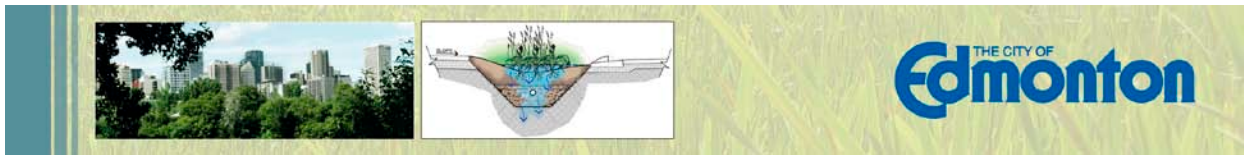


Figure 4.4 Street Layout Options According to Pavement Length

4.3.5 Development of Preliminary Integrated Site Plan

The preliminary integrated site plan gives context to the development and provides an opportunity to fine tune selected LID strategies. It provides a basis for comparison of



Hydrologically Sustainable Site – A development that minimizes its impact to the natural hydrological process.

pre- and post-development hydrology to ensure that the objective of creating a hydrologically sustainable site has been satisfied. The preliminary integrated site plan also provides construction management strategies for soils and vegetation to maintain the biologic, ecologic and hydrologic function of the LID site.

4.3.6 Hydrology Comparison

Hydrologic modelling allows stormwater engineers to identify where LID facilities will be most beneficial and the level of stormwater management provided through the selected facilities. Stormwater engineers will use hydrologic modelling to calculate any additional level of control required, beyond planned LID facilities, to ensure the site release rate and volume meet discharge requirements to the receiving stream or downstream stormwater management facilities. The modelled site hydrology can be compared to pre-development hydrology, enabling the developer, designer and approver to quantify stormwater impacts of the LID based development. Monitoring of the site following development will provide information on real-world performance of the LID site.

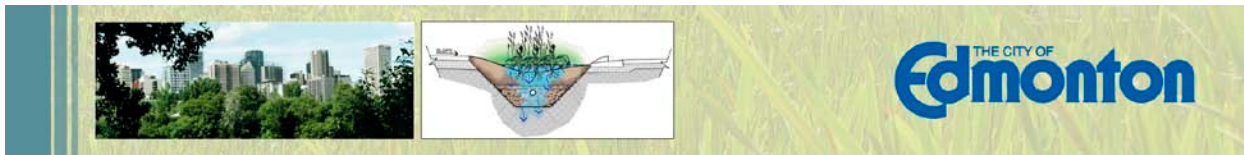
4.3.7 Construction Management

Soil and vegetation management during construction are critical to the success of an LID development. A construction management plan should be developed early in the planning process.

Soil Management

Soil management is a sustainable land development practice that is recommended from initial site planning through to final facility completion. Soil management can be achieved by:

- delineating and flagging or fencing on-site soil preservation areas identified during the soil assessment process to protect these areas from compaction and grading (PSAT, 2005);
- developing a soil management plan, to be implemented during grading and development, that defines topsoil stockpiling strategies and topsoil amendment requirements for on-site restoration;
- restricting construction access and traffic to clearly defined on-site routes; and
- measuring soil characteristics (**Table 3.2**), especially on retrofit sites, at planned facility locations immediately prior to



construction to confirm sub-soil characteristics and amendment requirements.

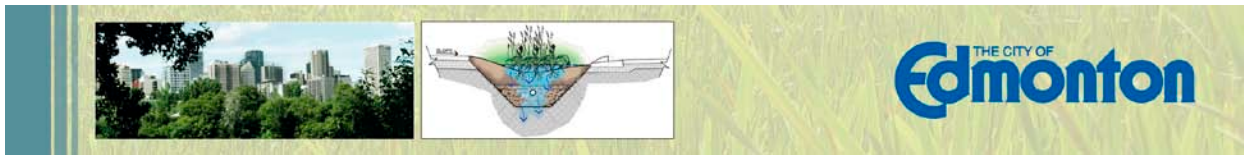
It is important to keep in mind that tight soils with low infiltration rates do not preclude the implementation of LID facilities. Rather, adaptations such as under-drains connected to downstream LID facilities or storm sewers may be required for successful implementation. Site evaluations are key components for the success of a LID-BMP facility as soil structure and composition often vary across a site.

Construction management is critical to the success of LID facilities because although soil permeability is strongly influenced by soil texture and moisture, compaction can dramatically modify infiltration rates (**Table 4.2**; Pitt et al, 2009). On-site soil storage and erosion control plans require compliance with local, provincial, and federal standards and must be planned in advance.

Table 4.2
Long Term Average Infiltration Rates for Compacted Soils

Soil Texture	Compaction Methods*	Long Term Average Infiltration Rate (mm/hr)
Sandy Loam	Hand	889
	Standard	229
	Modified	38
Silt Loam	Hand	33
	Standard	1
	Modified	0
Clay Loam	Hand	7

*Proctor compaction methods (modified and standard) followed ASTM standards (D1140-54)



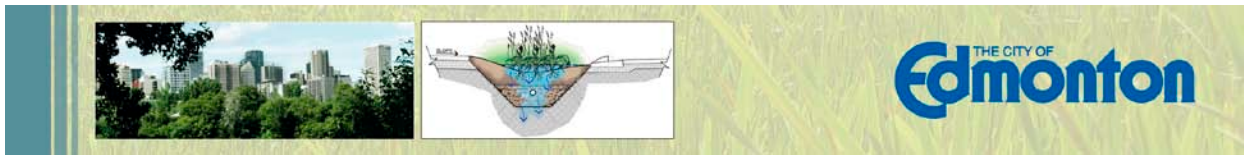
Vegetation Management

Preservation or restoration of site vegetation is possible on a construction site and may be done following the procedure below:

- delineate and / or flag on-site vegetation preservation areas identified through the site assessment process (**Table 4.1**); and
- select vegetation species for site conditions, coverage, and viability and develop a landscape plan in collaboration with landscape architecture, vegetation ecology, soil science and water resource engineering. Prepare a Landscape Maintenance Plan in accordance with the City of Edmonton Design & Construction Standards (COE, 2004). The plan should specify integrated pest and weed management, plant maintenance activities and facility inspection schedules.

4.3.8 Completion of the LID Site Plan

The LID Site Plan will outline findings of the assessments and modelling as background to the selected site layout. Hydrologic modelling of the planned site, detailed in the LID Site Plan, will be used to justify LID facility type, location and impact on stormwater management of the site. The site plan will also include any conventional stormwater management facilities required to meet discharge requirements of the site. The LID Site Plan will include expected erosion and sediment controls and operation and maintenance activities required over the life of the LID facility.



5.0 LID BMPs OVERVIEW

5.1 LID Facility Features and Description

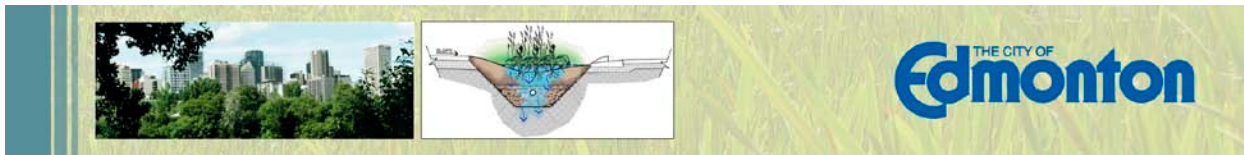
LID Best Management Practices are intended to manage stormwater near or at its source in addition to efficiently conveying and discharging excess stormwater into a receiving water body. Although there are various types of LID BMPs, all follow the same principle of “slowing it down, spreading it out, and soaking it in” (EPA, 2011), replicating the natural hydrological processes of absorption, infiltration, evaporation and evapo-transpiration.

Through a literature review, LID BMPs were assessed considering Edmonton’s climate and physical characteristics. Seven LID features were identified to be suitable for Edmonton’s environment: (1) bioretention; (2) bioswales; (3) green roofs; (4) permeable pavements; (5) box planters; (6) naturalized drainage ways; and (7) rainwater harvesting for re-use.

5.1.1 Bioretention / Rain Gardens

Bioretention areas (also referred to as rain gardens) are stormwater management and treatment facilities, within a shallow depression, using vegetation and amended topsoil. They provide water quality treatment, reduce runoff and allow for infiltration near where runoff originates, such as roofs, driveways and sidewalks. **Figure 5.1** shows examples of bioretention facilities installed in Canada.

On the surface, bioretention areas appear similar to flower / shrub beds and are often called rain gardens. Bioretention installations can range from highly urban environments with hard walls to extensive areas within parks, blending into the topography and extending to street corners and bump outs, to combinations with conveyance facilities such as bioswales. They may be designed to infiltrate water into the underlying soils for groundwater recharge or may provide soil moisture with excess water being directed to storm sewers through an under drain.



Roadside bioretention cell in Surrey, BC. Photo by Fayi Zhou, City of Edmonton, 2011

Big Lake Trumpeter rain garden in Edmonton, AB. Photo by Xiangfei Li, City of Edmonton, 2011

Figure 5.1 Bioretention Installations in Western Canada

The fundamental differences between a bioretention area and a conventional planting bed are that bioretention areas utilize engineered soils and vegetation to capture and treat rainwater and are located at the low point of a landscape. Rainwater then flows either naturally or through an inlet into the bioretention area's concave surface. Depending on the ability of the sub-soils to infiltrate water (hydraulic conductivity), a bioretention area may have four layers, including (**Figure 5.2**):

- 1 plantings and aged mulch;
- 2 topsoil, natural or amended;
- 3 gravel drainage layer; and
- 4 under drain with cleanouts.

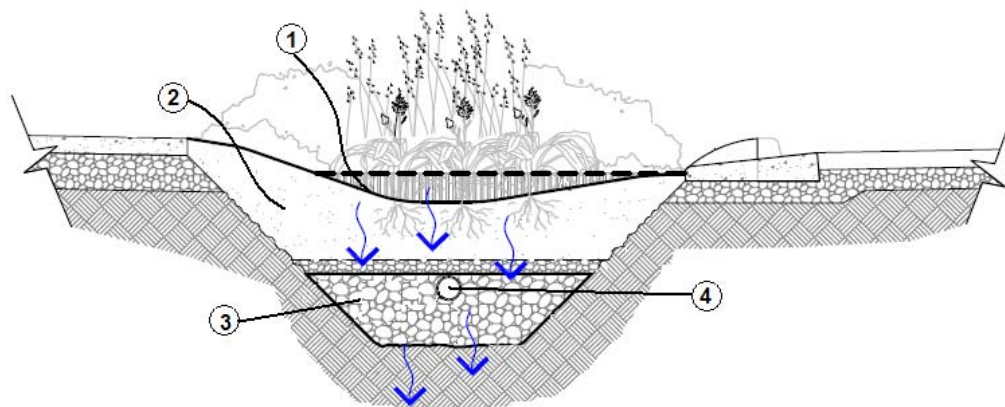
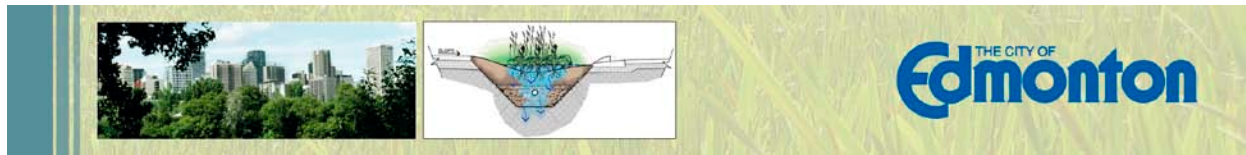


Figure 5.2 Bioretention Area Components

5.1.2 Bioswales

Bioswales, also called vegetated swales, are swales with grass and other vegetation, enhanced topsoil and an underlying infiltration layer (Claytor, 1996; TRCA, 2009; MDEP, 1997). They are designed to slow runoff velocities by increasing surface roughness. Increased surface roughness results in increased surface contact time, allowing more infiltration, evaporation, transpiration and water quality enhancement prior to the runoff entering another stormwater management facility. Examples of bioswale applications are depicted in **Figure 5.3**.

Bioswales differ from common grass swales. Grass swales have limited infiltration potential since they usually do not have an enhanced top soil or infiltration underlayer. The layers of a bioswale are similar to those of bioretention areas, as shown in **Figure 5.2**.



Altalink Cumberland bioswale in Edmonton, AB. Photo by Xiangfei Li, City of Edmonton, 2011

Terwillegar Recreation Centre bioswale in Edmonton, AB. Photo by Xiangfei Li, City of Edmonton, 2011

Bioswale in parking lot in Surrey, BC. Photo by Fayi Zhou, City of Edmonton, 2011

Figure 5.3 Bioswale Installation Examples

5.1.3 Green Roofs

Green roofs consist of live vegetation established on top of buildings. There are two types of green roofs: extensive and intensive (see **Figure 5.4**). An extensive green roof consists of a relatively thin layer of growing medium (approximately 50 to 150 mm) and a ground cover type of plant that is hardy to the harsh conditions of a rooftop. An intensive green roof consists of soil depths of at least 300 mm and may include woody plants such as shrubs and trees. Intensive green roofs are often used as public green spaces. Both types of green roof consist of a series of layers as illustrated in **Figure 5.5**.



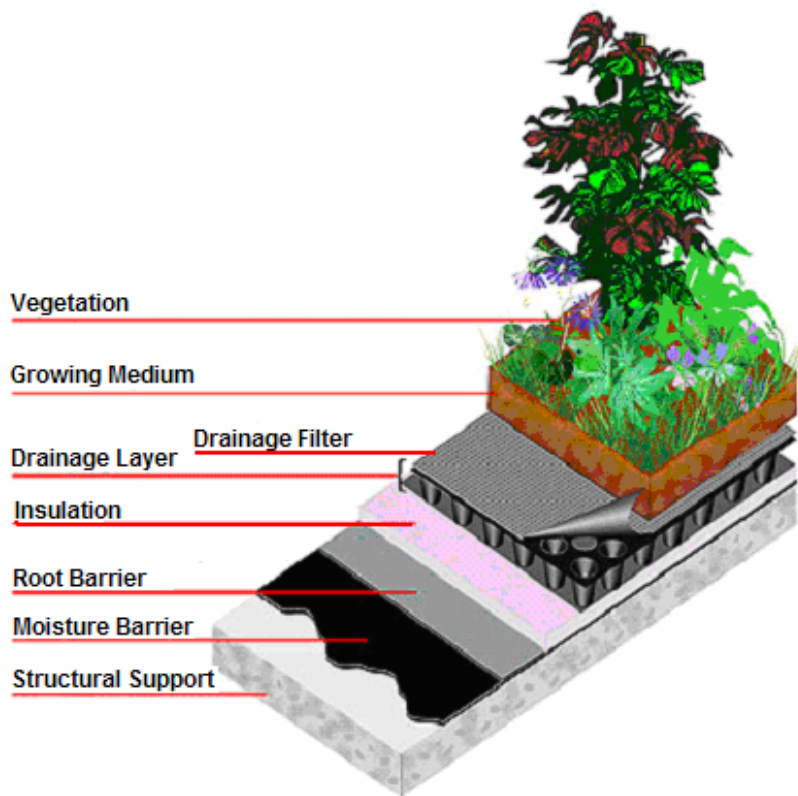
Stantec Building, Edmonton, AB. Photo courtesy Penny Dunford, Stantec Consulting, 2009



*REI Building, Intensive Green Roof, Denver
Photo Credit: Kerri Robinson, AMEC Earth & Environmental*

REI Building, Denver, CO. Photo courtesy Kerri Robinson, AMEC Earth & Environmental

Figure 5.4 Intensive and Extensive Green Roofs



(adapted from: greenwardliving.com/green.aspx)

Figure 5.5 Layers of a Green Roof

5.1.4 Permeable Pavement

Porous asphalt, porous concrete, permeable unit pavers and open grid pavers (**Figure 5.6**) are all considered to be permeable pavement, and may also be known as porous pavement. Incorporating permeable pavements into a development will reduce the effective impervious area of the development without losing its functionality. They are typically used in low traffic areas such as parking lots. In general, the structure of permeable pavement consists of four layers (**Figure 5.7**):

1. permeable pavement or pavers;
2. 'choker course' or bedding layer of washed stone;
3. reservoir layer consisting of clean washed uniformly graded aggregate or a tank consisting of a matrix of open weave boxes; and
4. perforated under-drain incorporated into the reservoir layer as required.



*Pervious paver in Surrey, BC.
Photo by Fayi Zhou, City of
Edmonton, 2011*

*Porous asphalt parking lot with
bioretention in Surrey, BC. Photo by
Fayi Zhou, City of Edmonton, 2011*

*Porous asphalt in Philadelphia, PA.
Photo by Xiangfei Li, City of
Edmonton, 2011*

Figure 5.6 Permeable Pavement Installation Examples

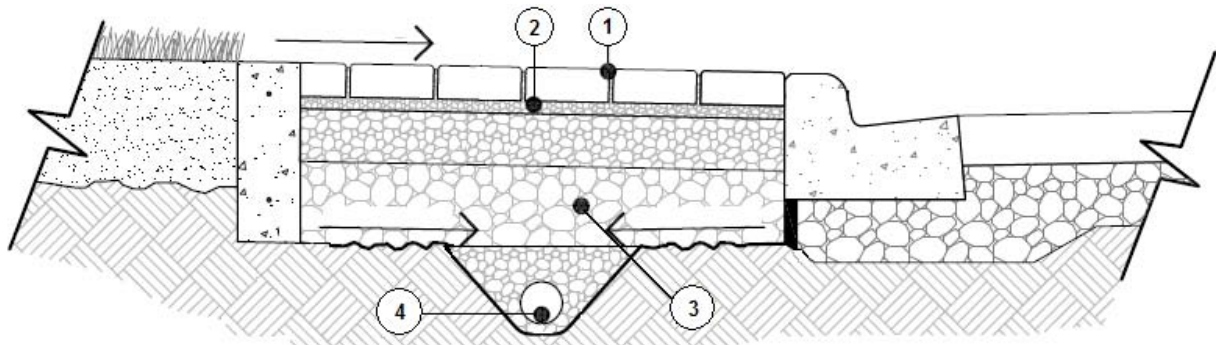
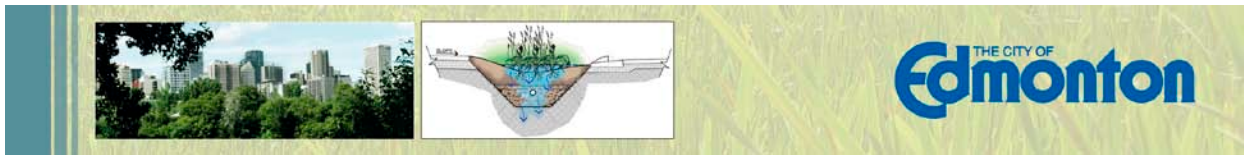


Figure 5.7 Components of Permeable Pavement Facilities

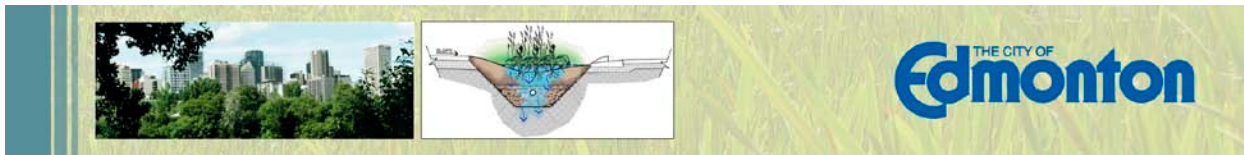
5.1.5 Box Planters

Infiltrating box planters are similar to bioretention systems as they use vegetation and amended soils to filter and retain stormwater (**Figure 5.8**). There are three types of box planters that may be implemented based on site characteristics and requirements:

- contained planters with outlet only through overflow;
- flow-through planters with an under-drain outlet; and
- infiltration planters that drain through deep infiltration and groundwater recharge.

A planter typically consists of a concrete box, which may or may not have a lined or concrete bottom (depending on whether infiltration is desirable), filled with a soil medium and planted with trees, shrubs or flowering species. An alternative to the concrete box is a matrix of buried plastic cells (**Figure 5.9**) that can be assembled to any required shape and size. The matrix provides structural support for sidewalks and roadways while allowing for deep root penetration.

Box planters are typically designed to provide treatment for frequent, smaller volume rainfall events. Infiltration planter boxes should be regularly spaced along the length of a corridor such that they provide an appropriate level of water quality treatment for the receiving drainage area and reduce the impervious surface area.



Box planter in Philadelphia, PA. Photo by Xiangfei Li, City of Edmonton, 2011



Box planter installation including trees in Kitchener, ON. Photo by Xiangfei Li, City of Edmonton, 2011

Figure 5.8 Examples of Box Planter Installations

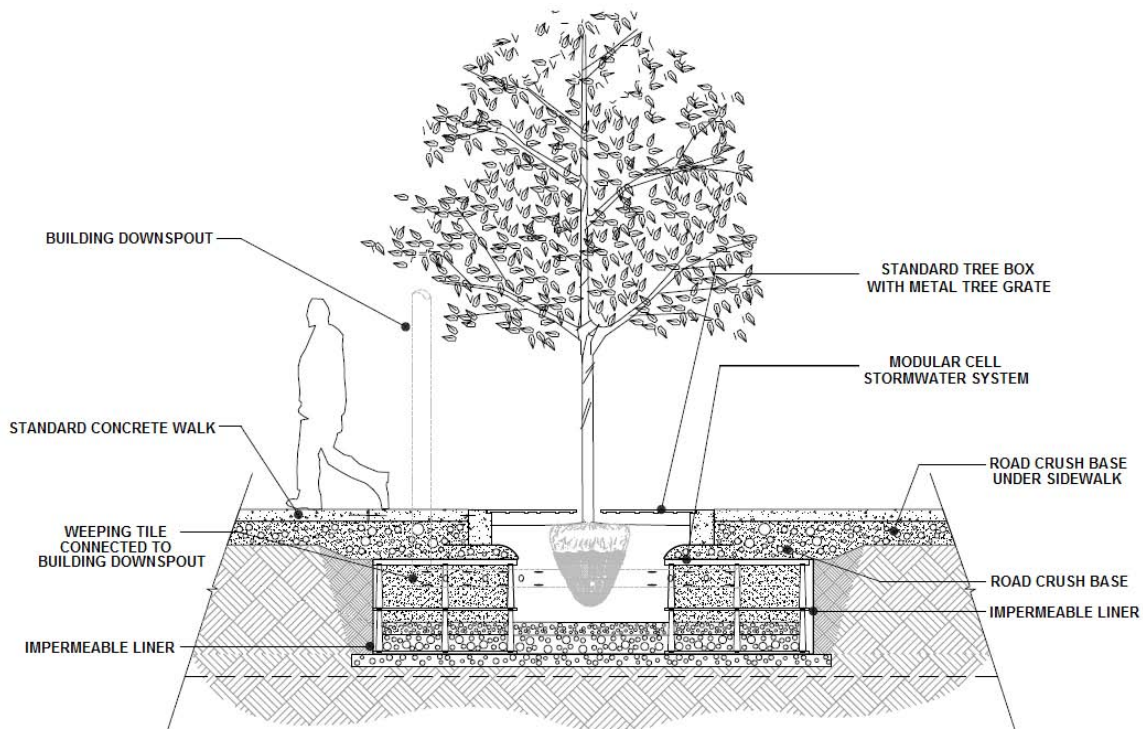


Figure 5.9 Tree Trench Box Planter with Cell Structure

Box planters can also aid in reducing runoff volume and peak flows. The primary mechanisms of stormwater management for infiltrating box planters (**Figure 5.10**) include:

1. surface infiltration;
2. transpiration;
3. deep infiltration (optional); and
4. delayed release to the minor system.

Typically, stormwater enters the infiltrating box planter through a curb cut and infiltrates through a layer of mulch and soil. Some of the water is retained by the soil and subsequently used by the vegetation and released through evapo-transpiration. Depending on the native soils' characteristics, infiltrated water will percolate (deep infiltration) to the groundwater table. If infiltration is not an option a perforated under-drain placed near the bottom of the box planter will convey excess water to the storm drainage system or a reservoir for re-use purposes (such as irrigation).

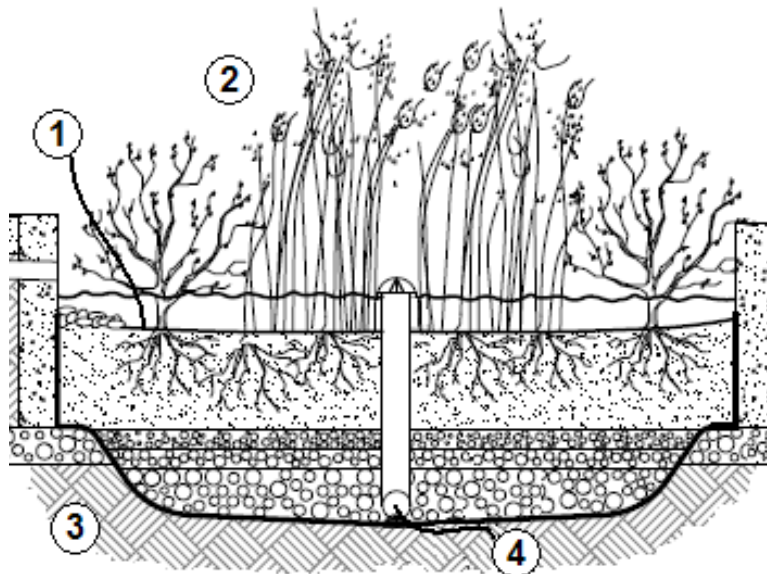


Figure 5.10 Stormwater Management Mechanisms in a Box Planter

Catchment – the area draining to a single point such as an LID-BMP facility

5.1.6 Naturalized Drainage Ways

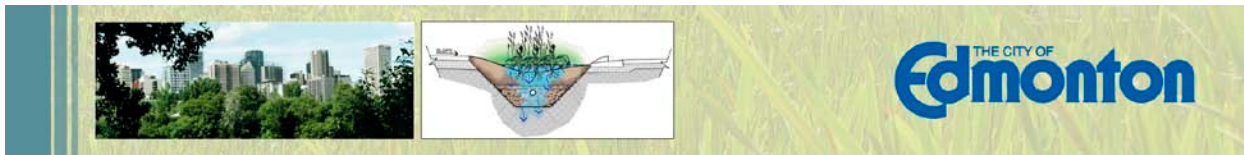
Naturalized drainage ways are surface stormwater conveyance features that use wetland zones, drop structures and natural materials and vegetation to replace storm sewer mains or prevent erosion of existing drainage ways (**Figure 5.11**). They generally have frequent or continuous runoff (base flow), even during periods of little or no precipitation. Base flow in these facilities results from residential irrigation and outdoor water use.

Naturalized drainage ways are often used as replacements for storm sewer trunks. As more development occurs in upstream catchments, increased base flows are observed in the drainage ways. These facilities are generally viewed as great amenities to surrounding communities and provide a refuge for birds and wildlife in the area.

Naturalized drainage ways are typically larger than grass swales, more engineered than natural wetlands and in some cases may appear similar to a small creek. Velocities of urban runoff and stormwater are slowed using natural vegetation, increased resistance along the flow path and drop structures (MDEP, 1997). Additionally, prolonged stormwater contact with natural materials promotes the hydrologic cycle through evaporation and transpiration.



Figure 5.11 Naturalized Drainage Ways in Medium and Low Density Developments
All photos courtesy Kerri Robinson, AMEC.



Naturalized drainage ways usually follow property lines and utility rights-of-way. Infiltration from naturalized drainage ways is typically not a significant contributor to the hydrologic cycle due to saturated soils and / or direct connection with the groundwater table.

Where longitudinal slopes exceed 1%, drop structures are used to reduce flow velocities and maintain flat grades. The primary mechanisms of stormwater management in a naturalized drainage way are shown in **Figure 5.12** and include:

1. slowed velocities through channel roughness and drop structures; and
2. evaporation and transpiration from surface flows and plant uptake.

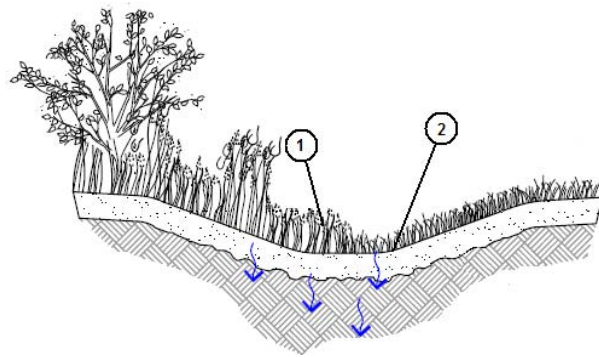


Figure 5.12 Stormwater Management Mechanisms in a Naturalized Drainage Way

5.1.7 Rainwater Harvesting for Re-use

Rainwater harvesting gathers and accumulates rainwater falling on a rooftop and stores it for re-use in irrigation or other legislated uses. Rainwater harvesting may be as simple as collecting rainwater from roof downspouts in a rain barrel and using it to water planters and gardens. On a larger scale, rainwater may be collected in a large cistern located underground or in a garage or basement, and then re-used for irrigation with a direct hook-up to automatic sprinklers or an outdoor hose bib (**Figure 5.13**).



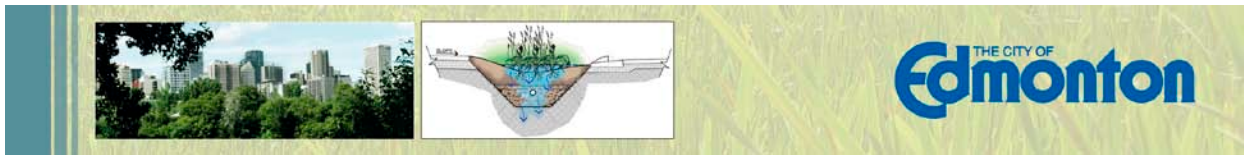
Clockwise from top left: typical plastic rain barrel; cast in place concrete cistern integrated within a parking garage (Source: TRCA); above-ground plastic cistern; underground pre-cast concrete cistern (Source: University of Guelph)

Figure 5.13 Types of Rainwater Storage Tanks
(From TRCA and CVCA, 2010)

5.2 Performance of LID-BMPs

LID BMPs replicate natural hydrological processes to manage surface runoff due to urbanization. They reduce both runoff volumes and rates and improve stormwater quality.

In general, treatment of stormwater begins with filtration of particulates as runoff flows over the surface and through vegetation, and again when it infiltrates through mulch and soil layers. Water is retained in the growing medium and contributed back to the hydrologic cycle through evapo-transpiration. Soil microbes within the soils provide decomposition for pollutants such as hydrocarbons and nutrients. Soils also allow metals and chemicals to sorb to soil particles and compounds within the soil, preventing their release to receiving streams.



For permeable pavements, water quality benefits begin with filtration of stormwater through the porous asphalt / concrete or bedding course layer. Contaminants such as fine particulates, oil and grease and heavy metals will be trapped within the pore structure of the porous asphalt / concrete or bedding course layer.

Due to the site specific characteristics of LID features, performance varies from site to site. Performance also depends heavily on design objectives and quality of construction. **Table 5.1** summarizes overall performance of LID BMPs for reduction of annual runoff and some key pollutants.

Table 5.1
Observed Removal Efficiencies (%) in LID-BMP Facilities
in the USA and Canada

Pollutant	Bioretention / Rain Garden	Vegetated Swale ¹	Box Planter / Green Roof ²	Permeable Pavement ³	Naturalized Drainage Way ⁴
Annual Runoff Reduction (RR)	50~90	40~80	45~60	45~75	
Total Suspended Solids	59-90	65-81	86	85-89	80
Hydrocarbons		65			
Metals	80-90	20-50		35-90	40-70
Total Phosphorus	5-65	25	59	55-85	20
Total Nitrogen	46-50	15-56	32	35-42	40
Bacteria		negative	37	40-80	

¹ based on monitoring results for grass swales

² filtering practices

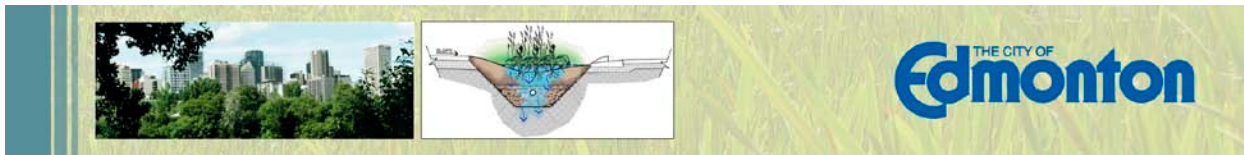
³ infiltration practices

⁴ based on monitoring results for wet swales
(CWP, 2007a; Claytor et al, 1996)

5.3 LID Benefits, Costs and Limitations

5.3.1 LID Benefits

Table 5.2 provides a summary of the benefits that the seven LID BMPs described in this guide can offer. These benefits can be realized at various scales according to local and site-specific



factors. Some of the benefits can be quantified with a monetary value while others are intangible. The *Value of Green Infrastructure*, developed by the Center for Neighbourhood Technology, provides a reference to calculate the economic benefit of LID applications (CNT, 2010). Benefits that can be quantified with economic values include avoided runoff treatment, total suspended solids (TSS) reduction, air pollutant removal, and energy savings from green roofs.

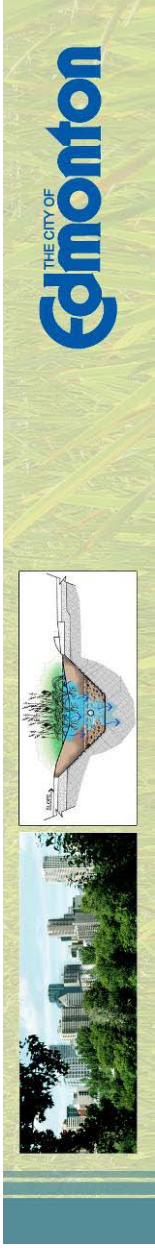
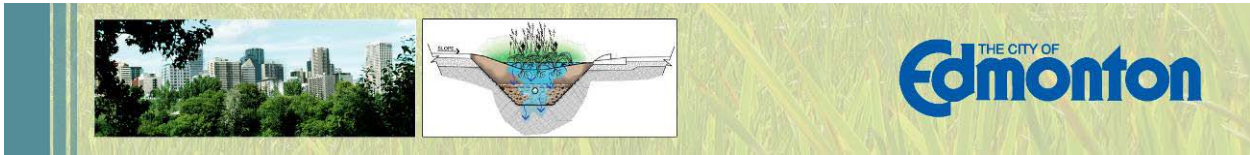


Table 5.2
Benefits of LID BMPs

Benefits	LID BMPs						
	Bioretention	Bioswale	Green Roof	Permeable Pavement	Box Planter	Naturalized Drainage Way	Rainwater Harvesting
Reduced Storm Runoff	+	+	+	+	+	+	+
Reduced Flooding	+	+	+	+	+	+	+
Reduced CSO	+	+	+	+	+	+	+
Improved Water Quality	+	+	+	+	+	+	+
Increased Groundwater Recharge	+	+		+	□	+	
Reduced Salt Application				+			
Improved Air Quality	+	+	+		+	+	
Reduced Urban Heat Island	+	+	+	+	+	+	
Reduced Energy Use	+	+	+	+	+	+	+
Improved Aesthetics and Property Values	+	+	+	□	+	+	
Improved Habitat	+	+	+		+	+	
Reduced Traditional Stormwater Infrastructure Expenditure	+	+	+	+	+	+	+

(CNT, 2010; ECONorthwest, 2007; USEPA, 2007)

+ Yes □ Possible



The benefits of LID originate from its approach of treating stormwater close to its sources by mimicking natural systems. Environmental benefits are realized because LID is able to reduce stormwater peak flow and volume and improve water quality. Realization of environmental benefits further brings social and economic benefits associated with LID applications. The benefits of LID are further described below.

Reduced stormwater runoff. LID is intended to intercept, infiltrate, filter, store, and detain stormwater runoff. For example, green roofs can store significant amounts of water in their growing media, while bioretention can infiltrate and attenuate storm runoff.

Reduced flooding. LID applied throughout a watershed can reduce urban runoff volumes and thus has the potential to reduce subsequent flooding risk.

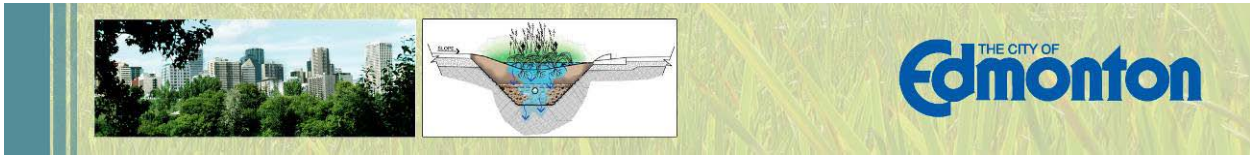
Reduced combined sewer overflow. Integrating LID into stormwater management practices can reduce overflow volumes, frequency, and impacts for both combined and separate systems through reducing peak flows and improving water quality. Some municipalities have found (Riverkeeper, 2007) that reduction of CSOs with LID BMPs was more cost-effective than conventional practices of CSO storage and sewer separation.

Improved water quality. LID can improve water quality by effective capture and treatment of pollutants and sediments that typically wash into sewers and receiving water bodies. Pollutants are filtered, absorbed, or biodegraded while moving through infiltration media.

Increased groundwater recharge. On-site infiltration of stormwater can increase groundwater recharge by directing rainwater into the ground instead of pipes.

Reduced salt application. Permeable pavement has been demonstrated to delay the formation of a frost layer in winter (Roseen, 2009; Houle, 2008), which can reduce salt application and reduce pollution to surface and groundwater resources. The economic benefit of salt reduction is a potential cost saving.

Reduced energy use. The presence of vegetation on LID facilities reduces the temperature of its surroundings. This can reduce requirements for heating and cooling systems, resulting in reduced energy use. For example, green roofs reduce roof surface temperatures through evaporative cooling from water retained in



Albedo – Reflective power or fraction of solar radiation reflected by a surface or object

the growing medium and reduce a building's energy consumption by providing superior insulation. Rainwater harvesting saves energy by reducing use of potable water that needs energy for treatment and transport.

Improved air quality. Vegetated LID facilities (e.g. bioswale, bioretention) can improve air quality through uptake of air pollutants and deposition of particulate matter. Permeable pavement, rainwater harvesting, and vegetated LID facilities can indirectly improve air quality by reducing the amount of water/wastewater treatment needed, in turn reducing greenhouse gas production and air pollution from power plants.

Reduced urban heat island. Permeable pavements help reduce the surrounding air temperature because they absorb less heat than conventional pavement. Vegetated LID facilities mitigate the urban heat island effect through evaporative cooling and reduction of surface albedo.

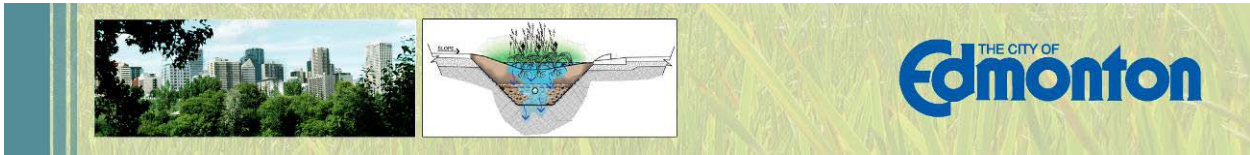
Improved aesthetics and property values. The vegetation cover of LID facilities can enhance aesthetic appeal of an area and increase adjacent property values by increasing desirability of the lots and their proximity to an open space (ECONorthwest, 2007). Some permeable pavements help to reduce noise.

Improved habitat. LID supports biodiversity and provides valuable wildlife habitat in the urban setting by contributing green spaces and connections to ecological corridors.

Reduced cost of stormwater infrastructure. LID can help reduce the demand for conventional stormwater controls (e.g. curb-and-gutter) and reduce requirements to upgrade downstream storm sewer capacity with additional infrastructure. LID can potentially reduce the long-term cost of operation, maintenance and rehabilitation of stormwater management infrastructure through improved environmental performance.

5.3.2 Life Cycle Costs

There is considerable interest in comparing the development costs of sites designed using LID-BMPs to manage stormwater runoff and those designed using conventional stormwater management practices. **Table 5.3** provides a cost comparison of sites designed using LID-BMPs and those designed using conventional



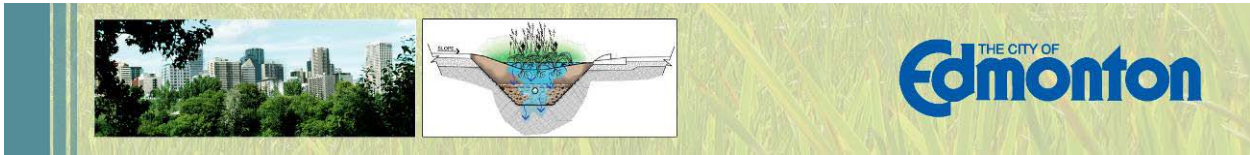
development practices. Development of LID-BMP stormwater management systems costs less than comparable conventional systems in most cases. However, every development is unique and should be considered and assessed individually.

In addition to whole site comparisons of the costs for implementing LID or conventional design methods, an understanding of the life cycle costs of LID-BMP facilities is necessary for planning and decision making purposes. **Table 5.4** provides a breakdown of capital costs, annual maintenance costs, expected life for well designed, constructed and maintained facilities and facility replacement costs. These costs are provided for comparison with conventional systems and infrastructure life cycle costs. In addition to capital construction and maintenance costs, the value of environmental and social benefits of both types of systems must be incorporated into cost-benefit analyses. It is important to note that design and engineering costs for LID-BMP facilities typically range from 5% to 40% of construction costs (TRCA, 2009).

The range of costs illustrated in **Table 5.4** is quite wide. In the development of LID-BMP facilities, economies of scale apply when assessing costs. Sites designed with several similar features utilizing the same materials, or incorporating large facilities will have reduced costs per unit area compared to sites with a single LID-BMP feature. The costs of retrofit applications of LID-BMP in highly urbanized areas are likely to be higher than greenfield developments due to site preparation costs. Several additional factors will contribute to increased costs of LID-BMP facilities, including:

Greenfield – land that has not been previously developed

- poor quality or contaminated site soils requiring extensive amendments or transport of soil;
- requirement of geotextiles to prevent infiltration where groundwater contamination may occur or in tight soils where frost heave is a concern;
- structural reinforcement requirements associated with retrofitting green roofs on existing buildings;
- application of intensive green roofs utilizing higher soil volumes and more plant varieties than extensive green roofs;
- plant selection variations for bioretention areas, bioswales and box planters depending on location, i.e., downtown planters may use species with higher initial costs or requiring more



maintenance;

- higher labour costs associated with permeable paver installation compared to porous asphalt or concrete; and
- small rainwater harvesting cisterns with higher costs per unit volume than large units.

Table 5.4 applies an approach for cost estimating where capital, operation and maintenance (O&M) costs are estimated based on facility size. This method is simple to use, but may not represent specific site conditions and installation options as the costs tabulated are the averaged costs from various projects.

A recently developed *Best Management Practice and Low Impact Development Whole Life Cost Model* by the Water Environmental Research Foundation (WLCM-WERF) is a parametric approach that incorporates capital costs using design parameters and a detailed O&M cost estimation using a prescribed maintenance schedule (WERF, 2009). Parametric methods such as the WLCM-WERF model offer a variety of factors to be adjusted to improve the accuracy of estimates. These factors include retrofitting, self or professional installation, level of capital cost and level of O&M (low, medium, or high) costs. However, this type of model requires significant input of parameters for which data may not be available.

Caution should be used when applying any models developed for LID projects outside of the Edmonton region. Users should modify model parameters using local data if available for estimating LID costs applicable to the Edmonton region.

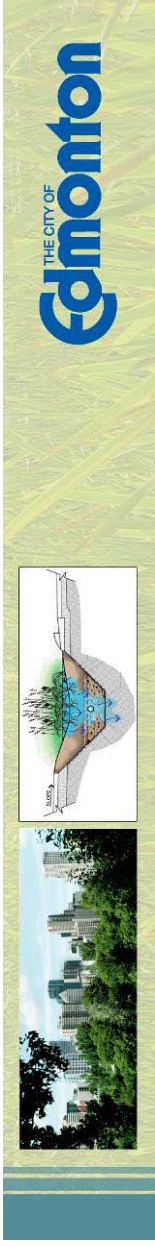


Table 5.3
Summary of Cost Comparisons of Conventional and LID Approaches

Projects ¹	Conventional Development Cost	LID Development Cost	Cost Difference	Percent Difference	LID-BMP Facilities Included ³
Ridgefield ² , New Hanover County, North Carolina	\$2,394,136	\$889,140	\$1,504,996	63%	S, W
2nd Avenue SEA Street, Seattle, Washington	\$868,803	\$651,548	\$217,255	25%	B, RIA, S
Auburn Hills, Wisconsin	\$2,360,385	\$1,598,989	\$761,396	32%	B, RIA, S, VL, W
Bellingham City Hall, Bellingham Washington	\$27,600	\$5,600	\$22,000	80%	B
Bellingham Bloedel Donovan Park, Bellingham, Washington	\$52,800	\$12,800	\$40,000	76%	B
Gap Creek, Sherwood, Arkansas	\$4,620,600	\$3,942,100	\$678,500	15%	RIA, VL
Garden Valley, Pierce County, Washington	\$324,400	\$260,700	\$63,700	20%	B, CD, S, PP, W
Kensington Estates, Pierce County, Washington	\$765,700	\$1,502,900	-\$737,200	-96%	CD, RIA, PP, VL, W
Laurel Springs, Jackson, Wisconsin	\$1,654,021	\$1,149,552	\$504,469	30%	B, CD, RIA, S
Mill Creek Lots, Kane County, Illinois	\$12,510	\$9,099	\$3,411	27%	CD, RIA, S
Prairie Glen, Germantown, Wisconsin	\$1,004,848	\$599,536	\$405,312	40%	B, CD, RIA, S, VL, W
Somerset, Prince George's County, Maryland	\$2,456,843	\$1,671,461	\$785,382	32%	B, S
Tellabs Corporate Campus, Naperville, Illinois	\$3,162,160	\$2,700,650	\$461,510	15%	B, S, VL, W

⁽¹⁾USEPA, 2007; The Watershed Academy, 2010)

²Additional lots were added to the site as a result of the LID measures for an additional profit of \$500,000

³Bioretention (B), Swales (S), Permeable Pavement (PP), Reduced Impervious area (RIA), Wetlands (W), Vegetated Landscape (VL), Cluster Development (CD)

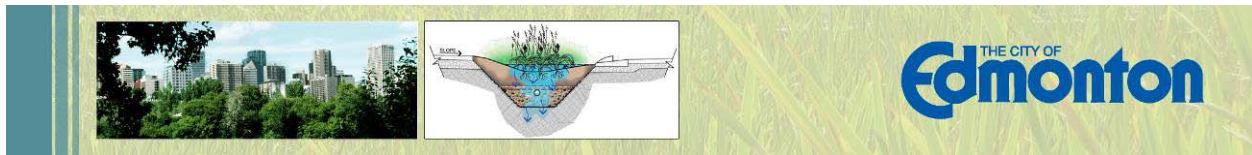
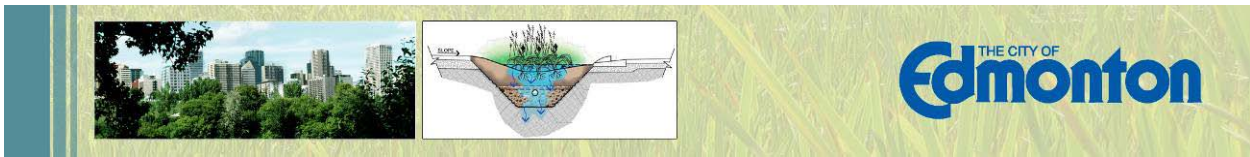


Table 5.4
Life Cycle Costs of LID-BMP Facilities

Feature	Generalized Costs			
	Construction	Annual Maintenance	Replacement	
			Life Cycle ¹	Cost
Rainwater Harvesting System	\$212-\$1000/m ³ of storage	Fall irrigation maintenance: \$25/yr residential; cistern flush/pump: \$100-\$150 /yr	25-100+ years	Construction costs
Green Roofs	Extensive: \$230-\$550 /m ² intensive: \$500-\$3000 /m ²	\$3-\$44/m ² during first 2 years (reduced following establishment of plantings after 2-5 years)	30-50 years	Replacement of waterproof membrane \$6/m ² plus general labour to remove and replace green roof.
Box Planters	\$30-\$350/m ²	\$13-\$30/m ³	25-50 years	Construction costs; drainage area characteristics may require replacement of soils (\$10-\$15/m ²) 2-10 times more often than the drainage structure
Bioretention	\$30-\$250/m ²	\$13-\$30/m ³	>20 years	Major rehabilitation: \$4-\$170 /m ² every 15-20 years
Permeable Pavement	\$340-\$500/m ²	\$0.15-\$0.30/m ² for vacuum or deep clean	>20 years	Construction costs
Biowales	\$11-\$35/m ²	\$0.20-\$1.00/m ²	>20 years	Construction costs; drainage area characteristics may require replacement of sod and soil (\$15-\$20 /m ²) up to 2 times more often than the drainage structure
Naturalized Drainage Ways	\$25-\$250/m ²	<\$1-\$18/m ²	>20-100+ years	Full replacement not expected when well maintained

¹Expected life for well designed and maintained facilities

(TRCA, 2009; Wayne County, 2001; CRDWS, 2008; Peck, 2003; SWRPC, 1991; Alberta supplier/installers; AMEC, pers. comm. 2010; Progressive Engineering Ltd, pers. comm, 2010)



5.3.3 Limitations of LID BMPs

Although LID provides many tangible and intangible benefits environmentally and socially, it has some limitations. This section lists the limitations of each of the seven LID BMPs discussed in this Guide.

5.3.3.1 Bioretention/Rain Gardens

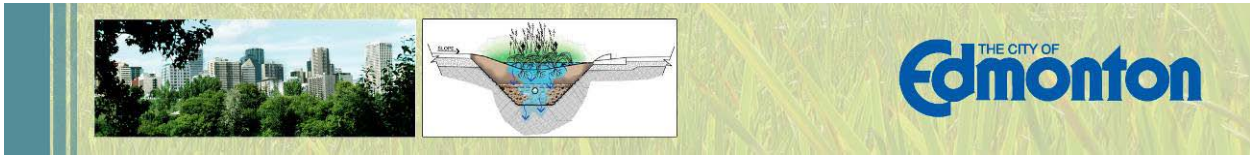
- Unlike stormwater ponds, bioretention cannot treat large drainage areas;
- They are susceptible to clogging by sediment. Therefore, pre-treatment may be required, especially in locations where anti-skid material has been applied to the contributing catchment;
- They may consume considerable space, between 5% to 20%, of the catchment area;
- Incorporation into parking lot design may reduce the number of parking stalls available; and
- Depending on the location and development type, construction costs can be relatively high compared to some conventional stormwater treatment practices.

5.3.3.2 Bioswales

- Improper installation will prevent removal of sediment and pollutants. Slopes and vegetation density are critical;
- Individual swales can treat only small areas;
- They are less feasible along roadsides with many driveway crossings;
- Phosphorus and bacteria removal capabilities are limited;
- Maintenance requirements are higher than curb and gutter systems; and
- They may be subject to damage from off-street parking and snow removal when located along roadways.

5.3.3.3 Green Roofs

- Costs to build green roofs are high compared to traditional roof treatments;
- Only direct rainfall is treated;
- Control of maintenance and operation is often beyond municipal



jurisdiction; and

- Design and construction experience is currently limited in Canada, though rapidly becoming less so.

5.3.3.4 Permeable Pavement

- Maintenance requirements are high compared to other LID-BMP stormwater management facilities;
- Costs to build permeable pavements are high compared to other stormwater management facilities;
- A small drainage area is treated;
- They are susceptible to clogging where anti-skid material is applied;
- Performance is reduced if freezing occurs while the surface is saturated;
- They are unsuitable for use in areas where heavy sediment loads are expected or in active construction or excavation areas that are not fully stabilized; and
- They are unsuitable for use in areas with heavy vehicle traffic, unless specifically designed for heavy loads.

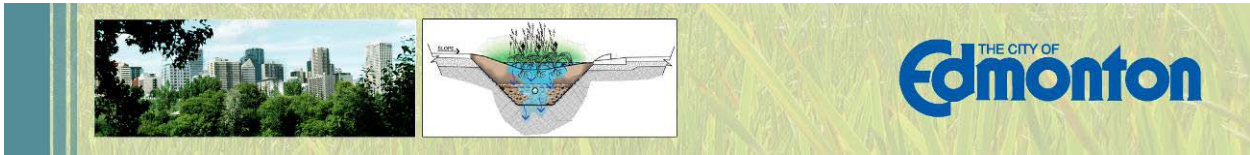
5.3.3.5 Box Planters

- Contained and flow-through box planters require downstream LID-BMP facilities or connection to a conventional storm sewer system to convey excess stormwater; and
- Contained and flow-through box planters do not contribute to groundwater recharge.

5.3.3.6 Naturalized Drainage Ways

- They are impractical to implement in areas with very flat or very steep topography;
- They may be subject to some erosion during high flow velocities or volumes resulting from large storm events;
- They require considerable space for implementation, which may preclude their use in highly developed sites;
- Potential for high flow rates and / or flash floods must be assessed to ensure public safety where pedestrian access alongside naturalized drainage ways is encouraged; and

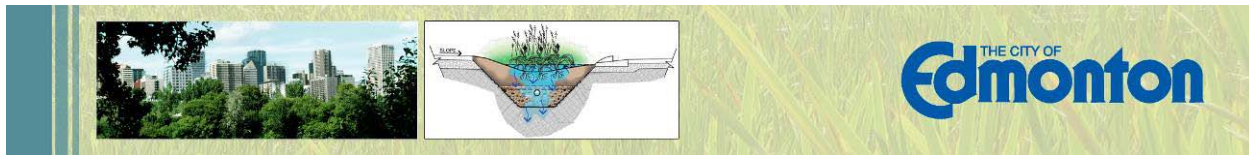
Flash Flood – may occur when water levels in a drainage way rise very rapidly with little or no warning



- Feasibility of application is reduced along roadsides with many driveway crossings.

5.3.3.7 Rainwater Harvesting for Re-Use

- Systems have minimal water quality treatment capabilities;
- In Alberta, rainwater re-use systems often require a potable water supplement since rainfall is not consistent enough to supply all irrigation or non-potable demands in a timely and economical manner;
- Installation **MUST** be done by experienced personnel to prevent any chance of cross contamination of the potable system;
- Due to installation on private property, control of operation and maintenance is typically beyond the jurisdiction of municipalities.



6.0 LID BMPs FACILITY DESIGN

This chapter provides general considerations for design of LID BMP facilities. Specific design recommendations for addressing local and climatic constraints will be described in later chapters.

All LID design parameters within this Design Guide are based on underlying assumptions that soils in Edmonton are tight and expansive and that winter snow accumulates to a final frost depth and spring melt. Facility design details include cold climate adaptations and consideration of the City of Edmonton's sand / salt winter maintenance regime.

Each LID site is unique and has specific characteristics that require consideration during the planning and design stages to ensure successful implementation. A thorough investigation of each design parameter is required to ensure the design accounts for all of local conditions surrounding the proposed application.

6.1 Vegetation Selection and Planting

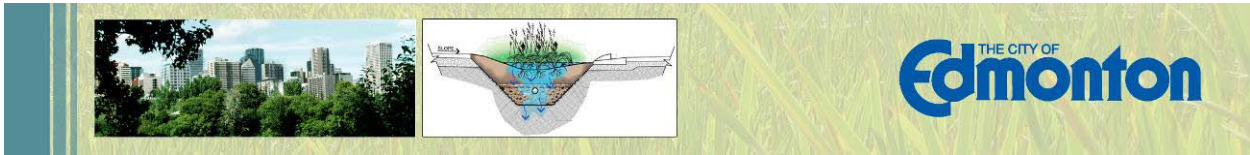
Vegetation selection and survival is an important facility feature as vegetation type, morphology, and structure influence hydraulics and pollutant settling or transport.

The use of native vegetation throughout the project site is recommended where appropriate (Appendix A; **Table A.1**). However, there is also a very large selection of ornamental trees, shrubs and perennials that will be successful in specific LID facilities (Appendix A; **Table A.2**).

Vegetation selections for LID facilities can be generally grouped into two basic soil scenarios: a well drained soil which receives periodic inundation; and a poorly drained soil which is moist to wet for most of the growing season. These two scenarios require different plant selections to be successful.

Regardless of the designation (native or ornamental), vegetation selection must meet the City of Edmonton Weed and Pest Control Bylaw and the designer must be aware of species considered noxious weeds (COE, 2008b). Vegetation selections and planning should include the following four parameters:

Ornamental Vegetation –
Vegetation typically grown for aesthetic (flowers, fruit, etc.) purposes.



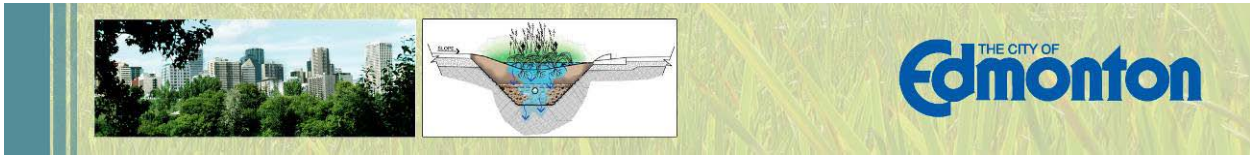
- select plant varieties that will thrive on the site conditions (climate, soil, and water availability) and that grow well together (e.g., group plants by water need). Base plant selections on mature sizes and recommended planting distances as outlined in the City of Edmonton Guideline for Planting Trees on City Property (COE, 2008c). Species selections should consider:
 - maintenance needs, including mowing and pruning;
 - reduction of water and fertilizer needs after establishment;
 - resistance to pests;
 - tolerance of seasonal salt loadings, depending on facility location; and
 - pollutant uptake capacity.
- plan vertically to incorporate ground cover, understory shrubs, and trees. Plant in the spring or fall for quicker establishment. When planting trees, select species based on morphology (e.g., rooting zones, branching patterns, size at maturity, etc.). Note that deep rooting trees can improve soil structure with results similar to tilling. However, in areas where perforated weeping tile is used, deep rooting vegetation may damage buried infrastructure;
- plant vegetation at proper depths, locations, and groups (COE, 2004; COE, 2008c); and
- provide City of Edmonton maintenance staff with a written Landscape Maintenance Plan and train as needed. Budget and plan for extra maintenance efforts during vegetation establishment.

6.2 Soil Management and Amendment

6.2.1 Soil Management

Water movement through soil is referred to as infiltration. The rate that water infiltrates is based on the soil's permeability (i.e., hydraulic conductivity). Saturated hydraulic conductivity refers to the rate of water movement through soil once void spaces within the soil are full of water and no more water can be retained within the soil structure. Although standard infiltration rates are difficult to determine, as both soil properties (chemical and physical) and vegetation cover influence water movement, unsaturated infiltration rates for native Edmonton soils are high regardless of soil type or vegetation cover (Verma and Toogood, 1969). A rapid decrease in infiltration rates following the first 30 minutes is attributed to the initial

Hydraulic Conductivity –
the rate at which soil
allows water to move
through it.



Porosity – a measure of the void space in a material, expressed as a ratio of the volume of void space to the total volume of the material

Permeability – the ability of a fluid to flow through a porous medium

physical soil characteristics including moisture content, temperature, texture, structure, and porosity. Hydraulic conductivity is higher at the top of the soil profile due to specific porosity, structure and texture of the soil.

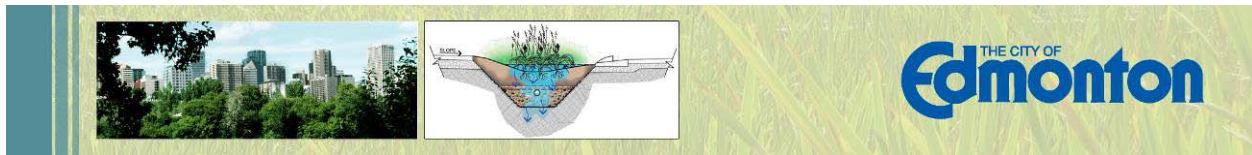
Compaction of soil particles is a factor in permeability. For example, materials consisting of strongly compacted clays, observed following construction with heavy machinery, have a hydraulic conductivity value of about 0.5 mm/hr (McKeague et al, 1986). After organic material is removed during site construction, sub-soils can become heavily compacted by construction activities. As well as reducing infiltration, this compaction due to construction traffic will impede root penetration, greatly reducing plant health and vigour. To increase plant survival and health:

- loosen subsoil to a minimum depth of 150 mm in areas without compaction and 300 millimetres in areas with heavier compaction;
- remove all subsoil material exceeding 50 millimetres in diameter (TRCA, 2009); and
- cover loose and friable subsoil with 200 to 300 millimetres of topsoil for grass areas and 450 to 600 millimetres for shrub beds (Rosen 2009).

6.2.2 Soil Amendments

Soil amendments, including mixed soil types, organic matter, fertilizers, and compost, are often required to ensure specific vegetation growth and to meet predetermined infiltration rates for the LID facility. Organic compost can be an excellent source of required nutrients for plant growth. However, selection of compost type and source is critically important.

The most common sources of compost include tree and vegetation prunings, construction waste and animal manure. In BMP facilities that promote surface infiltration through amended soils either for groundwater recharge or to an under-drain, it is not recommended that animal manure compost be used due to its high nutrient (nitrogen (N) and phosphorus (P)) concentrations. These nutrients may leach and contribute to elevated downstream loadings. Organic compost must be completely composted (i.e., no recognizable components) prior to use in LID facilities to prevent



denitrification, weed growth, bacterial contamination and leaching of nutrients from amended soils.

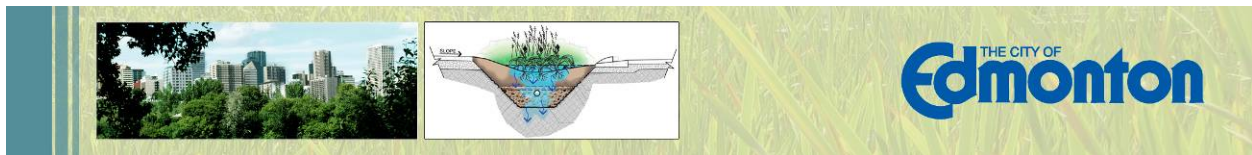
Amendment additives may be used to meet specific hydrologic or pollutant mitigation needs of the site. Gypsum compost may be added to amended topsoil so that the calcium ion will reduce levels of exchangeable sodium in soils impacted by de-icing salts and help to regenerate water absorption qualities (Grieve et al, 2007). In addition to its mitigative effect for de-icing products, gypsum compost adds sulfur and calcium (necessary for plant growth) to the soil without changing its pH.

Compost amendments can assist in increased aeration, percolation, water holding capacity, and plant nutrient availability. The amount of compost required to be mixed into topsoil depends on both the type of topsoil and the type of subsoil it will overlay. For example, a sand-compost mix should only be used on well drained sub-soils, as it will form an impermeable layer when used in combination with clay subsoil. For the same reason, clay-laden topsoil should not be mixed with, or placed over, sand.

Figure 6.1 is a general summary of the recommended compost to be added to topsoil for good long-term water holding, aeration, and percolation capabilities for a typical rain garden. The chart in **Figure 6.1** is a general guideline only, as each unique site must be thoroughly assessed for site specific characteristics that may have an impact on required soil amendments. The added compost must be balanced with the following factors: surface run-off conditions; sub-surface infiltration; planting regimen; storage requirements; and, cost effectiveness.

Amended topsoil characteristics are important factors in the success of vegetated LID facilities. A general list of desirable characteristics is provided in **Table 6.1**. Another important soil characteristic to be considered in topsoil amendment is the water holding capacity (**Figure 6.2**), which is affected by the soil texture and organic matter content. Soils that hold generous amounts of water are less subject to leaching losses of nutrients or soil applied pesticides.

On-site amendment of native topsoil is often the most cost effective and sustainable method of ensuring soil parameters meet the

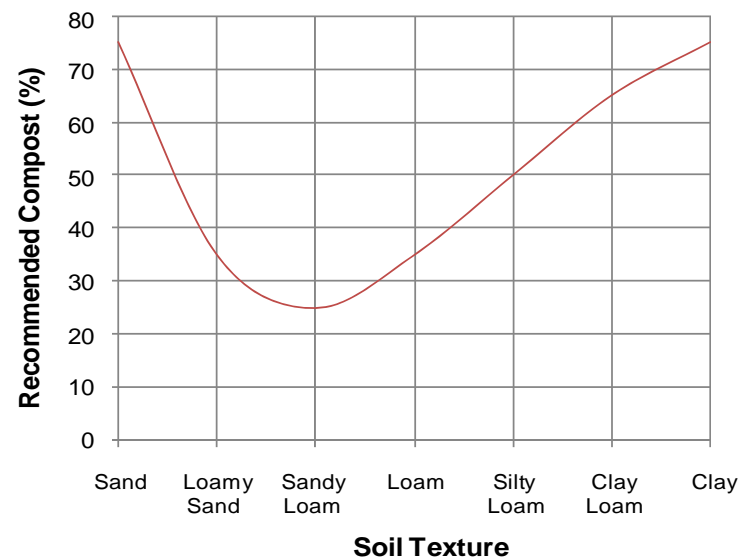


premixed topsoil or structural soils (**Table 6.1**; Appendix B) that meet the site requirements to support vegetation may be imported.

Table 6.1
Amended Topsoil Characteristics

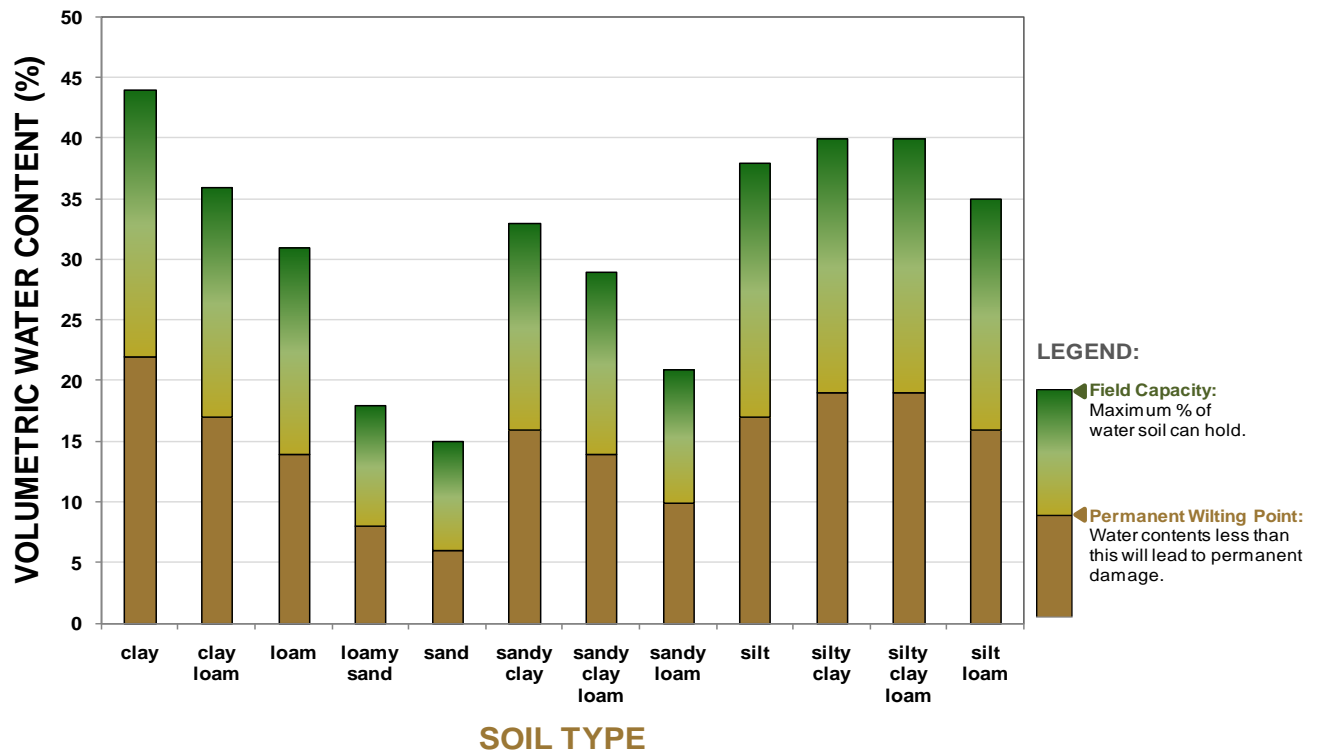
Parameter	Standard
Texture Classification	Loamy Sand
	Sandy Loam
Phosphorus	10-30 ppm
Cation Exchange Capacity (CEC)	10 meq/100g
Particle size	<50 mm
pH	5.5 to 7.5
Infiltration rate	≥25 mm/hr

(TRCA, 2009; Hunt et al, 2006; LIDC, 2003;)



(Lton, 1991)

Figure 6.1 Compost Amendment Ratios for Topsoil and Subsoil Types



(Spectrum Technologies Inc, 2010)

Figure 6.2 Water Holding Capacity by Soil Type

6.3 Cold Climate Considerations

There are several cold climate design challenges that are always a design concern for implementation and operation of LID facilities (MSSC, 2005, Roseen et al, 2009). Similar to conventional stormwater management facilities, these challenges do not preclude implementation of LID facilities, but are listed here (Table 6.2) to inform the designer of the considerations that must be specifically addressed in the design of any LID facilities operating in cold climates.

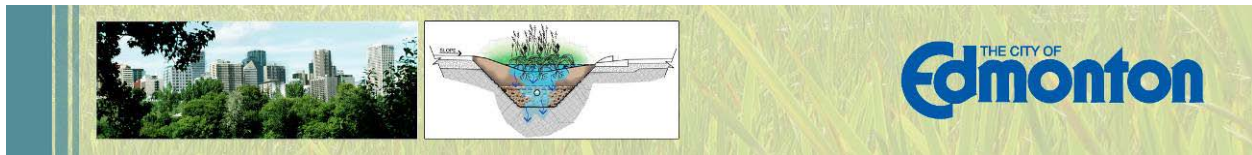


Table 6.2
Challenges to Design of LID-BMP Facilities in Cold Climates

Cold Climate Characteristics	BMP Design Challenge
Cold Temperature	<ul style="list-style-type: none"> ◆ pipe freezing ◆ reduced biological activity ◆ reduced settling velocities
Deep Frost Line	<ul style="list-style-type: none"> ◆ frost heaving ◆ reduced soil infiltration ◆ pipe freezing
Short Growing Season	<ul style="list-style-type: none"> ◆ short time period to establish vegetation ◆ different plant species appropriate to cold climates than moderate climates
Significant Snowfall	<ul style="list-style-type: none"> ◆ high runoff volumes during snowmelt and rain-on-snow ◆ high pollutant loads during spring melt ◆ other impacts of road salt / deicers ◆ snow management affecting BMP storage ◆ weight of snow piles causing soil compaction

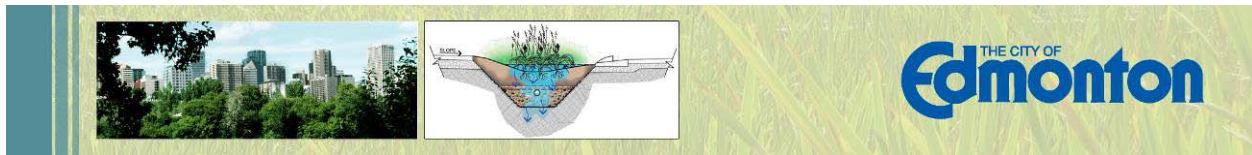
(Adapted from Caraco and Claytor, 1997)

6.3.1 Managing and Designing for Road Salt Applications

Road salt used for winter de-icing can alter physical properties of soil and have an impact on vegetation growth and permeability. Detrimental impacts at high concentrations include increased soil swelling and crusting, increased erosion and soil dispersion, decreased structural stability and increased electrical conductivity. Salts have also been shown to increase bio-availability of heavy metals by allowing them to become water soluble in soils (EC, 2001). Additionally, soil microbes, which are necessary for pollutant breakdown, soil structure and permeability, can become inhibited with elevated salt concentrations (EC, 2001).

Vegetation injury is the most visible consequence of road salt application and spray. All species of vegetation are not equal when it comes to tolerance for road salt. Appendix A identifies salt tolerant species.

Salt concentrations in soils are highest in spring and decrease during warm weather rain events, as rainwater and road spray facilitate



leaching of salts from soils. Based on impacts of road salt on roadside soil and vegetation, and on documented crop injury due to saline waters (Fipps, 2003; Bauder et al, 2007), the recommended maximum winter loading of chloride to a roadside LID facility planted with salt tolerant grasses is 1000 mg/L (Texas Agricultural Extension Service, 1998).

LID facilities can be designed to accommodate road salt loadings. Soil amendments can be used to buffer some salt loading. Precipitation and irrigation will leach salt from soil. The amount of water required to reduce a damaging concentration of salt to an acceptable level is dependent on the depth and type of soil being treated (Boumans et al, 1977). Appendix D provides examples of planters and swales sized based on Edmonton's current de-icing operations (EC, 2010b).

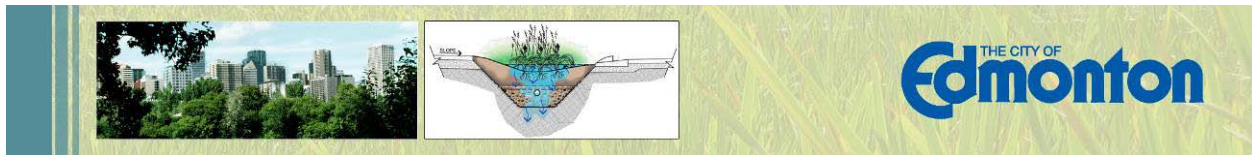
6.3.2 Managing and Designing for Sand and Gravel Applications

LID facilities with filtration or infiltration components are particularly susceptible to clogging by anti-skid materials such as sand. Filtration based LID facilities are well suited to treating melt water and, depending on the design, providing storage for snow, ice and melt water during the spring season. To capitalize on the treatment properties of such systems and prevent clogging by anti-skid material, a settling zone for melt water, such as a vegetated filter strip, settling basin or forebay, is required prior to its entry into the facility. The designer may also choose to locate LID facilities away from areas where large quantities of these materials are routinely applied and where the snow being stored is relatively free of anti-skid materials.

6.3.3 Recommendations for Edmonton

6.3.3.1 Design Adaptations

Adaptations to frequently used LID-BMPs make application in cold climates feasible and introduce excellent opportunities to treat melt water. Although biological pollutant removal may slow down in cold weather, standing vegetation still provides some filtering capabilities and soil microbes are alive and active (Roseen, 2009). By carefully evaluating the location and type of LID-BMP facility when designing a site, cold climate LID-BMP facilities can be a very effective and

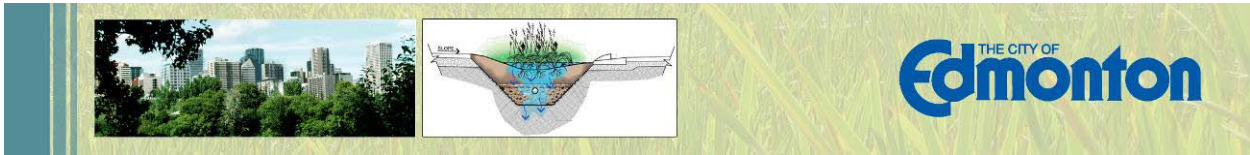


***Treatment Train** – LID-BMPs placed in series to improve water quality treatment so that each successive cell receives cleaner water than the pervious one.*

valuable part of a treatment train even during spring melt (Gunderson, 2008).

Adaptations for cold climates including, but not limited to, areas where considerable anti-skid and de-icing materials are necessary, may include:

- **careful site selection** for infiltration and filtration facilities to avoid implementation in zones where high concentrations of pollutants and sediments are unavoidable. Where space is available implement pre-treatment (forebay) or straining features (vegetated filter strips) for runoff prior to its entry to the filtration or infiltration facility;
- **careful plant selection and placement** to use more salt-tolerant plants to buffer less salt-tolerant plants from the impacts of road salt and to minimize damage to LID facilities treating stormwater runoff from streets with heavy salt application;
- **strategic application of sand and salt** to reduce impacts (clogging and elevated salinity) in snow storage zones and LID facilities receiving roadway runoff;
- **placement of filter strips along roadways** to promote settling of sand and gravel prior to runoff entering an infiltration or filtration facility and to allow removal of anti-skid material from the filter strip during spring street sweeping. Filter strip widths vary depending on the type of roadway and the quantity of anti-skid material applied and may range from 5 m to 35 m depending on location and application rate;
- **snow storage zones** for contaminated or gravel / sand laden snow may be located on pervious surfaces or impervious surfaces where melt water is directed to treatment facilities and contaminants are diluted prior to release;
- **timely maintenance activities** to remove sand and gravel from streets and boulevards as soon as the spring melt has occurred;
- **direction of sand / salt laden flows** away from sensitive facilities during spring runoff. This may be through a vegetated swale or using traditional minor and major storm sewer systems;
- **sizing of facilities** to accommodate snow melt volumes where public safety may be compromised in the event minor flooding occurs (such as near sidewalks and crosswalks);
- **enlargement of curb cuts or employment of alternate curb**



types to allow runoff to enter facilities during times when ice and snow may partially block inlets; and

- **location of facilities** away from crosswalks and sidewalks to prevent ice build up on pedestrian routes during the spring melt period.

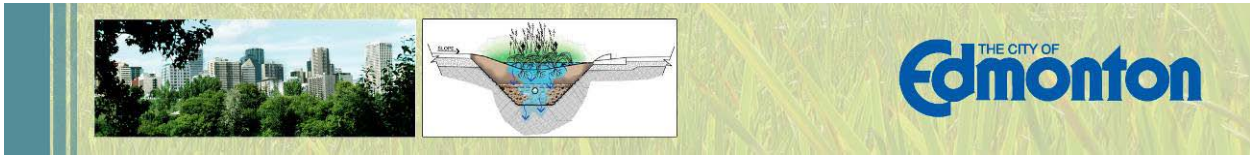
In residential and open space areas where high concentrations of chloride or soluble toxic pollutants are not present, infiltration (or filtration where sub-soils are tight) of melt water is an effective way to remove many typical contaminants. Pre-treatment for particulates, including sand and gravel, are required to prevent clogging of facilities and may consist of filter strips, vegetated swales or settling basins.

6.3.3.2 Operation and Maintenance

Preventing contamination of receiving waters due to winter de-icing activities requires proactive operation and maintenance. The initial focus must be on keeping contaminants out of accumulated / dumped snow. Management approaches that aid in accomplishing these goals may include:

- wise and strategic use of de-icing and anti-skid materials;
- improved application technology on sanding trucks such as road weather information systems, direct roadway application or brine wetting;
- avoidance of salt additives (e.g., cyanide) which can be toxic at low doses;
- storage and mixing of chemicals in covered areas and mixing only amounts required;
- snow removal and / or melt water routing to appropriate treatment facilities;
- a dilution system (may include irrigation) to reduce direct impact of high chloride concentrations;
- rapid and regular street sweeping as soon as snow is gone from roadways;
- litter control; and
- erosion control.

Snow storage areas, for relatively clean snow, should be located on permeable surfaces to facilitate some level of filtering prior to melt



water entering receiving waters. If soil is highly impervious, the groundwater table is high or snow contains high concentrations of anti-skid or de-icing materials, storing the snow on an asphalt pad and directing melt water to a treatment facility is recommended. LID filtration systems may be used to treat snow storage melt water provided particulates are settled out prior to discharge into the filter.

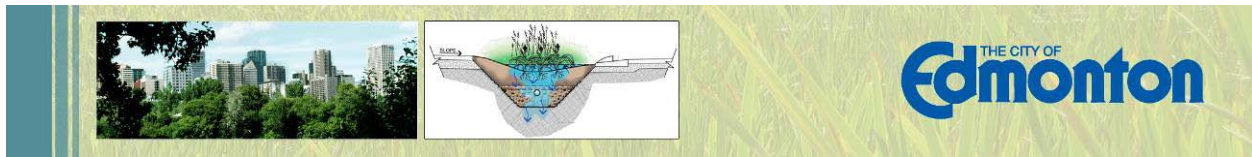
6.4 LID Facility Design Process

LID facility design starts after the LID site design (described in the previous chapter). Since each LID facility is site-specific, there is no universal step-by-step design procedure applicable for all LID facility designs. In general, the facility design usually starts with selection of LID facility types according to site suitability. The following factors should be considered when selecting LID features (O'Brien & Company, 2009).

- **Available space.** Ensure there is sufficient functional open space to install LID facilities. Existing hydrological functional spaces should be preserved.
- **Soil performance.** Infiltration and water bearing capacity of soils and sub-soils must be investigated and assessed. For tight soils that have limited infiltration capability, sub-drains should be installed.
- **Slopes.** LID design must properly account for slope to ensure effective detention and infiltration performance. Small scale LID facilities perform well on gentle to moderate slopes.
- **Depth to groundwater table.** For bioretention, bioswales, and naturalized drainage ways, the facility base should be at minimum 0.6 m to 1 m above the seasonal high water table.
- **Proximity to foundations and underground utilities.** For bioretention and bioswales, leave enough space between the LID facility and building foundations or other underground utilities to prevent saturation and uncontrolled moisture intrusion into these structures.

Once facilities are selected, the next step is sizing of the selected facilities. Sizing of the LID facility is primarily influenced by runoff reduction and quality improvement requirements for the defined drainage area.

The LID facility design should also consider constructability and requirements for operation and maintenance.



6.4.1 Facility Selection

6.4.1.1 Site Characteristics

Selecting an appropriate LID facility to address requirements of the site is critical. A matrix (**Table 6.3**) has been developed to define capabilities of each of the seven LID facilities identified in this Design Guide in meeting the three primary objectives of:

- stormwater volume control;
- stormwater peak flow control; and
- stormwater water quality.

Also indicated in **Table 6.3** are types of urban land uses where application of these LID facilities is most suitable and their relative land area requirements.

All selection criteria are based on the underlying assumptions that soils in Edmonton are tight and expansive and that winter snow accumulates to a final frost depth and spring melt. In areas where soils are more permeable, opportunities may exist to implement facilities that rely on infiltration in addition to evapo-transpiration, detention and filtration to manage runoff. Additionally, the sand / salt winter maintenance regime is incorporated and cold climate suitability of each facility is evaluated based on impacts of these activities on the LID facilities.

Table 6.4 summarizes site constraints associated with each type of LID facility discussed in this document. The combination of information from **Tables 6.3 and 6.4** will facilitate appropriate LID selection based on site characteristics.

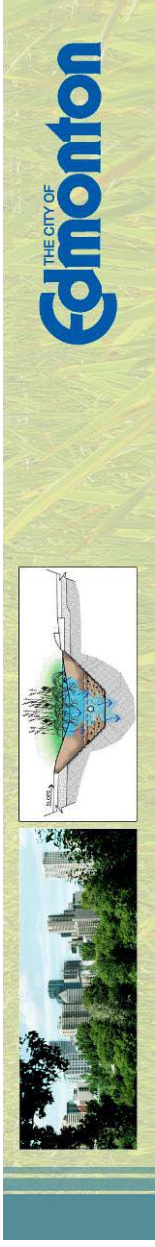


Table 6.3
LID Facility Selection Matrix

Facility Type	Management Objective			Land Use							Cold Climate	Land Area Req.
	Vol.	Peak Dis.	Water Quality	School	Comm.	High Density Urban	Indust.	Single Family Res.	Multi-Family Res.	Parks / Open Space	Roads	
Bioretention / Rain Garden	+	+	+	+	+	■	□	+	+	+	+	■
Vegetated Swale	■	■	+	+	+	□	+	+	+	+	+	■
Green Roof	■	+	+	+	+	+	+	□	+			□
Porous Pavers	+	+	■	+	+	+	■	+	+	+	□	□
Infiltration Box Planters	■	■	+	■	+	+	□	+	+	+	□	□
Naturalized Drainage Ways	□	■	■	■	■	□	■	■	■	+	+	■
Rainwater Harvesting / Re-use	■	□	□	+	■	+	■	+	+	■	□	□

(Adapted from: AMEC, 2009; Alaska Department of Environmental Conservation, 2009; SEMCOG, 2008)

Symbol	Legend	Effectiveness in Meeting Objective	Land Use / Cold Climate Suitability	Land Area
+	High	one of the functions of the facility is to meet the management objective	well suited for land use application / cold climates	high relative dedicated land area required.
■	Medium	facility can partially meet management objective but should be combined with other facilities	average suitability for land use application / cold climates	moderate relative dedicated land area required.
□	Low	facility contribution to management objective is by product of other functions and additional controls should be used in the treatment train if objective is important	operational adaptations required for use in cold climates (see Section 6.0)	low relative dedicated land area required.

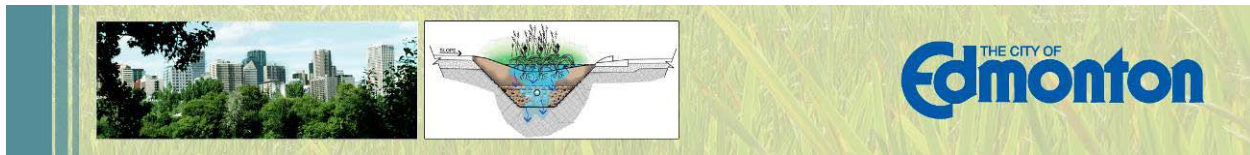


Table 6.4
LID Facility Site Constraint Matrix

Facility Type	Depth to Water Table or Bedrock ¹ (m)	Typical Drainage Area Treated (m ²)	Native Soil Infiltration Rate (mm/hr)	Head ² (m)	Space ³ (%)	Slope ⁴ (%)	Setbacks ⁵
Bioretention / Rain Garden	1	5 to 1,000	Under-drain required if <13 mm/hr	1 to 2	5 to 10	0 to 2	B,U,W
Vegetated Swale	1	≥50	Under-drain required in dry swales if <13 mm/hr	1 to 3	5 to 15	0.5 to 3	B,U,T,W
Green Roof	N/A	≥20	N/A	0	0	0	None
Porous Pavers	1	≥5	Under-drain required if <13 mm/hr	0.5 to 1	0	1 to 5	B, U, W
Infiltration Box Planters	N/A	5 to 20	N/A	1 to 2	2 to 5	0 to 2	B
Naturalized Drainage Ways	N/A ⁶	≥50	N/A	>1	15 to 30	>2%	B,U,T,W
Rainwater Harvesting / Re-use	1	≥20	N/A	1 to 2	0 to 1	N/A	U, T

N/A = Not Applicable

¹ Minimum depth between base of facility and elevation of seasonally high water table, or bedrock

² Vertical distance between the inlet and outlet of the LID facility

³ Percent of open pervious land on the site required for LID facility

⁴ Slope at the location of the LID facility, effective slope of facility

⁵ Setback Codes: B = building foundation; U = underground utilities; T = trees; W = drinking water wellhead protection area

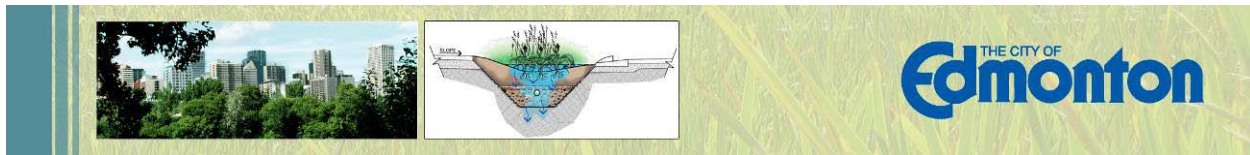
⁶ Naturalized drainage ways that incorporate wetland components must be kept moist and may be located within the groundwater table

(adapted from TRCA, 2009)

6.4.1.2 Water Quality Treatment Capabilities

The urban environment has many non-point sources of pollutants that are becoming more of a problem in receiving streams due to increased runoff from developed areas. The ideal method of reducing pollutants reaching these streams is by implementing source controls that prevent pollutants from entering stormwater.

Table 6.5 illustrates the sources of pollution in urban and industrial areas.



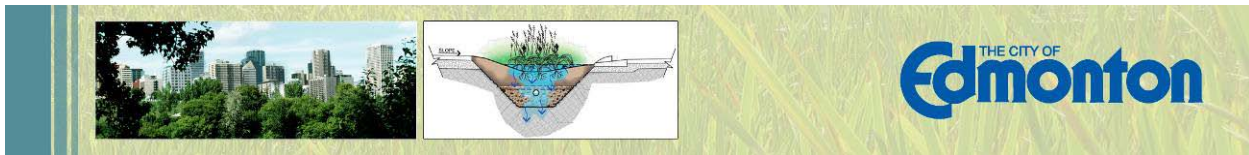
As it is often not possible for source controls to completely remove non-point source pollutants, strategically placed and specifically designed LID facilities may provide some removal capacity of pollutants commonly occurring in the urban environment (**Table 5.1**). Stormwater pollutant removal capabilities of LID occur through five primary removal mechanisms including:

- sedimentation through reduced runoff velocities and extended detention;
- filtering through soil and sand;
- straining and settling of particulates passing through standing vegetation;
- infiltration reducing pollutant loadings in runoff by allowing percolation into underlying soils; and
- biological uptake of nutrients and contaminants by plants and soil microbes.

Table 5.1 shows pollutant removal efficiencies for six of the seven LID facilities discussed in this Design Guide based on their ability to provide water quality enhancement in monitored LID facilities in Canada and the USA. The number of monitored LID facilities in Canada is limited and monitoring of LID pilot projects in Edmonton is recommended to determine more specific pollutant removal capabilities for this area.

Water quality treatment in rainwater harvesting systems (the seventh LID practice) is minimal without reuse. However, reuse for irrigation of other LID facilities will provide treatment at the levels indicated for those facilities (**Table 5.1**). Controlled irrigation through soil moisture monitoring can be designed to prevent runoff from irrigated areas, thereby removing 100% of pollutants occurring in the rainwater harvested for reuse.

Removal efficiencies can be misleading as high influent pollutant loads will tend to have higher removal efficiencies than low influent loads even though they have higher effluent loads than those with low influent loads (England, 2009). The best solution for reducing pollutants in stormwater runoff is to reduce pollutant loads at their source. This can be done through operation and management practices that prevent high pollutant loads from reaching the minor system or LID facilities. Selecting appropriate LID facilities to



manage pollutants coming from a particular site is vital to the success of both the LID facilities and the source control objectives of the site. **Table 5.1** is provided to facilitate this process.

Table 6.5
Non-Point Sources of Pollution in Developed Areas

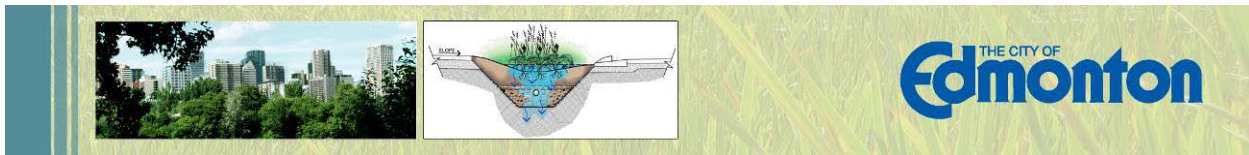
Constituents	Possible Sources	Potential Effects
Sediments – total suspended solids (TSS), turbidity, dissolved solids	Construction sites, urban / agricultural runoff, landfills, csos, septic fields, atmospheric deposition	Habitat changes, stream turbidity, recreation and aesthetic loss, contaminant transport, bank erosion
Nutrients – nitrogen and phosphorus (N and P)	Lawn / agricultural runoff, landfills, septic fields, atmospheric deposition, erosion	Algae blooms, ammonia toxicity, nitrate toxicity
Pathogens – total and faecal coliforms, E.Coli, viruses	Urban / agricultural runoff, septic systems, illicit sanitary connections, csos, domestic / wild animals	Ear / intestinal infections, recreation / aesthetic loss
Toxic pollutants – heavy metals, toxic organics	Urban / agricultural runoff, pesticides / herbicides, underground storage tanks, hazardous waste sites, landfills, illegal disposals, industrial discharges	Toxicity to humans and aquatic life, bioaccumulation in the food chain
Salts - NaCl, MgCl₂	Urban runoff, snowmelt	Contamination of drinking water, harmful to salt intolerant plants

(USEPA, 1993)

6.5 Hydrological Analysis

Stormwater management systems that utilize LID technologies may have a centralized stormwater management facility to assist in peak release rate control. Additional source control is provided by individual LID facilities dispersed throughout the development area.

LID deals with smaller and more frequent rainfall events. These events are usually less than 2 year return period but generate most of the annual runoff from an urban watershed. Small rainfall events tend to dominate hydrologic design of systems aimed at improving water quality.



Continuous Simulation – modelling the performance of a stormwater management facility using precipitation records over a number of years to account for: antecedent moisture conditions; seasonal variations; and inter-event processes.

Antecedent Moisture – soil moisture level prior to a rainfall event.

Water Quality Capture Volume – is the storage needed to capture and treat the runoff from 90% of Edmonton's average annual rainfall.

First Flush – during a rain event, the initial surface runoff from impervious surfaces, which contains elevated pollutant loads accumulated during the preceding dry period.

Design Event – Hypothetical rainfall event used for design. The magnitude and duration of the design event is usually based on observed historical data.

For LID design, hydrological analysis should pay a greater attention to **abstractions potentials**. Abstraction Potential is defined as the ability of the landscape to retain runoff in surface storage on vegetation (leaves) and minor depressions (puddles) and through infiltration. Also, antecedent soil moisture conditions prior to an event are of greater importance when considering small storms. Whenever possible, continuous simulations are recommended to assess performance of systems designed to accommodate small storms. The use of computer models is at the discretion of designers. Appendix E provides a case study using SWMM5 LID module.

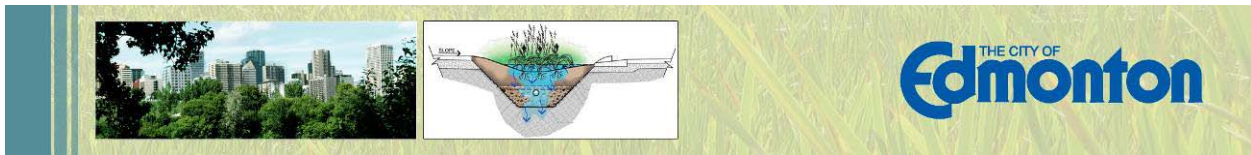
The *water quality capture volume* represented by rainfall depth provides a practical means for establishing an appropriate hydrologic design basis for LID systems. Analysis of the long-term rainfall record provides guidance on selecting an appropriate water quality capture volume. For the Edmonton region, most rainfall events are less than about 26 mm in depth and have durations of 5 hours or less, as indicated in **Figure 3.3**.

The initial runoff from larger storms is significant in that it picks up and carries pollutants that are washed off impervious surfaces (e.g., pavements). This initial volume is commonly referred to as the *first flush*. In practice, many jurisdictions specify a depth of rainfall (typically 2.5 cm or 1 inch) to capture the first flush component (USEPA, 2004). The amount of pollutants carried by the first flush depends on a variety of factors including:

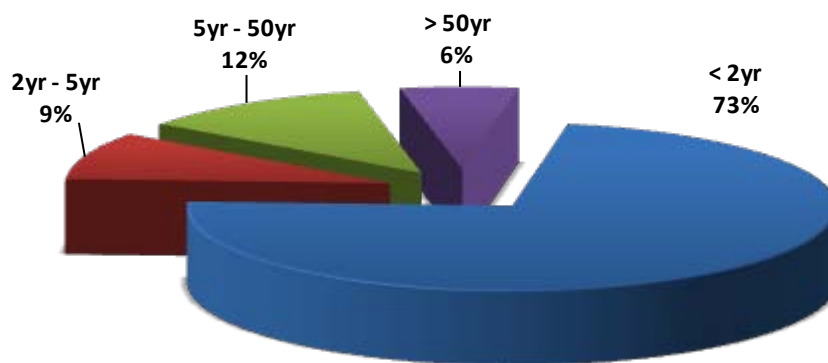
- the pollutants available for wash off;
- the time between storm events;
- the storm characteristics; and
- characteristics of the subwatershed.

For LID hydrological design purpose, the water quality capture volume of 26 mm (per day) should be used to meet the first flush capture requirement. This provides a familiar design event size and distribution that is consistent with existing drainage design standards. (1:2 year event).

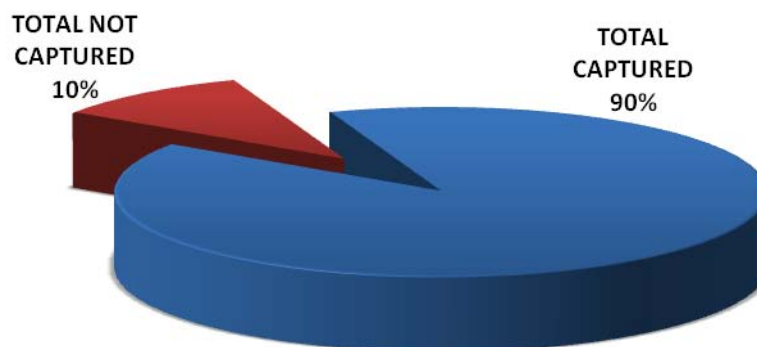
Figure 6.3 provides a summary of the total percentage of runoff volumes generated by rainfall events of various recurrence intervals (based on the observed 585 precipitation events at the City Centre



Airport Gauge). 73% of the total rainfall depth is generated by events smaller than the 2-yr rainfall event (**Figure 6.3a**). LID systems designed with 26 mm rainfall capture will capture 90% of the total rainfall depth (**Figure 6.3b**).

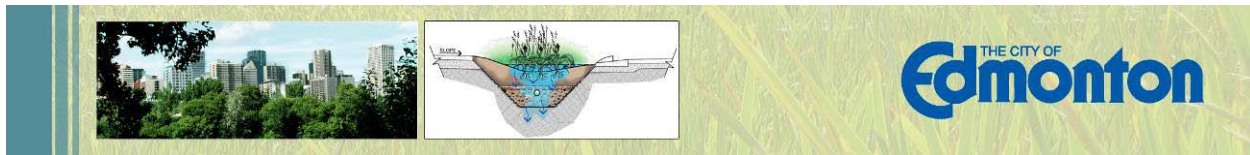


(a) Distribution of Total Rainfall Depth by Individual Events



(b) Rainfall Capture Distribution for 26 mm Capture Volume

Figure 6.3 Distribution of Total Rainfall at Edmonton City Centre Gauge



6.6 Site Monitoring

Many options exist for sensors suitable for monitoring performance of LID-BMP facilities. Development of a monitoring program should consider precipitation, water quality and flow sensors. Consultation with equipment suppliers during development of the monitoring program will ensure unique site characteristics are accounted for in the design of the monitoring network.

6.6.1 Precipitation

Site precipitation may be estimated from regional weather stations, or a site-specific meteorological station may be deployed to capture localized weather variations. The meteorological station should be equipped with a rain gauge as a minimum. If additional knowledge regarding evaporation on the site is desired, temperature, relative humidity and wind gauges are recommended.

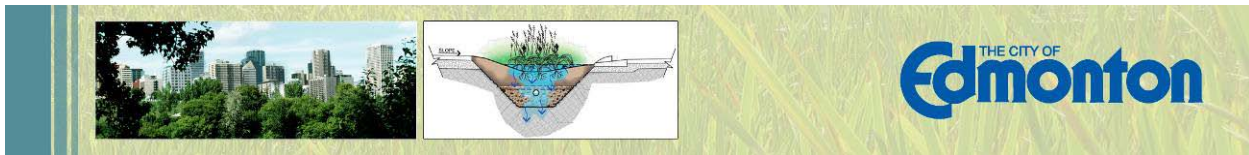
6.6.2 Flows

Measurement of inflows to LID-BMP facilities may be difficult since flow inputs may be non-point source and numerous. However, inflow volumes and flows may be estimated based on precipitation at the site and the catchment area contributing to each individual facility.

Outflows can be measured by deploying a permanent or semi-permanent flow sensor (Doppler or ultrasonic are recommended) in the outlet pipe from a facility, treatment train or the site. Outflow measurements can be used to provide a comparison with modelled estimates developed during the planning stage. If considerable topsoil amendments have been applied throughout the site and disconnection of impervious areas is a method used to reduce runoff, overestimation of runoff into a facility may occur when using standard modelling methods. Since all LID-BMP facilities within the treatment train are designed to reduce runoff, the resulting outflow reductions (compared with estimated values) can be attributed to the LID-BMP site plan and facilities.

6.6.3 Water Quality

Monitoring of incoming and outgoing water quality in non-research based LID-BMP facilities can be difficult due to the fact that flow



Non-Point Source – Any source of water that is diffuse. Examples of stormwater non-point sources are land runoff, precipitation and seepage.

Water Quality Sonde – device in a logging assembly that senses and transmits water quality data.

Turbidity – cloudiness or opacity in the appearance of water caused by suspended solids or particles.

inputs to the facilities are often non-point source and may be numerous. This characteristic makes comparison of pollutant levels in inflows and outflows difficult but, with some planning upfront, it is not necessarily impossible.

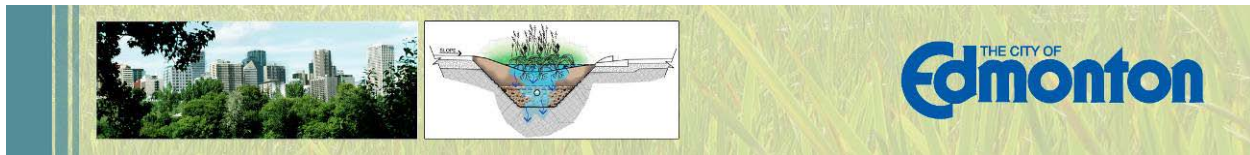
Total Suspended Solids (TSS) is a frequently regulated pollutant, and reduction of TSS in stormwater is commonly identified as an operational objective for stormwater management facilities. In addition to TSS, nutrients are becoming more of a problem in many receiving streams as algae and aquatic plant growth impacts oxygen levels and fish health during summer months.

Water quality sondes commonly measure turbidity (a substitute for TSS), nutrients and water temperature with the option to add other parameters. Sondes are easily deployed for either spot samples or long-term monitoring in stormwater catchbasins and outlet control vaults. Measurement of flows and water quality at the same locations may be desirable, and data loggers can be obtained to record all parameters for download at the same time. Depending on the location of deployment, recorded data may be uploaded to the internet via satellite or cellular connection for ease of download.

6.6.4 Optional Parameters

Other sensors or measurements that may provide additional information of interest include:

- soil moisture sensors;
- water depth sensors within the reservoir layers of infiltration facilities;
- a pump recorder for irrigation systems to measure pump rates and time of operation;
- a water quality autosampler triggered by storm events;
- a heated rain gauge to monitor snow water equivalents; and
- infiltration measurements conducted manually as spot checks to determine long-term soil capacity.



7.0 BIORETENTION / RAIN GARDENS

7.1 Description

Bioretention is a stormwater management practice that uses plants and soils to filter, retain, infiltrate, and distribute stormwater runoff. The term “bioretention area” is generally used interchangeably with the term “rain garden.” In general, a bioretention system consists of pretreatment, flow entrance, ponding area, plant materials, a mulch cover, a filter medium (a mixture of sand, fines and organic materials), and an overflow outlet. The system may also include an under drain if the in-situ soils have a low infiltration rate.

7.2 Application

Bioretention facilities should be located close to where runoff is generated. Typical locations are near parking lots, in traffic islands and near building roof leaders (**Figure 7.1**). Bioretention areas can be incorporated into either new or retrofit sites based on the site-grading plan. Bioretention areas can be used for snow storage during winter at locations near parking lots and roadways, provided that salt-tolerant plants and soils are used. Depending on the runoff volume to be controlled, site locations and soil conditions, enhanced infiltration may be required. **Figures 7.2 and 7.3** provide cross sectional details for a standard bioretention area without enhanced infiltration and a bioretention area combined with a filtering infiltration gallery for enhanced infiltration.

Bioretention is not recommended in areas where slopes adjacent to the facility exceed 20% due to the risk of erosion (Winogradoff, 2002). As with all LID facilities, bioretention facilities should not be planned in locations where removal of existing mature trees is required.

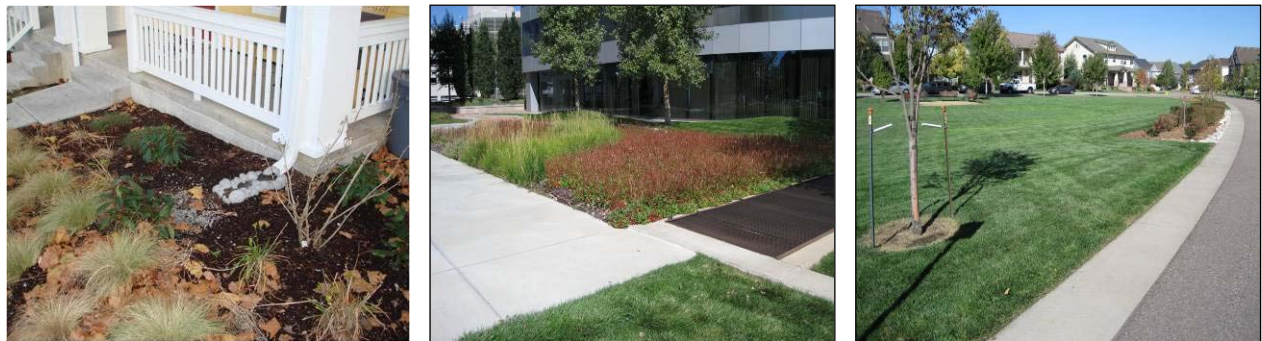
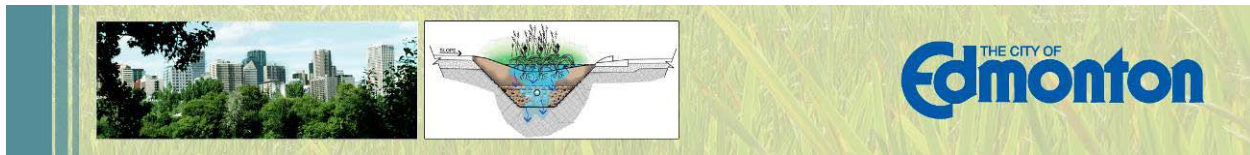


Figure 7.1 Bioretention Installations in Residential, Commercial and Park Settings

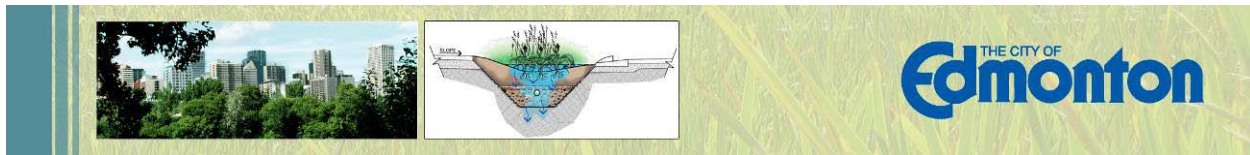
7.3 Design Considerations

Several key factors must be understood prior to facility design to ensure success, including:

- sand and salt application methods and rates, and application variability throughout the site;
- snow plowing methods and snow dump and storage locations;
- sediment and salt concentrations resulting from road de-icing and snow storage; and
- combined maximum volume of snow, ice and melt water during spring thaw.

To ensure long-term viability of a bioretention area, key components of a bioretention facility (i.e., the inlet, outlet, ponding depth, captured volume, media layers, under drains, buffers for ground water and structure), must meet the requirements listed in **Table 7.1**. The details of all bioretention areas planned for the site must be included on design drawings as indicated in **Table 7.2**.

Bioretention areas that allow deep subsoil infiltration require sub-soils with hydraulic conductivity >13 mm/hr (USEPA, 1999a). In areas with lower hydraulic conductivities, the design of facilities to take advantage of deep infiltration to attenuate stormwater volumes is more challenging. Where sub-surface stability is not a concern and the ground water table is at least 1.8 metres below the base of the facility (USEPA, 1999a), significant deep infiltration can occur in sub-soils with limited hydraulic conductivity if sufficient time is allowed. If additional time is required, it can be provided by



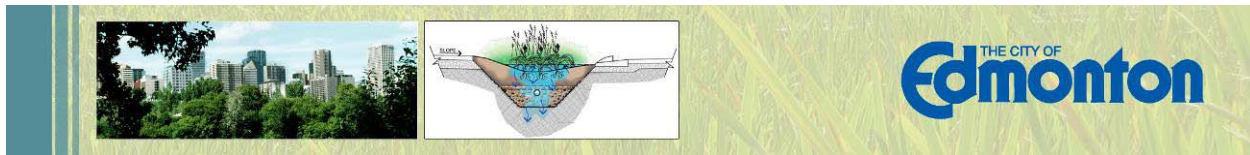
increasing storage capacity in the facility to allow infiltration to occur between major storms while still managing the design storm. Other considerations are:

- where necessary, to prevent icing of sidewalks and streets, size surface ponding volumes to accommodate the spring thaw volume of snow, ice and melt water without considerable infiltration by topsoils;
- provide filter strips (ranging from 3 to 5 m on collectors to 35 m wide at intersections along arterial roadways) between urban roads and the bioretention facility to allow sediments and particulate salts to settle prior to contact with the topsoils (EC, 2001);
- plant salt tolerant plants as a buffer between the roadway and the less tolerant species (Appendix A);
- plant species that grow later in the spring to avoid salt-spray damage to leaves and flowers as much as possible and to reduce the potential of repeated injury;
- amend topsoil to mitigate the impact of de-icing compounds; and
- locate snow storage areas away from bioretention facilities unless vegetation and soil structure is specifically designed to accommodate snow storage (MSSC, 2005).

De-icing salt loadings to bioretention areas should not exceed 1000 mg/L during winter months (Texas Agricultural Extension Service, 1998) to avoid salt induced injury to vegetation and soils. Bioretention areas that will receive higher loadings must be designed with salt tolerant species, highly permeable soils and under-drains. Irrigation may also be considered as a mitigation method.

Other design considerations besides those listed in **Table 7.1** include, but are not limited to:

- locating facilities appropriately to minimize damage due to pollutants and de-icing and anti-skid materials, as well as snow plowing operations;
- designing vertical profile of vegetation located along roadways or near intersections to prevent impedance of driver visibility;
- sizing facilities receiving road runoff containing salts to prevent salt induced injury to plants and soils per Appendix D;
- designing soil type and structure and selecting vegetation to



account for weight, added pollutants and melt volumes in facilities built with the intent to provide snow storage;

- sizing curb cut inlets to prevent blockage by ice and snow during spring runoff; and
- designing soil amendments in roadside facilities to buffer high salt loadings.

7.4 Operation and Maintenance

Operation requirements include street sweeping, restricted or no pesticide or herbicide use and regular soil testing. Detailed operation, maintenance and replacement activities for bioretention facilities are contained in **Table 7.3**. The recommended timeline for these activities may vary depending on location and contributing area characteristics. Facility inspections should be conducted quarterly during establishment (first 2 years) and semi annually thereafter. Inspecting after a major storm event may be necessary to facilitate early detection of erosion or debris blockages occurring during elevated or sustained flows. Highly contaminated sites may require more frequent upkeep and replacement activities while sites which remain relatively undisturbed with little potential for contamination or sedimentation may require very little attention. Facility designers must provide site specific schedules for operation, maintenance and replacement to ensure long term functionality of the LID BMP facility.

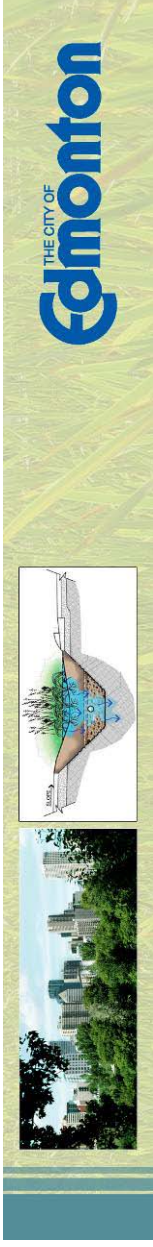


Table 7.1
Bioretention Parameters and Guidelines

Reported Parameters	Description
Sub-Soil Infiltration Rate	≥13 mm/hr, under-drain is not required; under-drain required in tighter soils (<13 mm/hr); for design and modeling, use 50% of specified or measured rate
Inlet design	0.5 m to 3 m grass filter buffer for non-point source inlet; erosion control at point source inlet; filter strips to buffer salt impacts are required as follows: 3-5 m width along collectors (may use sidewalk) and 5-35 m width along arterials
Design Discharge	Max overflow or under-drain flow rate in design events (2-year, 5-year, 10-year, 25-year and 100-year)
Surface Area	3%-30% of contributing impervious area, several small facilities provide better treatment than one large facility; facilities to be sized by designer based on snowmelt volumes and salt loadings as required
Contributing Impervious Area	<4 ha; pretreatment (grass filter with level spreader, etc) to facility required if imperviousness <75%
Facility Flow Velocity	<0.3 m/s in planted areas and <0.9 m/s in mulched zones, to prevent erosion
Outlet Release Rate	From under-drain or catchbasin lead; less than or equal to on-site release rates defined in Master Stormwater Drainage Plan
Ponding Depth	< 0.3 m during a 2 year design event; max. 0.35 m depth per City of Edmonton standards
WSE1 in Design Storms	Show that HWL during 5-year, 10-year and 100-year design events does not compromise adjacent structures
Captured Volume	Volume of water retained through ponding and surface infiltration during the 2 year design event; additional volume captured during larger events if applicable
Emptying Time	Duration of ponded water following a 2-year design event is <48 hrs
Media Layers	Mulch: 70-80 mm depth
	Growing media: (amended topsoil with infiltration rate 15-50 mm/hr) 500-1000 mm depth
	Filter layer: (16-25 mm washed rock <0.1% silt) 100 mm depth
Surface Geometry	Drainage / infiltration: (>40 mm washed rock <0.1% silt) 300-1000 mm depth
	Flat bottom, recommended length / width = 2:1
	4:1 (H:V) preferred (max 2:1)
Infiltration Trench (optional)	0.5 m to 1 m depth (dependent on native soils infiltration rate); 1 m to 6 m width, through length of facility; bottom slope 0%
Groundwater Buffer	Groundwater must be >1.8 m below final surface grade; facility base must be 0.6 m to 1 m above groundwater level
Structural Buffer	Facility located 3 m (significant clay content) to 5 m (heavy clay soils) from building foundations
Vegetation	Species selected for contaminant removal, aesthetics and inundation / drought resistance (see Appendix A)

(USEPA, 1999a, Stephens et al, 2002; GVRD, 2005; Caraco et al, 1997; COP, 2004b; MSSC, 2005)

¹ WSE is Water Surface Elevation

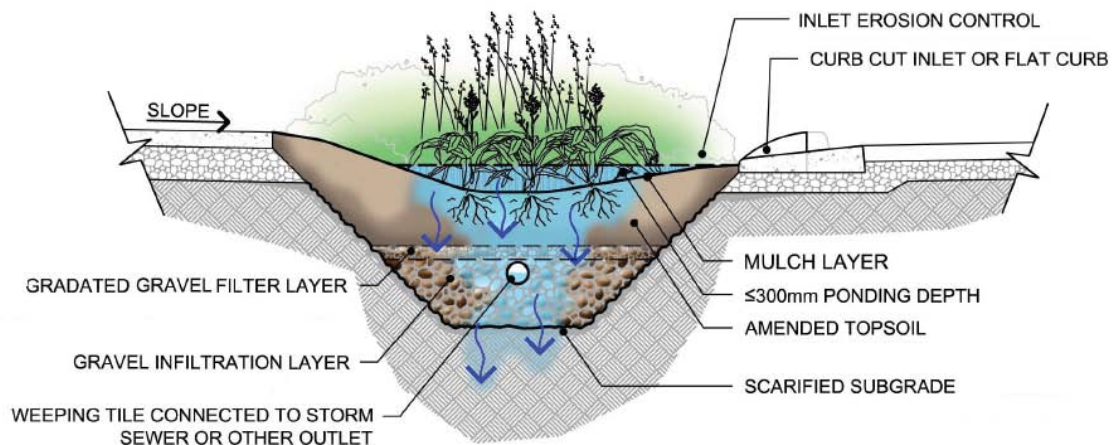


Figure 7.2 Cross Section of a Basic Bioretention Area

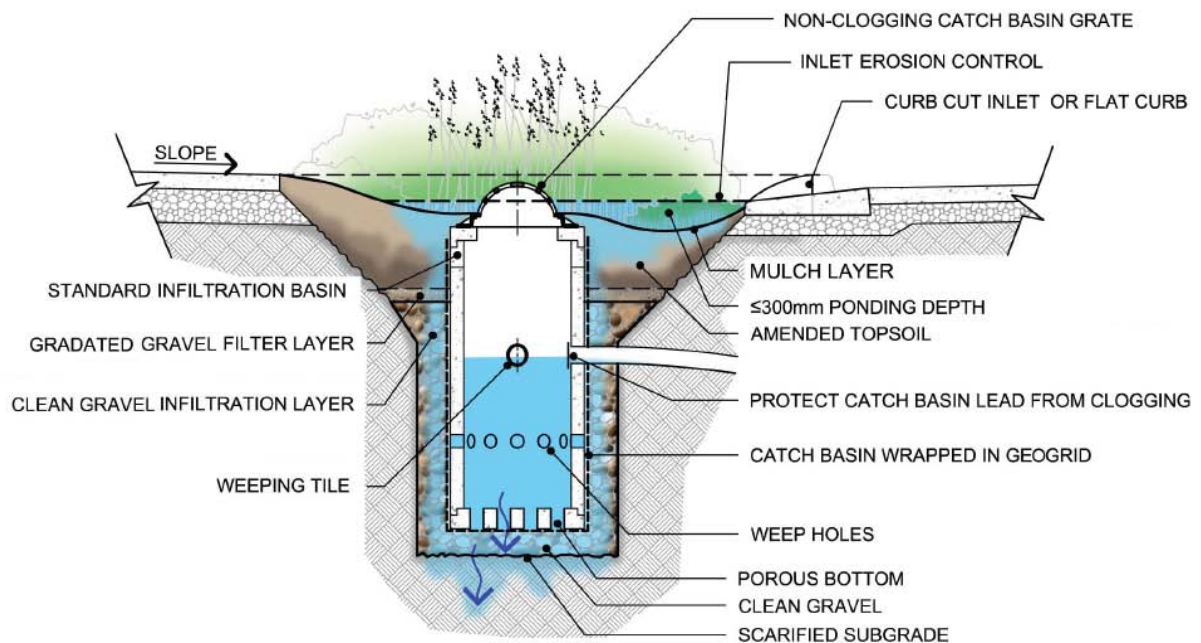


Figure 7.3 Cross Section of a Deep Infiltration Bioretention Area

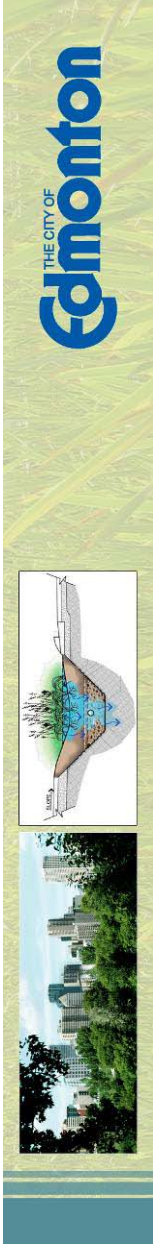


Table 7.2
Bioretention Drawing Details

Parameter	Plan	Detail	Profile	Description
Location	x			Areal extent shown on plan view (bump-outs, municipal reserves, private lots, parks)
Surface area	x			Outlined on plan view drawings and stated in report
Inlet	x	x		Shown on plan view and typical detail provided (curb cut, flow spreader, ribbon curb)
Materials		x	x	Material specs (soil, drainage layer), depth, hydraulic conductivity, porosity
Vegetation	x	x		Planting plan and vegetation details (species, mature density, succession plan)
Outlet		x	x	Under-drain spec & slope, spill elevation, catchbasin type and grate, weir type and location, inlet control device details
Catchment	x			Delineated catchment area directed to bioretention facility
Flow Arrows	x			From contributing area and overflow route
Water Depth		x		Ponding depth and water surface elevation during design storm and maximum prior to spill
Inundation	x			Extent of inundation during design storms
Erosion control	x	x		Located at inlet, outlet if overland spill

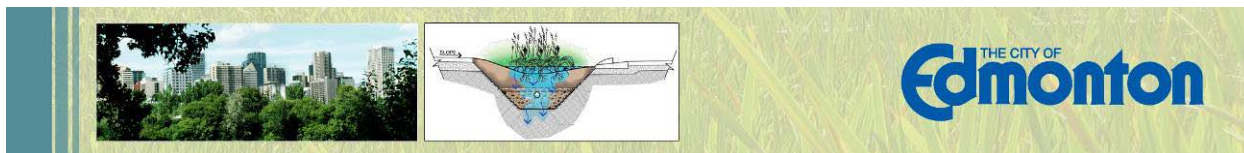
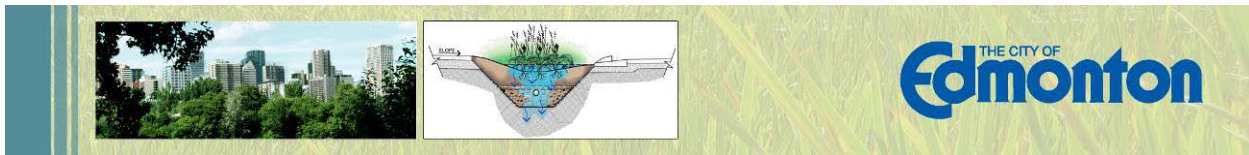


Table 7.3
Bioretention Operation, Maintenance and Replacement Schedule

Operation Activities	Scheduling
Inspect for sedimentation, erosion, plant health, mulch condition	Semi-annually (spring, fall), quarterly during establishment (2 yrs)
Avoid use as snow storage facility unless specifically designed for this purpose	Winter
Strategic application of de-icing and anti-skid material on roadways contributing to facility	Winter
Street sweeping to prevent sedimentation	Semi-annually (spring, fall)
Soil contamination testing in areas with high levels of contaminants	Annually
Soil infiltration (empty time <36hrs) and pH (5.2-7.0) testing	Bi-annually
Maintenance Activities	
Weed control	Monthly
Mow grass and remove clippings, minimum length (50-250 mm) no shorter than maximum flow depth	Monthly (May-October)
Prune vegetation when access or operation limited	Annually
Litter and debris removal from inlets, outlets, vegetation and flow paths	Bi-monthly
Tilling or deep raking	Bi-annually, prior to infiltration testing
Sand and sediment removal	Annually (spring) or when sediment depth >100 mm
Under-drain flush	Annually (spring)
Erosion repair of soils, mulch, splash pad, rip rap	As indicated by inspection, annually (spring)
Grass/plants (unhealthy or dead >10%)	As indicated in inspection (1-10 years)
Mulch, replenish or replace	As indicated by inspection (1-3 years)
Replacement Activities	
Soils	As indicated by contaminant / infiltration testing (2-20 years)
Gravel drainage layer	As indicated by infiltration testing (25-50 years)
Under-drain	When flushing indicates irreparable clogging (25-50 years)

(TRCA, 2009; GVRD, 2005; COP, 2004b)



8.0 BIOSWALES

8.1 Description

Bioswales, are open channels with dense vegetation specifically designed to attenuate, treat, and convey stormwater runoff. They are distinguished from bioretention mainly by a linear shape and sloped bottom that facilitates water movement. Bioswales use amended topsoil, selected plantings, and may include an infiltration layer to provide enhanced water quality treatment and promote infiltration.

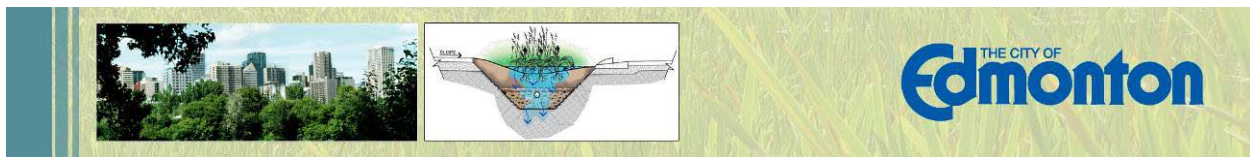
Used as a replacement for, or in conjunction with, curb and gutter, bioswales are designed to strain particulates from the water, slow flow velocity and reduce volumes through surface infiltration and evapo-transpiration.

Directing stormwater through vegetation improves surface infiltration and soil moisture for evapo-transpiration. Stormwater quality treatment in a bioswale is realized through straining and settling of particulates through vegetation, deep infiltration, biodegradation from soil microbes, and filtration through soil layers. Water quality treatment efficiency can be improved by increasing retention time through use of check dams.

8.2 Application

Bioswales can be applied in most development situations, including residential areas, office complexes, along roadways, parking lots, parks, and other green spaces (**Figure 8.1**). Bioswales are well-suited to treat roadway runoff because of their linear nature and ability for receiving sheet flows. They are often located within utility rights-of-way along property boundaries for serving one or multiple properties.

Using bioswales to replace existing drainage ditches is a common retrofit opportunity. Ditches are traditionally designed only to convey stormwater away from roads. In some cases, they can be retrofitted to bioswales to enhance infiltration and pollutant removal using check dams.



Bioswale at Big Lake Trumpeter neighbourhood in Edmonton, AB to treat roadway runoff. Photo by Xiangfei Li, City of Edmonton.



Bioswale at Terwillegar Recreation Centre, Edmonton, AB to treat roof runoff. Photo by Xiangfei Li, City of Edmonton.

Figure 8.1 Local Bioswale Installations in Residential and Commercial Settings

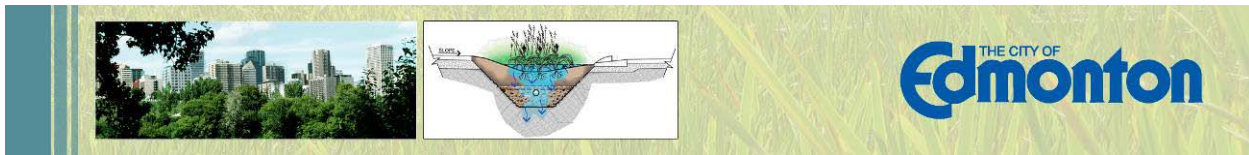
8.3 Design Considerations

Bioswales must be designed to fit the unique characteristics of each site. The designer is responsible for ensuring the physical attributes of the site can accommodate a swale.

To ensure the long-term functionality of bioswales, the facility's physical and performance parameters listed in **Table 8.1** should be considered during the preliminary design process. A bioswale cross section is shown in **Figure 8.2** and accompanying longitudinal profile in **Figure 8.3**. **Figure 8.4** shows a plan view of a bioswale.

Bioswale designs must filter and convey Edmonton's 1-in-2 year storm event, within the parameters listed in **Table 8.1**. The drainage area to a bioswale is based on the soil type, ponding depth and surface area. Surface flow velocity within a swale at a given slope is determined by the roughness of the channel. Different types of vegetation and surface treatments applied in a bioswale will impact flow velocities. Modelling should be performed by designers to demonstrate the function of the bioswale.

The drawdown time of bioswales is based on soil type and ponding depth, and must be reported to ensure safety and aesthetics are maintained. Bioswales along roadways must be designed to prevent compromising the road structure with water infiltration. Ponding areas in bioswales are created by using check dams to retain water and reduce the effective slope (**Figure 8.3**). Effective



Effective Slope – gradient governing flow velocity within a swale. If the slope of the surrounding terrain is too steep for a vegetated swale, the effective slope may be flattened by using check dams or drop structures.

slope can be determined using the following equation:

$$S_e = S_t - \frac{h}{L}$$

Where S_e is the effective slope;

S_t is the terrain slope;

h is the height of the check dam; and

L is the distance between check dams.

Other design considerations besides those listed in **Table 8.1** include, but are not limited to:

- Weaving swales around mature trees along boulevards and green spaces rather than removing the trees;
- Preventing icing of sidewalks and streets by sizing surface ponding capacity of the swales to accommodate the spring thaw volume of snow, ice and melt water without considerable infiltration by topsoils (see Appendix C);
- Designing bioswales that will receive additional snow to account for the added weight because snow piles can cause topsoil compaction;
- Providing curb cuts designed to direct the rate of flow and volume of runoff stormwater into bioswales and protect bioswales from plow blades during snow removal;
- Amending topsoil to mitigate, as much as possible, the effects of de-icing compounds on soils and plants;
- Providing a buffer along arterial roads (5 to 35 m vegetated filter strip) and along collector roads (3 to 5 m filter strip or sidewalk) to protect swale vegetation from salt damage;
- Planting salt tolerant grasses and plants as a buffer between the roadway and less tolerant species (Appendix A);
- Considering spring thaw volumes, soil compaction and salt damage to sensitive vegetation when the bioswale is designed specifically for snow storage;
- Equipping bioswales designed to receive high salt loadings with an under-drain to allow salt to leach from the swale.
- Selecting vegetation that will be able to structurally withstand moderate flow velocities and erosive forces of design events; and
- Providing a buffer between facilities with deep infiltration

capability and roadways or building foundations to reduce the risk of heaving or foundation damage due to saturated soils.

Design considerations to manage de-icing salt loading in roadside swales are provided in Appendix D. The details of bioswales planned for the site must be included on design drawings as indicated in **Table 8.2**.

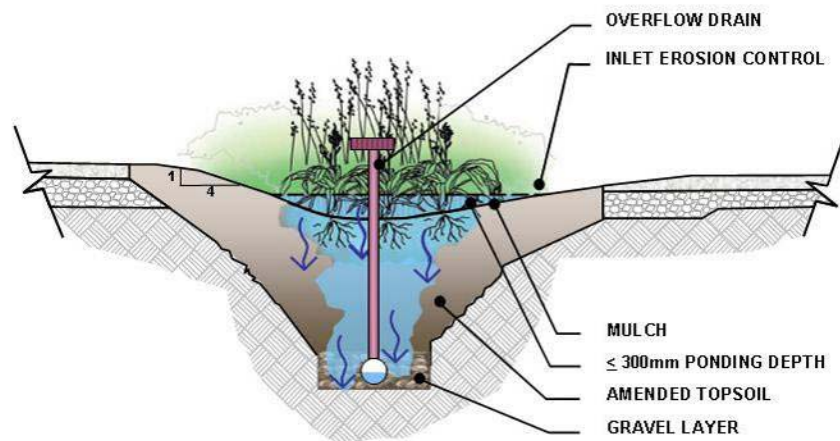


Figure 8.2 Cross-Section of a Bioswale

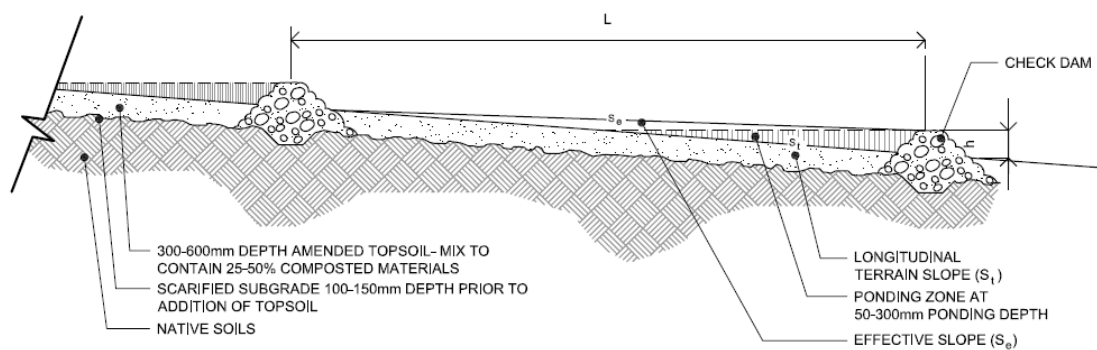


Figure 8.3 Longitudinal Profile of a Bioswale with Check Dams

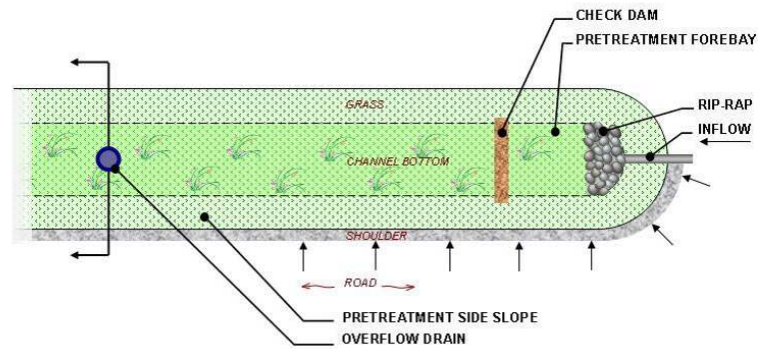


Figure 8.4 Plan View of a Bioswale

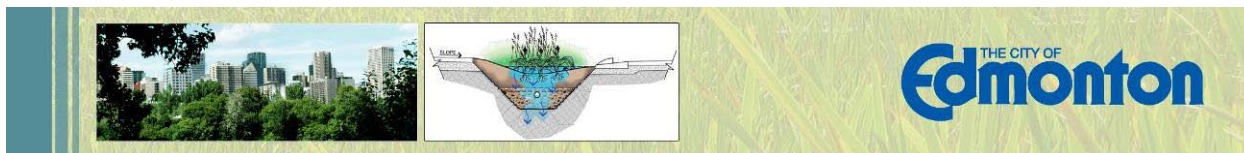


Table 8.1
Bioswale Design Parameters and Guidelines

Reported Parameters	Description and Recommendation
Soil Infiltration Rate	≥13 mm/hr, under-drain is not required; under-drain required in tighter soils (<13 mm/hr) and with longitudinal slopes (S_L) less than 1%
Inlet Design	Grass filter buffer (2 m to 30 m) prior to overland entry into swale; filter strips to buffer salt impacts are required as follows: 3-5 m width along collectors (may use sidewalk) and 5-35 m width along arterials
Design Discharge	Flow rate within facility for 2-year, 5-year, 10-year, 25-year and 100-year design events and maximum rate from Edmonton's continuous precipitation record
Overland Flow Velocity	Determine using Mannings equation based on soil type and vegetation density; ensure velocities remain non-erosive during the 10-year, 25-year and 100-year design events
Outlet Release Rate	From under-drain or catchbasin lead; must correspond to on-site release rates defined in Master Stormwater Drainage Plan
Flow Depth	≤0.3 m during 2-year design event
Ponding Depth	≤ 0.15 m during 2-year design event; max. 0.35 m depth as per City of Edmonton standards for drainage swale
Media Layers	Growing media: (amended topsoil) >300 mm depth
	Filter layer: (16-25 mm clean gravel with <0.1% silt) 100 mm depth
	Infiltration / storage layer: (<40 mm clean gravel with <0.1% silt) >450 mm depth
Vegetation	Grasses and dense vegetation (100% coverage at establishment – 2 years); turf grass recommended on slopes >0.5%
WSE in Design Storms	Show that HWL at 2-year and 100-year design events does not compromise adjacent structures
Captured Volume	Volume of water retained through ponding and surface infiltration during the 2 year design event; additional volume captured during larger events if applicable
Emptying Time	Duration of ponded water following the 2-year design event <24hrs
Surface Area	10% to 20% of contributing impervious area; determined through continuous modelling; facility to be sized by designer based on snowmelt volumes and salt loadings as required
Geometry	Trapezoidal or triangular, provide cross-section detail with dimensions labelled
Facility Width (Surface)	0.6 m to 2.4 m width
Side Slopes	4:1 (H:V) preferred (max 3:1)
Longitudinal Slope	Sufficiently flat to maintain non-erosive velocities in the 10-year design event; typically in the range of 0.5% to 1.0%. Grade control structures required for longitudinal slopes (s_L) in excess of 1.0% to reduce the longitudinal slopes (s_e) to 0.5% to 1.0% between grade control structures
Under-drain	Required when longitudinal slope of site (S_L) <1%; also required when high salt loadings expected
Groundwater Buffer	Bottom of facility located minimum of 0.6 m to 1 m above groundwater table
Structural Buffer	Facility located ≥3 m from building foundations

(TRCA, 2009; USEPA, 1999b; Claytor and Schueler, 1996; Stephens et al, 2002; GVRD, 2005; Caraco et al, 1997; COE, 2009)

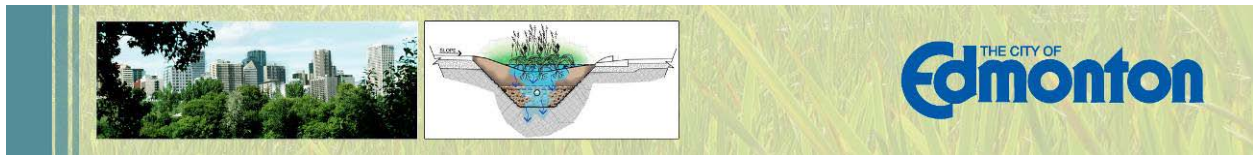
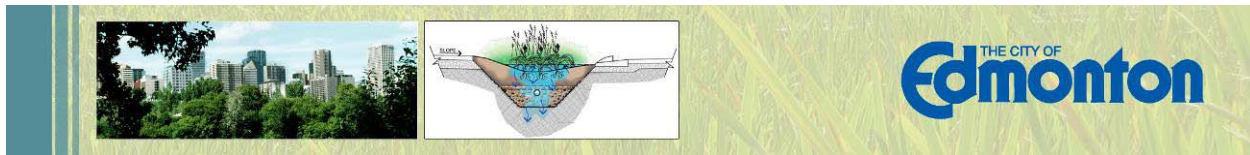


Table 8.2
Bioswale Drawing Details

Parameter	Plan	Detail	Profile	Description
Inlet	x	x		Shown on plan view and typical detail provided (curb cut, flow spreader, ribbon curb, OGS)
Materials		x	x	Material specs (soil, drainage, geotextile), depth, hydraulic conductivity, void space
Vegetation	x	x		Planting plan and vegetation details (species, mature density, succession plan)
Slope	x	x	x	Side slopes, longitudinal slope, effective slope, check dams or drop structures
Outlet		x		Under-drain spec & slope, spill elevation, catchbasin type and grate, weir, ICD
Catchment	x			Delineated catchment area directed to swale
Surface area	x			Outlined on drawings and stated in report
Depth		x		Ponding depth and water surface elevation during design storm and maximum prior to spill
Flow Arrows	x			From contributing area, within swale and overflow route
Inundation	x			Extent of inundation during design storms
Erosion control	x	x		Located at inlet, outlet if overland spill



8.4 Operation and Maintenance

A schedule for operation, maintenance and replacement activities for bioswales is contained in **Table 8.3**. The scheduling for these activities varies depending on location and drainage area characteristics. Facility designers must provide site specific schedules for operation, maintenance and replacement to ensure the long-term functionality of the LID-BMP facility.

Facility inspections should be conducted quarterly during establishment (first 2 years) and semi-annually thereafter. Inspecting after a major storm event will facilitate early detection of erosion or debris blockages occurring during elevated or sustained flows. Snow plows should be careful not to cause damage to bioswales along roadways. Sediments and debris should be removed in the fall before snow covers the facilities and in spring before snowmelt runoff occurs. LID-BMP facilities designed to receive runoff from contaminated sites may require more frequent inspections, tests and maintenance activities; sites that remain relatively undisturbed with little potential for contamination or sedimentation may require less maintenance.

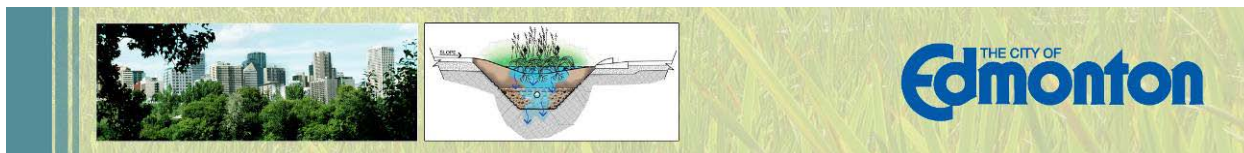


Table 8.3
Bioswale Operation, Maintenance and Replacement Schedule

Operation Activities	Scheduling
Inspect for sedimentation, erosion, plant health, mulch condition	Semi-annually (spring, fall), quarterly during establishment (2 yrs)
Irrigation	As needed during establishment (2 yrs)
Use for snow storage only where sufficient volumetric capacity exists and snow weight can be accommodated	Winter
Strategic application of de-icing and anti-skid material on roadways / parking lots contributing to facility	Winter
Street sweeping to prevent sedimentation	Semi-annually (spring, fall)
Soil contamination testing in areas with high levels of contaminants	Annually
Soil infiltration testing (empty time <48hrs)	Bi-annually
Maintenance Activities	
Weed control	Bi-monthly
Mow grass and remove clippings, minimum length (50-250 mm) no shorter than maximum flow depth	Monthly (May-October)
Prune vegetation when access or operation limited	Annually
Litter and debris removal from inlets, vegetation and flow paths	Bi-monthly
Tilling or deep raking	Bi-annually, prior to infiltration testing
Sand and sediment removal	Annually (spring) or when sediment depth >100 mm
Under-drain flush	Annually (spring)
Erosion repair of soils, mulch, splash pad, rip rap	As indicated by inspection, annually (following spring snowmelt)
Replacement Activities	
Grass / plants (unhealthy or dead >10%)	As indicated in inspection (1-10 years)
Mulch, replenish or replace	As indicated by inspection (1-3 years)
Soils	As indicated by contaminant/infiltration testing (2-20 years)
Gravel drainage layer	As indicated by infiltration testing (25-50 years)
Under-drain	When flushing indicates irreparable clogging (25-50 years)

(TRCA, 2009; GVRD, 2005; COP, 2004b)

9.0 GREEN ROOFS

9.1 Description

Green roofs are a stormwater management practice that uses vegetation overlaid on rooftops to delay and retain rainfall. They also offer shade and insulation benefits that result in reduced energy usage. While green roofs are experiencing a surge in popularity in recent years, they are a practice that actually dates back to 500 B.C. in Sumerian civilization (Collins, 2011).

A typical green roof consists of several layers overlying the roof structure. These layers are: vegetation, growing medium, drainage filter, drainage layer, root barrier, waterproof/roofing membrane, cover board, thermal insulation, vapour barrier and roof and building support structure. These layers are illustrated in **Figure 9.1**. **Table 9.1** describes these layers and their function.

The amount of rainfall retained on a green roof depends on the depth of the growing medium and the roof slope, and are reported to be between 70% and 90% of the annual rainfall that lands on them (Perry, 2003). Green roofs provide shade to underlying surfaces, reducing heat transmission to the building and effectively reducing cooling costs by up to 25% (Goom, 2003). Winter heating costs may also be somewhat reduced (www.soprema.ca). Additionally, the process of evapo-transpiration by vegetation lowers the temperature of the surrounding air, reducing the urban heat island effect (Peck et al., 2003). Green roofs also provide urban green space and habitat for birds and insects (Peck et al, 2003).

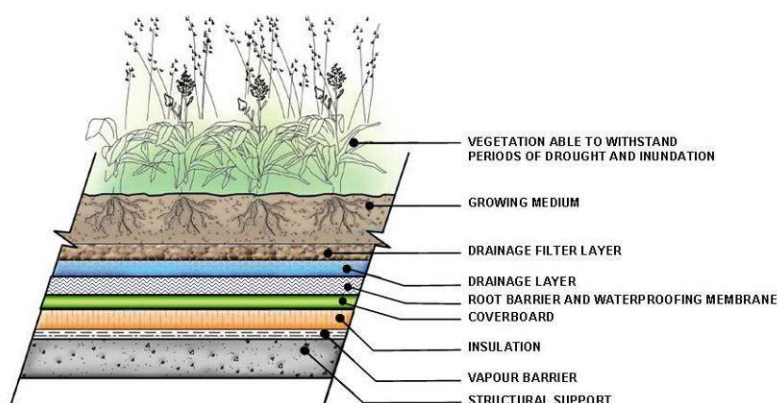
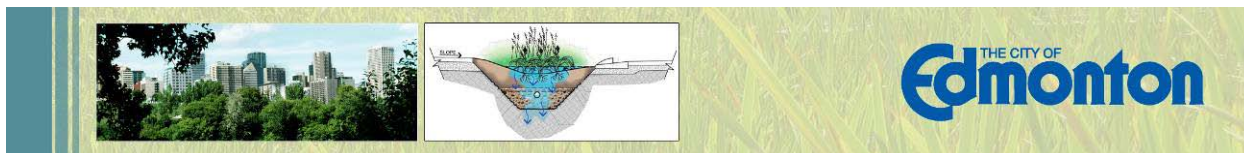
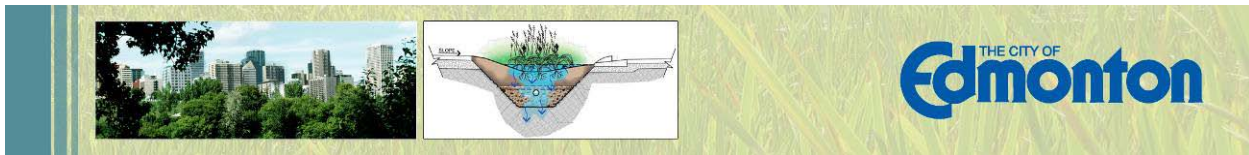


Figure 9.1 Cross-Section of Typical Green Roof Layers

**Table 9.1
Function of Green Roof Layers**

Layer	Description and Purpose
Vegetation	<ul style="list-style-type: none"> Provides the biomass for evapo-transpiration and insulation Selection depends on the type of roof, building design, climate, sunlight, irrigation needs, intended roof use and similar considerations
Growing Medium	<ul style="list-style-type: none"> Engineered for optimum support of vegetation, minimum weight and maximum water retention without water logging of plants
Drainage Filter	<ul style="list-style-type: none"> Geotextile membrane to protect drainage layer Prevents loss of growing medium and clogging of the drainage layer from migration of fines
Drainage Layer	<ul style="list-style-type: none"> Removes excess water, prevents overloading of roof and provides good air-moisture balance in growing medium to prevent plant rot or water logging
Root Barrier	<ul style="list-style-type: none"> Prevents plant roots from damaging roofing membrane and structural support of roof
Waterproofing/ Roofing Membrane	<ul style="list-style-type: none"> Protects structural support from moisture damage Typically more durable in green roofs than in conventional roofs
Cover Board	<ul style="list-style-type: none"> Thin semi-rigid board Provides protection, separation and support for waterproofing membrane
Insulation	<ul style="list-style-type: none"> Usually required to meet thermal insulation requirements of the Building Code Can be installed either above or below membrane of green roof
Vapour Barrier	<ul style="list-style-type: none"> Resists passage of moisture through the ceiling
Structural Support	<ul style="list-style-type: none"> Supports weight of saturated green roof, snow and wind loads, roof users, etc.

Adapted from USEPA, 2008.



9.2 Application

Green roofs can be designed as part of new construction or installed as a retrofit, following a structural assessment. They are suitable for installation on a wide range of buildings, including industrial, educational, and government facilities, offices, commercial properties, and residences. Generally, buildings with large roof areas are targeted for stormwater management.



Green roof planted with grasses at the Mazankowski Heart Institute in Edmonton. The Institute has four extensive green roofs, with one visible from the Healing Garden.

Selection of intensive or extensive green roofs will depend on the location and desired function of the roof. Extensive green roofs are lighter weight, typically requiring little to no additional structural support, making them a more economical choice for retrofitting existing structures, whereas a new building may be specifically designed for the extra weight of an intensive green roof. Green roofs can be designed for many roof types. However, where the roof slope is more than 20 degrees, protection against slipping and slumping of the plant layer must be provided. Steeper roofs may retain less stormwater than an equivalent flatter roof.

In general, intensive green roofs are better suited to flatter roofs (5 degrees or less), and may be designed similar to a conventional garden or park space. They are often installed to reduce energy costs and provide an aesthetically pleasing park-like environment for building occupants or the general public to enjoy. Since intensive green roofs are heavier than extensive green roofs, they require more structural support to handle the weight of additional growing medium and public use, resulting in a higher initial investment. They may have greater maintenance requirements, including the need for irrigation systems. However, they are ideal candidates for dense, urbanized areas that have limited or no space available for planting at ground level. **Table 9.2** provides a comparison of the distinguishing features of intensive and extensive green roofs.

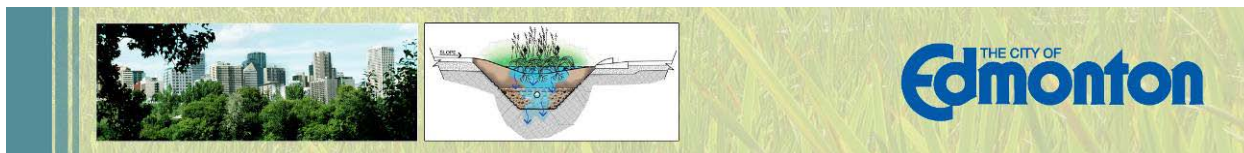


Table 9.2
Green Roof Characteristics – Extensive and Intensive

Green Roof Type	Growing Medium Depth (mm)	Growing Medium Saturated Weight (kg/m ²)	Recommended Vegetation
Extensive	100 to 150	129.1 to 169.4	<ul style="list-style-type: none"> ◆ Native grasses ◆ Sedums
Intensive	200 to 600	290 to 967.7	<ul style="list-style-type: none"> ◆ Native grasses ◆ Sedums ◆ Shrubs ◆ Trees

(City of Toronto, 2009)



Newly planted green roof at Terwillegar Recreation Centre showing perimeter drainage, Edmonton, AB. Photo by Xiangfei Li, City of Edmonton, 2011.



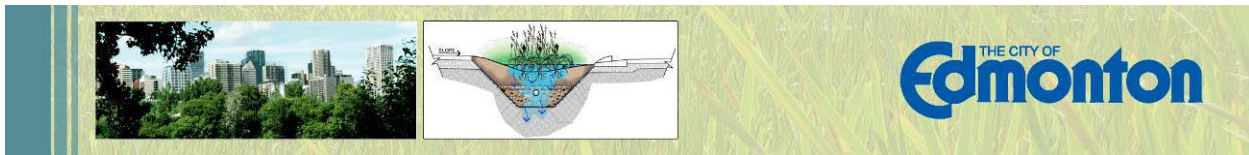
Established green roof at Stantec Consulting corporate office, Edmonton, Alberta. Photo courtesy Penny Dunford, Stantec, 2011.

9.3 Design Considerations

Green roof designs must include a structural assessment completed by a professional engineer to ensure that the structural loading capacity of the building can support the green roof. To maximize the benefits of the green roof, heating and cooling implications for the building should be considered in the design. At a minimum, green roof designs must:

- ensure structural stability of the roof to support the weight of both green roof and snow loads, based on continuous precipitation records;
- confirm compliance of the roof with the Alberta Building Code;
- consider melt water runoff from the roof in the hydrologic model because water storage and detention benefits of green roofs will not be realized to the full extent during cold periods while the vegetation is dormant and infiltration through the soil layer is minimal;
- select plants that can withstand the winter temperatures and snow pack with minimal or no injury; and
- provide irrigation during the vegetation establishment period. This period may be extended due to Edmonton's limited growing season.

The green roof design should also incorporate a drainage system to manage overflows from the green roof. The drainage system prevents damage to and erosion of the growth medium during heavy rains, maintaining optimum growing conditions. Adequate drainage also helps to preserve the roof structure.



The physical and performance parameters that are critical for long term operational success of green roofs are listed in **Table 9.3**. These parameters must be considered in the preliminary design process. Details of green roof layers, including material type, saturated weight, installation, maintenance and testing must be specified in the green roof design and are guided by consideration of these critical parameters. Pertinent details for green roof specification are listed in **Table 9.4**. Specifications that must be included on design drawings are identified in **Table 9.5**.

Irrigation of green roofs must be carefully considered during the design of the green roof to ensure that irrigation water will not take up available soil storage space that would then be unavailable during the next rainfall event. A continuous hydrologic model or one of many commercially available soil moisture or evapo-transpiration based automatic sprinkler controllers may be warranted with the additional irrigation water input to ensure proper rainwater management is achieved. To reduce reliance on potable water supplies, water for green roof irrigation should be obtained from a cistern collecting excess rooftop runoff.

An electronic leak detection system may also be considered during the design process to help protect the roof from moisture damage. In addition, an electronic leak detection system may provide early warning of maintenance issues.

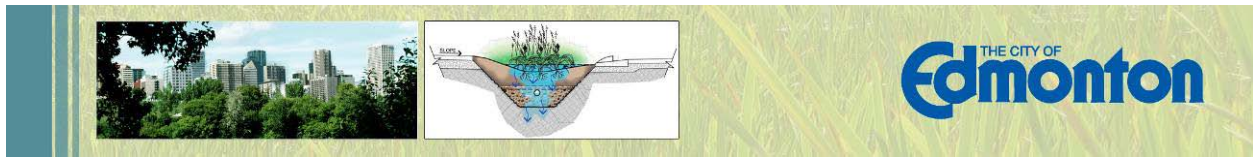


Table 9.3
Guidelines for Green Roof Physical and Performance Parameters

Reported Parameters	Description
Soil Infiltration Rate	Provide infiltration rate of growing medium
Design Discharge	Discharge rate through roof overflow during 2-year, 5-year-, 10-year, 25-year and 100-year design events
Captured Volume	Volume of water retained within the growth media layer during the 2-year design event; additional volume captured during larger events if applicable
Roof slope	<5% requires sloped under-drain; 5-20% gravity drainage; >20% lath grid to hold growing medium and drainage layer in place
Material details	Layer specifications as per Table 9.4
Saturated weight	Weight of layers when saturated and weight of retained rainwater not contained within facility
Plant density	List of species and mature height, weight and density of vegetation (seeds $\geq 325/\text{m}^2$; cuttings $\geq 12 \text{ kg}/100\text{m}^2$; plugs $\geq 11/\text{m}^2$)

(City of Toronto, 2009)

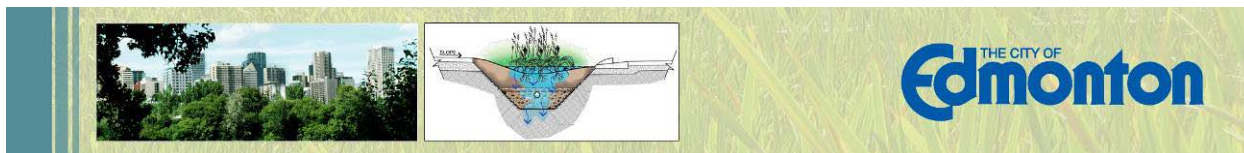


Table 9.4
Details and Considerations for Green Roof Selection and Design

Layer	Profile Schematic Requirements
Moisture Barrier	<ul style="list-style-type: none"> ◆ Material type and specifications ◆ Installation requirements ◆ Testing requirements
Root Barrier	<ul style="list-style-type: none"> ◆ Material type and specifications ◆ Installation requirements
Insulation	<ul style="list-style-type: none"> ◆ Material type and specifications ◆ Material thickness
Drainage	<ul style="list-style-type: none"> ◆ Material type and specifications ◆ Depth of layer ◆ Slope of layer ◆ Infiltration rate / hydraulic conductivity ◆ Percent void space
Filter	<ul style="list-style-type: none"> ◆ Material type and specifications ◆ Installation requirements
Growing Medium	<ul style="list-style-type: none"> ◆ Material type and specifications ◆ Depth of layer ◆ Infiltration rate / hydraulic conductivity ◆ Percent void space
Planting	<ul style="list-style-type: none"> ◆ Plant species ◆ Planting density ◆ Maximum height of highest species ◆ Weight of fully matured planting ◆ Transpiration rate (based on species or biomass density)

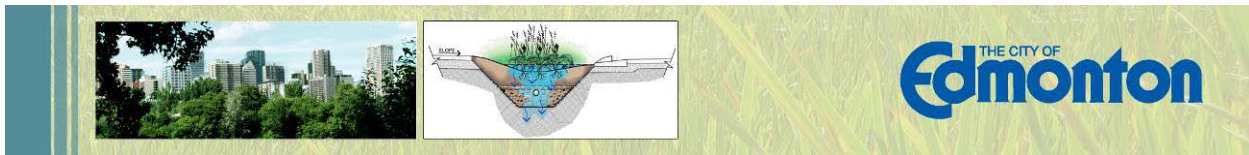


Table 9.5
Green Roof Drawing and Reporting Details

Parameter	Plan	Detail	Building Dwgs	Description
Materials		x	x	Layer material type, specifications, depth
Slope		x	x	Roof slope, illustrated to meet specifications
Outlet		x	x	Roof scupper or downspout with erosion control; provide type, slope, diameter, height above membrane
Surface area	x		x	Facility area outlined on drawings and stated in report
Installation				Requirements for surface preparation and layer installation
Testing				Leak testing, detection and maintenance requirements and schedule

(City of Toronto, 2009)

9.4 Operation and Maintenance

A recommended schedule for operation, maintenance and replacement activities for green roofs is contained in **Table 9.6**. This table is provided as a minimum recommendation as the schedule for these activities may vary depending on roof and vegetation type, climate and the level of maintenance acceptable to the owner. Facility designers must provide site specific schedules for operation, maintenance and replacement to ensure the long term functionality of the green roof.

Facility inspections should be at minimum, conducted monthly from April to September. Maintenance will include irrigating, fertilizing and weeding until plantings are established. After establishment, maintenance can be limited to two visits per year in the snow-free season for:

- Weeding
- Debris removal
- Safety inspection
- Repair of moisture and root barrier membranes
- Replacement of dead or dying plants
- Replacement of clogged or contaminated soils

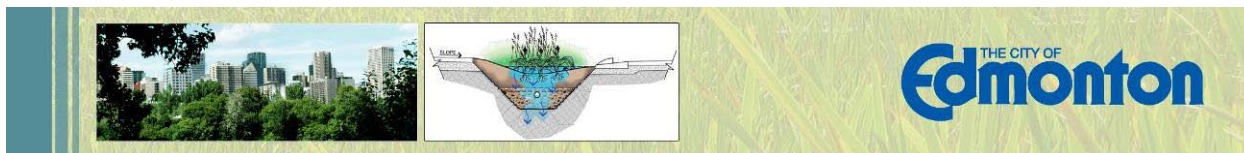
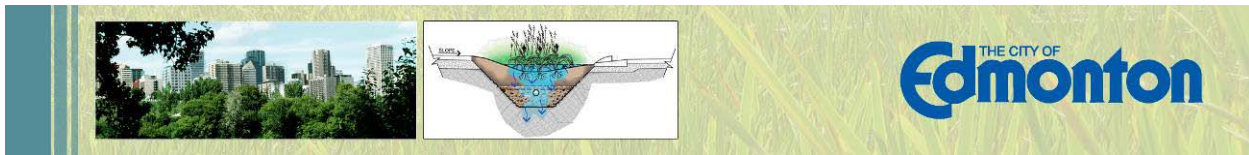


Table 9.6
Green Roof Operation, Maintenance and Replacement Schedule

Operation Activities	Scheduling
Irrigation (5 mm per application)	Every 3 days during establishment (2 yrs), then as required at a minimum of at least once every 2 weeks
Fertilizing (use slow release complete fertilizers)	As required, semi-annually (spring, fall)
Leak testing and Safety inspection	Semi-annually (spring, fall)
Inspection for plant health, soil erosion, layer deterioration	Monthly (April to September)
Maintenance Activities	
Weeding	Semi-annually (spring, fall)
Removal and replacement of unhealthy / dead vegetation	As indicated by inspection, monthly during establishment (2 yrs), then annually
Replacement of eroded soils	As indicated by inspection, annually
Repair roof membranes and detected leaks	As indicated by inspection / detection system
Remove debris and ensure clear path through roof drainage outlet	Annually (spring)
Replacement Activities	
Waterproof membrane	As indicated in inspection (30-50 years)

(Peck, 2003; COP, 2004b; GVRD, 2005, City of Toronto, 2009)



ENK & Associates Parking Lot, Denver
Photo Credit: Kerri Robinson, AMEC



Porous Asphalt Parking Lot, Denver
Photo Credit: AMEC Earth & Environmental

10.0 PERMEABLE PAVEMENT

10.1 Description

Permeable pavements, also called porous pavement (pavers), include modular and cobble block pavers, structurally reinforced grass and gravel, porous asphalt and porous concrete. In general, the structure of permeable pavement consists of pavement layer, angular rock filter course, angular rock sub-base, reservoirs course, underdrain (optional), insulations and barriers to protect adjacent buildings or roadway sub-base (**Figure 10.1**).

10.2 Application

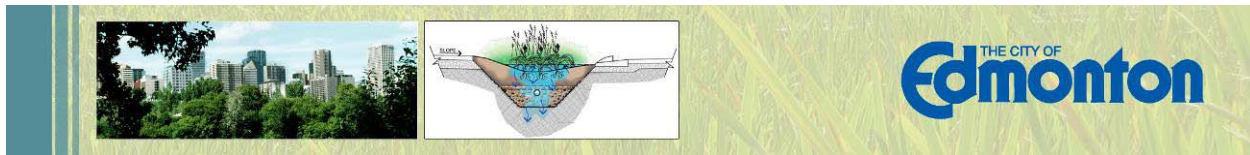
Permeable pavements have been installed in cold climates with excellent results when designed, constructed and maintained properly. The locations of permeable pavement systems must be carefully considered at the planning stage to ensure that traffic volume, de-icing activities and operation and maintenance activities are suitable for the long-term functionality of the system. Permeable pavements can be used for low traffic roads, parking lots, driveways, pedestrian plazas and walkways. They are ideal for sites with limited space for other surface stormwater BMPs (TRCA, 2010).

Use of permeable pavements in sites with high levels of sedimentation and high pollution such as gas stations, handling areas for hazardous materials and heavy industrial sites is not recommended (TRCA, 2010). Contaminated sites must be well understood and the impacts of infiltrated contaminants mitigated.

Properly designed, installed and maintained permeable pavements have been shown to reduce frost heave, icing, pollutant loading and runoff and to increase pavement longevity (Gunderson, 2008; Hun-Dorris, 2005).

10.3 Design Considerations

Unique site characteristics must be accounted for in the design based on professional knowledge and judgement. To reduce or eliminate potential for frost heaving, the structure and depth of the



reservoir and drainage layer in a permeable pavement structure is vital. Appropriate design and construction for cold climates is possible and has been accomplished in other jurisdictions (SMRC, 2010). Consultation with an experienced professional is recommended during the design and construction process.

Table 10.1 lists design requirements for the facility's physical and performance parameters such as paver and sub-soil infiltration rate, layer material sizes and depth, under drain size, contributing area, and groundwater buffers.

Permeable pavements should be able to filter and convey the 1-in-2 year storm event. They may also be designed to provide some infiltration capacity within the sub-soils provided the infiltration rate of the underlying soils is ≥ 13 mm/hr.

Selection of pavement material is at the discretion of the designer, provided the infiltration rate and void requirements listed in **Table 10.1** are met. Porous asphalt and concrete must adhere to industry standards for gradation, mixing and installation. Using contractors with experience installing porous asphalt and concrete is essential due to the sensitivity of the material to mixture and compaction requirements. Pavement materials must be inspected by the design engineer throughout the construction process to confirm consistency of the product, ensuring long-term success of the facility.

Other factors to be considered in permeable pavement design include:

- Alternate methods of discharge of excess stormwater (other than infiltration) if sub-soils have high clay content in order to reduce the risk of heaving during winter;
- Locate facilities appropriately to minimize damage due to anti-skid materials; and
- Provide adequate, rapid drainage for the base structure to minimize the likelihood of freezing while saturated.

Details of all permeable pavement areas planned for the site must be included on design drawings as indicated in **Table 10.2**.

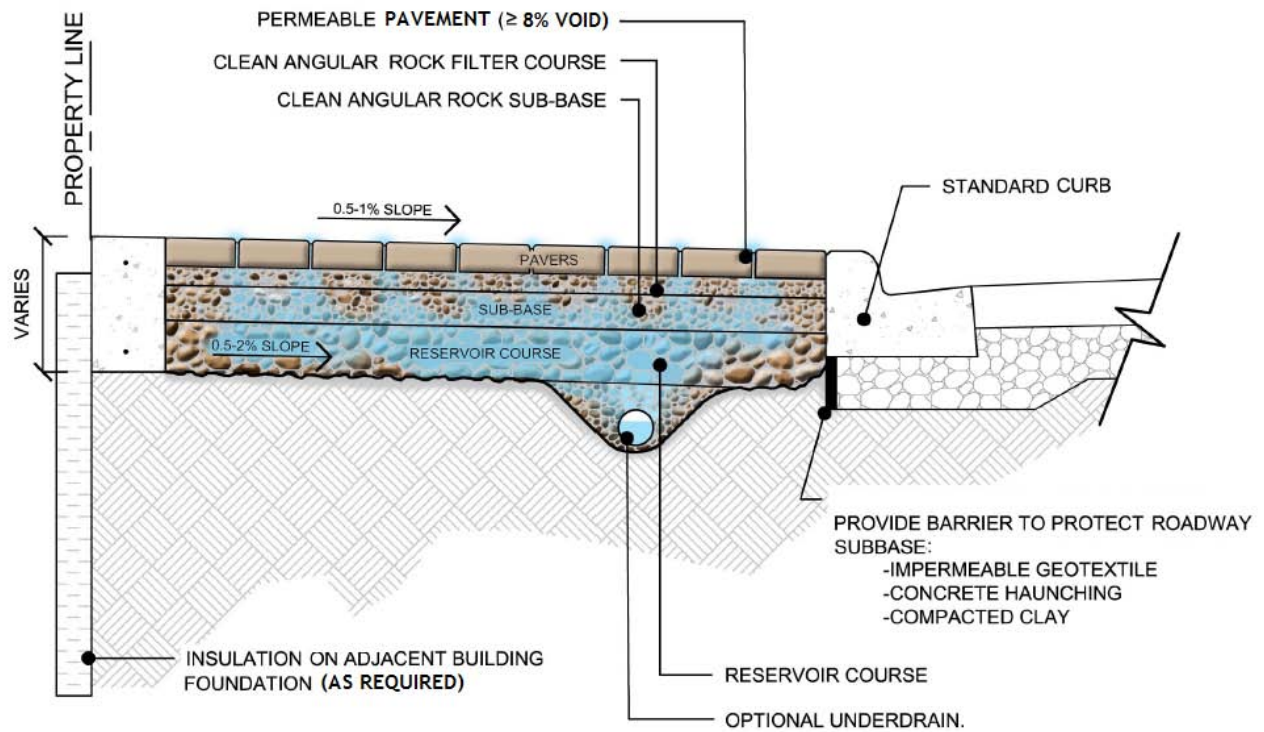


Figure 10.1 Cross-Section of Permeable Pavement Installation

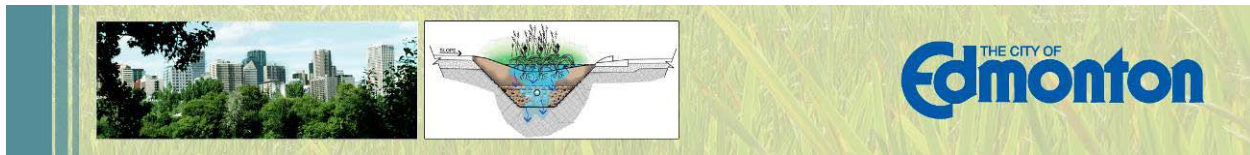


Table 10.1
Permeable Pavement Parameters and Guidelines

Reported Parameters	Description
Sub-Soil Infiltration Rate	≥ 13 mm/hr, under-drain required in tighter soils; ≥ 26 mm/hr when contact with anti-skid material expected; ≥ 35 mm/hr when contributing area >4 hectares
Pavement Infiltration Rate	Capable of maintaining 28 mm/hr over lifetime based on manufacturers tests and factor of safety of 10
Open Annular Space	Cobble: min 8%; modular block / plastic grid: min 20%; asphalt / concrete: min 2%
Layer Materials	Filter course: (10-12 mm angular stone with <0.1% silt) 25-30 mm below base of pavers / pavement
	Subbase: (25-40 mm angular stone with <0.1% silt) 50-250 mm depth below filter course
	Stone reservoir: (>50 mm clean gravel with <0.1% silt) 50-500 mm depth below subbase
Contributing Area	Contributing impervious area up to three times the permeable pavement area
Design Discharge	Discharge rate through under-drain for 2-year, 5-year, 10-year, 25-year and 100-year design events
Longitudinal Slope	Subgrade slope 0.5-2%; surface slope 0.5-1%, ideally directed toward adjacent landscaped areas
Captured Volume	Volume of water retained within the pavement structure during the 2-year design event; additional volume captured during larger events if applicable
Surface Flow Velocity	As per City of Edmonton specifications for overland flow
Emptying Time	Duration of water detention in reservoir layer <72 hrs
Groundwater Buffer	Bottom of reservoir layer located minimum 0.6 m to 1 m above groundwater elevation

(USEPA, 1980; SMRC, 2010; GVRD, 2005)

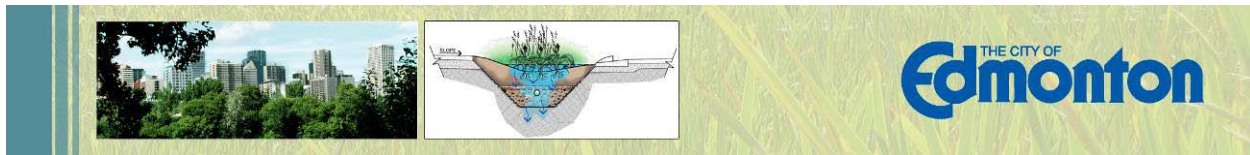


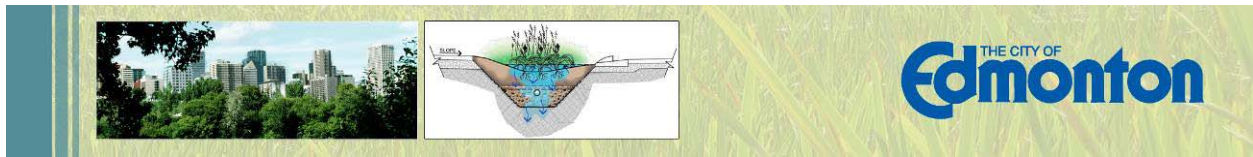
Table 10.2
Permeable Pavement Drawing Details

Parameter	Plan	Detail	Profile	Description
Location	x			Shown on plan view (driveways, parking stalls, pedestrian areas, emergency / delivery vehicle access)
Inlet	x	x		Shown on plan view, detail (if applicable), and in report
Permeable Pavement	x	x	x	Permeable surface (pavers, asphalt, concrete) with porosity and mix specifications
Sub-Surface Materials		x		Layer order (filter, reservoir, geotextile) and specifications (gradation, hydraulic conductivity, void space)
Slope		x	x	Sub-base slope and surface slope
Outlet	x	x		Under-drain diameter, material, slope & outlet, overflow spill elevation
Catchment	x			Delineated catchment area directed to swale, report imperviousness ratio
Surface area	x			Outlined on drawings and stated in report
Depth		x		Depth of each layer, reservoir retention depth (if applicable), surface ponding depth (if applicable)
Flow Arrows	x			From contributing area, within pavement structure and overflow route
Inundation	x			Extent of inundation during design storms
Erosion control	x	x		Located at inlet (until site stabilized), outlet if erosion potential exists

10.4 Operation and Maintenance

Over time, sediments will accumulate in the pores of permeable pavement, reducing the infiltration rate. To mitigate this, regular (annual) vacuuming of the permeable pavement surface is required. Some studies recommend designing the facility so that the installed pavement can maintain a minimum infiltration rate of 28 mm/hr with an applied factor of safety of 10 (initial rate: >280 mm/hr) to account for this reduction in efficiency (GVRD, 2005).

Facility designers must provide site-specific schedules for operation, maintenance and replacement to ensure long-term functionality of



the LID-BMP facility. The schedule for operation, maintenance and replacement activities for permeable pavement is contained in **Table 10.3**. The recommended timeline for these activities may vary depending on location and contributing area characteristics.

Damage to permeable pavements and pavers during winter plowing activities can be avoided by careful installation and maintenance and by using rubber spacers to buffer the plow blade from the surface, if required. Past experience has shown that permeable pavement is not subject to the level of ice build-up that occurs on traditional impervious materials since melt water can infiltrate immediately. This characteristic should reduce or eliminate the need for de-icing chemicals. If anti-skid materials are required it is recommended that clean gravel (2 to 5 mm) is used instead of sand, since it is resistant to breakdown and will not clog the permeable pavement pores.

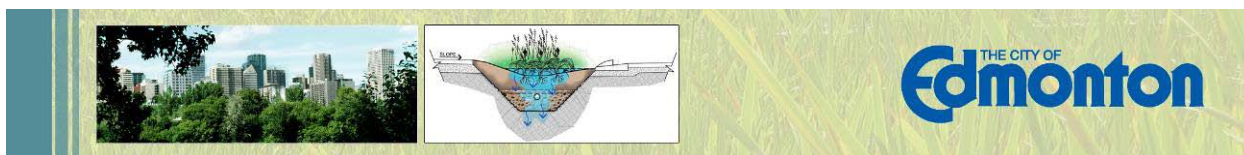
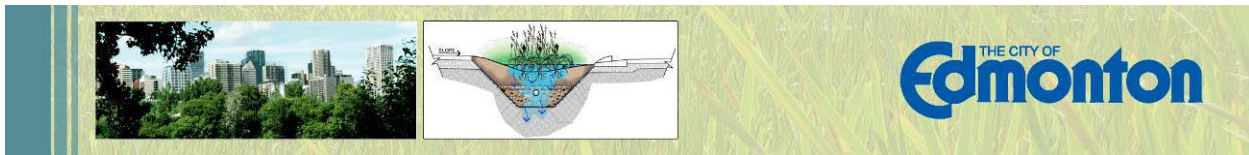


Table 10.3
Permeable Pavement Operation, Maintenance and Replacement Schedule

Operation Activities	Scheduling
Inspect for broken pavers, loose asphalt / concrete, clogged areas	Semi-annually (spring, fall)
Do not apply sand for anti-skid	Winter
Use salt sparingly, in spot applications, for de-icing	Winter, as needed
Raise plow 10-25 mm to avoid damage to pavement surface while clearing snow	Winter
Stabilize contributing catchment to prevent sedimentation, erosion	Semi-annually (spring, fall)
Street sweeping in contributing catchment to prevent sedimentation	Semi-annually (between snowmelt and spring rain, following spring rains)
Surface infiltration testing	Bi-annually
Maintenance Activities	
Immediately clean chemical or granular spills with vacuum and pressure washer	As required
Mow (length >100 mm) and remove clippings from structural vegetated surfaces	Monthly
Weeding of invasive species	Quarterly, as required
Litter, leaves, debris and weed removal	Quarterly, as required
Prune nearby vegetation to avoid debris accumulation	Annually
Repair broken / loose surface material	Semi-annually (spring, fall)
Under-drain flush	Annually (spring)
Site vacuuming / gravel replacement to remove sedimentation	Annually or bi-annually (based on testing)
Replacement Activities	
Pavers, asphalt or concrete	As indicated in inspection (>30 years)
Grass / plants in structural vegetated surfaces (unhealthy or dead >10%)	As indicated in inspection (1-10 years)
Gravel drainage layer	As indicated by infiltration testing (>30 years)
Under-drain	When flushing indicates clogging (>30 years)

(Diniz, 1980; COP, 2004b; Gunderson, 2008)



11.0 BOX PLANTERS

11.1 Description

Infiltrating box planters are similar to bioretention systems as they use vegetation and amended soils to filter and retain stormwater. A planter typically consists of a concrete box, which may or may not have a lined or concrete bottom (depending if infiltration is desirable), filled with a soil medium and planted with trees, shrubs or flowering species. An alternative to the concrete box is a matrix of buried plastic cells (**Figure 11.1**) that can be assembled to any required shape and size and that provides structural support for sidewalks and roadways while allowing for deep root penetration. Box planters may be designed as contained planters with outlet only through overflow; as flow-through planters with an under-drain outlet; or as infiltration planters which drain through deep infiltration and groundwater recharge.

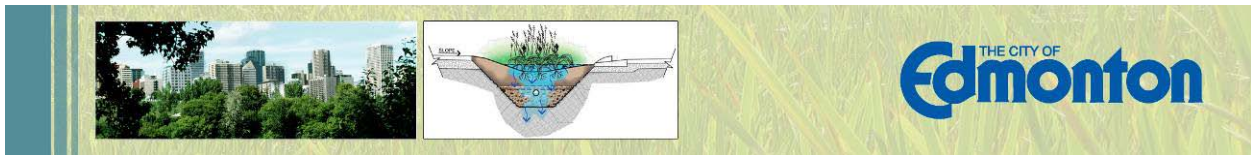
11.2 Application

Box planters are often designed for highly urbanized areas and retrofits where impervious surface reduction or stormwater quality enhancements are required. Runoff from surrounding impervious surfaces is directed into raised or inset box planter facilities to provide source control treatment, allow for a small amount of retention within the growing media (**Figure 11.1**) and, depending on subsoil types, facilitate deep infiltration. The size and type of planter dictates runoff reduction and water quality treatment capacity. However, they are expected to perform similarly to bioretention areas.



Flow through box planter, South Bay, CA. Photo Credit: Kerri Robinson, AMEC.

The primary mechanisms of stormwater management for infiltrating box planters include surface infiltration; transpiration; deep infiltration (optional); and delayed release to the minor system. Typically, stormwater enters the infiltrating box planter through a curb cut and infiltrates through a layer of mulch and soil. Some of the water is retained by the soil and subsequently used by the vegetation and released as evapo-transpiration. Depending on native soils, infiltrated water will percolate (deep infiltration) to the groundwater table. If infiltration is not an option, a perforated under-drain placed near the bottom of the box planter will convey excess water to the storm drainage system or a reservoir for re-use purposes (such as irrigation). Contained and flow-through box



planters require downstream LID-BMP facilities or connection to a conventional storm sewer system to convey excess stormwater, and do not contribute to groundwater recharge.

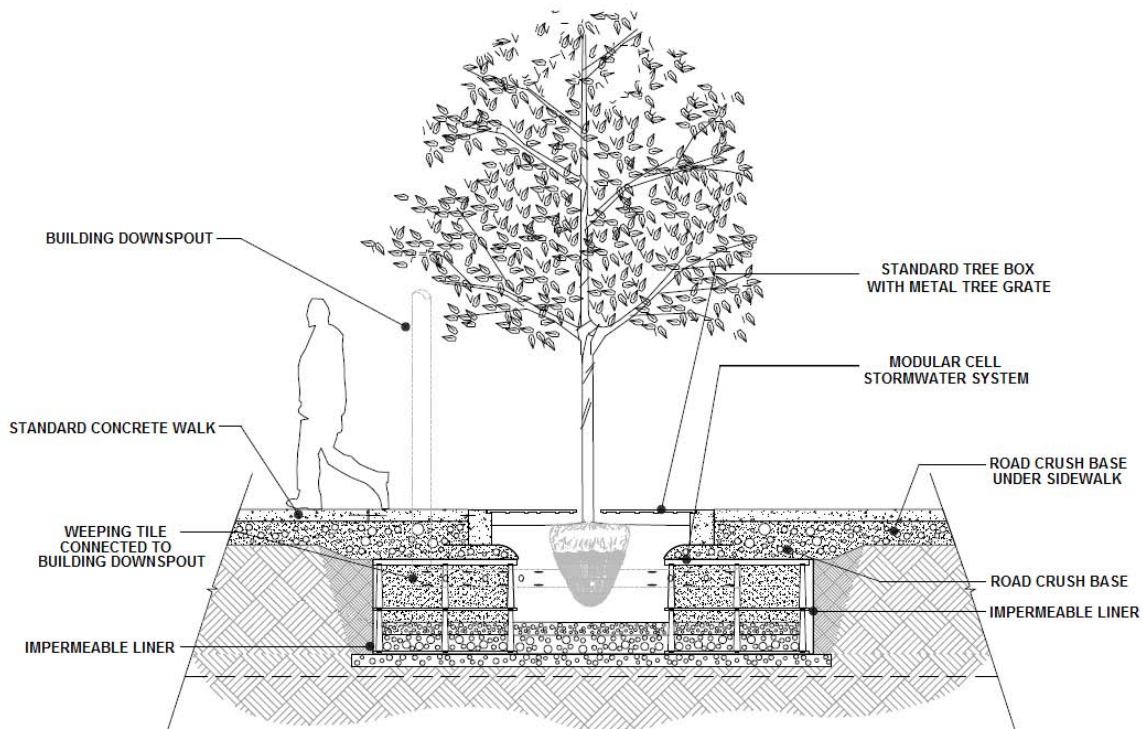


Figure 11.1 Tree Trench Box Planter with Structural Cells

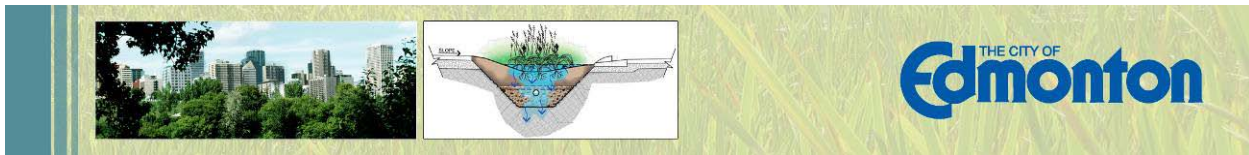


Box planters, Oregon. Photo credit: Dennis Uvbiama, AMEC..

11.3 Design Considerations

To ensure the long term function of a box planter, the facility's physical and performance parameters listed in **Table 11.1** must be considered during the preliminary design process and inspected during construction. Other design considerations besides those listed in **Table 11.1** include, but are not limited to:

- locating facilities appropriately to minimize damage due to pollutants and de-icing and anti-skid materials;
- providing an impermeable barrier between an infiltrating box planter and any roadway or adjacent building to prevent heaving or foundation damage;
- directing outlet of flow-through planters away from pedestrian walkways to prevent icing during spring thaw;



- designing vertical profile of vegetation located along roadways or near intersections to prevent impedance of driver visibility;
- selecting salt tolerant species to be planted nearest the road runoff inlets to buffer more sensitive species from the impacts of salt (Appendix A);
- sizing facilities receiving road runoff containing salts to prevent salt induced injury to plants and soils as per Appendix D;
- designing soil type and structure and selecting vegetation to account for weight, added pollutants and melt volumes in facilities built with the intent to provide snow storage; and
- sizing curb cut inlets to prevent blockage by ice and snow during spring runoff.

Contained and flow-through box planters are easily implemented in retrofit situations, highly urbanized areas and new developments. Infiltration box planters are more suitable for new developments where appropriate siting and subsurface testing can be completed; however, implementation in retrofit zones may be possible with careful assessment. While some stormwater volume reductions may be realized with box planters, their primary function is water quality enhancement achieved by filtration and biodegradation of pollutants through the vegetation and soil matrix. The structural nature of these facilities lends itself well to connection from impervious areas, providing opportunity for these facilities to serve as pre-treatment for facilities downstream in the treatment train. **Figures 11.2 and 11.3** provide cross sectional details for the flow through and infiltration box planters.



*Clermont Elementary School,
Virginia. Photo credit: AMEC
Earth & Environmental.*

Required plan view details and dimensional profiles of each type of box planter planned for a development are listed in **Table 11.2**.

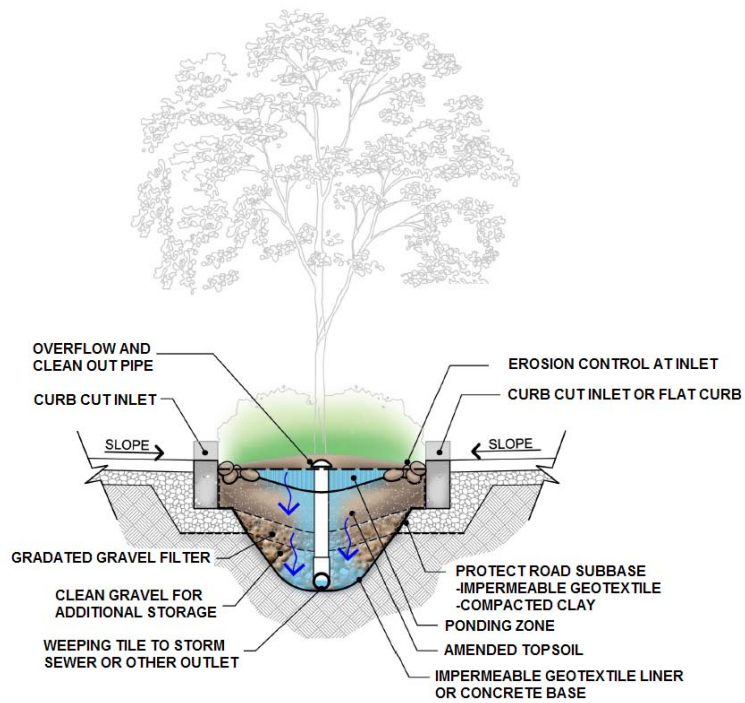


Figure 11.2 Cross-Section of Flow-Through Box Planter

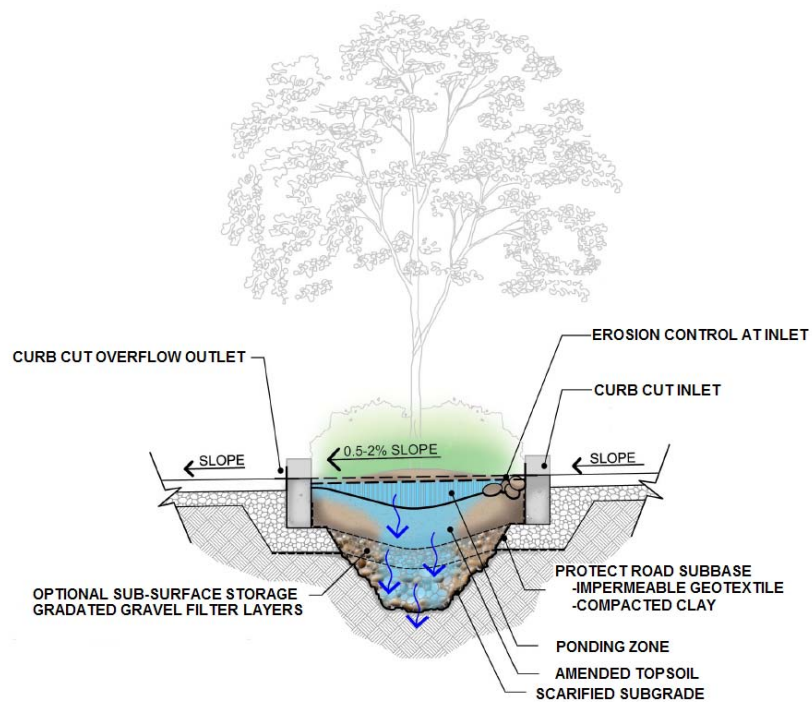


Figure 11.3 Cross-Section of Infiltration Box Planter

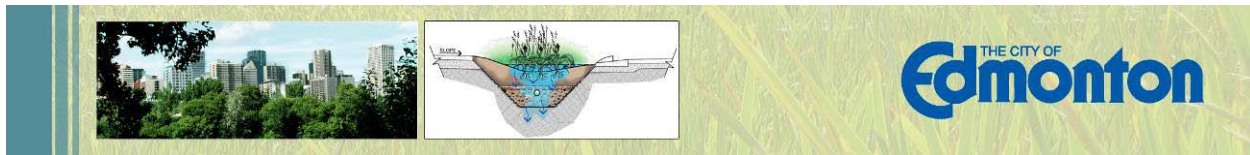
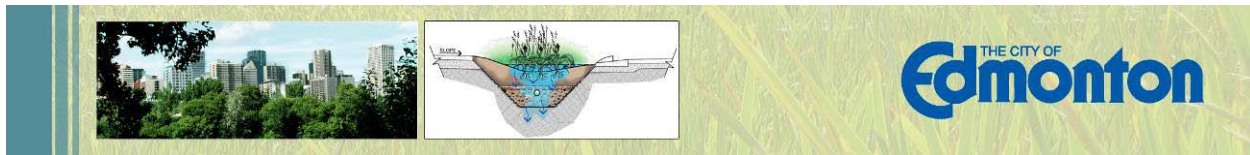


Table 11.1
Box Planter Parameters and Guidelines

Reported Parameters	Description	Facility Applicability		
		Contained	Infiltration	Flow-Through
Sub-Soil Infiltration Rate	≥50 mm/hr minimum, with 30 mm/hr used in design and modeling; under-drain required if infiltration <50 mm/hr		x	
Inlet design	Erosion control at point source inlet		x	x
Contributing Area	Contained planter: 1-to-1 area ratio; infiltration / flow-through planters: <1400 m ² (based on an event producing 100 mm precipitation in 24 hr)		x	x
Design Discharge	Overflow discharge rate in design events (Q ₂ , Q ₅ , Q ₁₀ , Q ₂₅ and Q ₁₀₀); infiltration / flow-through: minor system connection must comply with discharge rate set in Area Master Plan	x	x	x
Planter Material	Stone, concrete, brick, wood (chemically treated wood unacceptable due to the leaching potential of toxic substances), clay, plastic acceptable for contained planters	x	x	x
Media Layers	Growing media: (amended topsoil) 300-450 mm depth	x	x	x
	Filter layer: (16-25 mm washed rock <0.1% silt) 100 mm depth		x	x
	Drainage layer: (20-40 mm washed rock <0.1% silt) 25-300 mm depth		x	x
Max. Ponding Depth	Contained planters: 50 mm; infiltration / flow-through planters: 300 mm	x	x	x
Captured Volume	Volume water retained through ponding and surface infiltration during the Q ₂ event; additional volume captured during larger events if applicable	x	x	x
Outlet design	150 mm (min) weeping tile drain through length of facility to minor system lead		x	x
Emptying Time	Duration of ponded water following design events ≤12hrs		x	x
Surface Geometry	Infiltration planters: ≥750 mm width; Flow-through planters: ≥450 mm width; Contained planters: as site allows	x	x	x
Surface Slope	Contained / infiltration planters: flat surface; Flow-through planters: <0.5% surface slope	x	x	x
Infiltration Features	Scarify sub-soils		x	
Groundwater Buffer	Facility base must be 1 m above groundwater level		x	
Structural Buffer	Infiltration: 10 m setback from building foundations required; flow-through: damp proofing along foundation and impervious water barrier within planter required		x	x



**Table 11.1 cont'd.
Box Planter Parameters and Guidelines**

Reported Parameters	Description	Facility Applicability		
		Contained	Infiltration	Flow-Through
Vegetation	Drought tolerant trees, shrubs, herbs, succulents, grasses to cover 50% of surface area at maturity; irrigation acceptable	x	x	x

(GVRD, 2005; COP, 2004b)

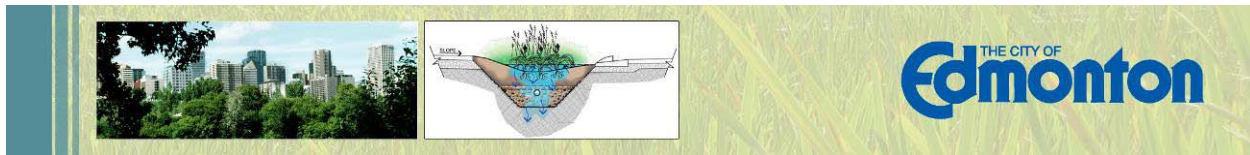
**Table 11.2
Box Planter Drawing Details**

Parameter	Plan	Detail	Profile	Description
Location	x			Areal extent on plan view, including building setbacks, structures and property lines
Surface area	x			Dimensions shown on plan view drawings and areas stated in report
Inlet	x	x		Shown on plan view and typical detail provided (curb cut, flow spreader, downspout)
Materials		x	x	Dimensions and specifications for: planter wall material; waterproofing membrane; growing media; drainage media
Vegetation	x	x		Landscaping / planting plan and vegetation details (species, mature density, succession plan, transpiration rate, treatment capability)
Outlet		x	x	Under-drain material, size, slope and inverts at all connections, overflow spill location and dimensions
Catchment	x			Delineated catchment area directed to bioretention facility
Flow Arrows	x			From contributing area and overflow route
Water Depth		x		Maximum ponding depth
Erosion control	x	x	x	Inlet splash pad material, dimensions, specifications

(COP, 2004b)

11.4 Maintenance Schedule

The schedule for operation, maintenance and replacement activities for box planters is contained in **Table 11.3**. The recommended timeline for these activities may vary depending on



location and contributing area characteristics. Facility inspections should be conducted quarterly during establishment (first 2 years) and semi-annually thereafter. Inspecting after a major storm event will facilitate early detection of erosion or debris blockages occurring during elevated or sustained flows. More contaminated sites may require more frequent inspection, upkeep and replacement activities while sites which remain relatively undisturbed with little potential for contamination or sedimentation may require very little attention. Facility designers must provide site specific schedules for operation, maintenance and replacement to ensure the long-term functionality of the LID-BMP facility.

Table 11.3
Box Planter Operation, Maintenance and Replacement Schedule

Planter Type	Operation Activities	Scheduling
C, I, F	Operation and structural stability inspections	Quarterly (first 2 yrs), semi-annually (spring, fall)
C, I, F	Downspout and splash block inspection for clogging, leaks and erosion	Semi-annually (spring, fall)
C, I, F	Filter media infiltration and contamination testing	Annually
C, I, F	Irrigation	Weekly
C, I, F	Vegetation health and density inspection	Annually
	Maintenance Activities	
C, I, F	Weed control	Monthly
C, I, F	Litter and debris removal from vegetation, inlet and overflow	Monthly
I, F	Hand removal of accumulated sediment >100 mm	Annually (spring)
I, F	Hand repair of soils at locations where infiltration compromised	Annually (spring)
I, F	Downspout, inlet and under-drain flush	Annually (spring)
I, F	Erosion repair	Annually (spring)
C, I, F	Overflow flush or repair	As indicated in inspection (at 50% conveyance)
C, I, F	Plug holes inconsistent with design and which allow water to seep into ground	As indicated in inspection (1-10 years)

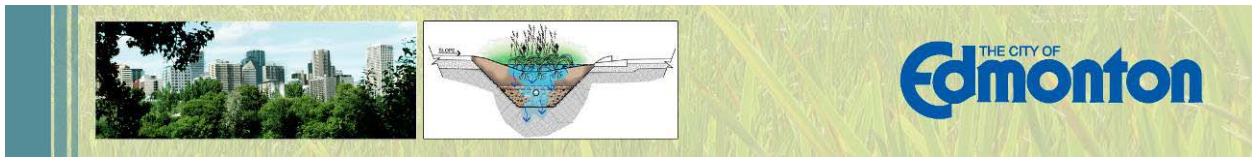


Table 11.3 cont'd.
Box Planter Operation, Maintenance and Replacement Schedule

	Replacement Activities	
C, I, F	Plants (unhealthy or dead >10%)	As indicated in inspection (1-10 years)
C, I, F	Mulch, replenish or replace	Annually
C, I, F	Soils	As indicated by contaminant / infiltration testing (2-20 years): when contaminant level is stable from one year to the next with no change in incoming levels; when infiltration rate is below the modelled rate
I,F	Gravel drainage layer	Based on infiltration inspection: when surface layer no longer meets emptying time criteria (25-50 years)
I,F	Under-drain	When flushing indicates irreparable clogging (25-50 years)

C = contained; I = infiltration; F = flow-through
 (GVRD, 2005; COP, 2004b; Claytor and Schueler, 1996)



Photo Credit: Dr. Robert McGregor, AMEC

12.0 NATURALIZED DRAINAGE WAY

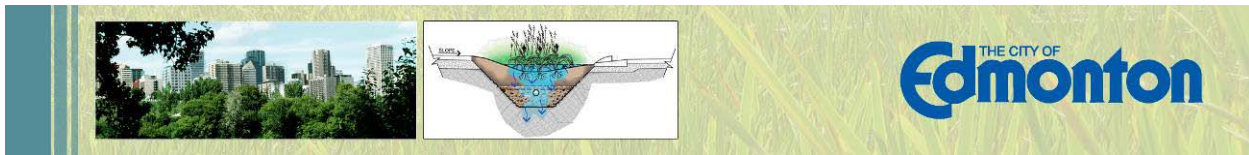
12.1 Descriptions

Naturalized drainage ways are surface stormwater conveyance features that use wetland zones, drop structures and natural materials and vegetation to replace storm sewer mains or prevent erosion of existing drainage ways. Naturalized drainage ways generally have frequent or continual runoff (base flow). They are typically larger than grass swales, more engineered than natural wetlands and in some cases may appear similar to a small creek. Velocities of urban runoff and stormwater are slowed using natural vegetation, increased resistance along the flow path and drop structures (MDEP, 1997). Additionally, prolonged stormwater contact with natural materials promotes the hydrologic cycle through infiltration, evaporation and transpiration. **Figure 12.1** provides cross sectional details for a naturalized drainage way, with an outlet into a constructed wetland prior to entry into the storm sewer or receiving water body.

12.2 Applications

Naturalized drainage ways are typically located near the downstream outlet of a developed basin as they require continuous base flow to maintain the health of wetland and riparian vegetation and prevent occurrence of stagnant pools. They can be implemented as retrofits to replace overloaded storm trunks or small eroded streams, or as part of new developments with long term growth in mind to prevent the occurrence of such situations.

As is indicated by their name, naturalized drainage ways must be designed to fit the unique drainage, topographic and development characteristics of each site. Natural drainage ways should not be implemented in areas with very flat or very steep topography. The designer is responsible for ensuring that physical attributes of the site can accommodate a drainage way and that the naturalized drainage way will enhance treatment and aesthetics of stormwater management in the area.



12.3 Design Considerations

Naturalized drainage ways require continuous base flow to meet all losses due to evaporation, transpiration and seepage. The design may incorporate existing natural features such as wetlands, drainage paths and recharge zones so long as care is taken to maintain natural patterns and avoid sedimentation or pollutant deposition. When incorporating wetlands, discussions with Alberta Environment will be required to approve the design.

Soils must be able to sustain vegetation growth and with vegetation present, withstand storm flows. Loamy soil is recommended for the channel and amended soils must be based on constructed wetland requirements.

The physical and performance parameters listed in **Table 12.1** must be considered during the preliminary design process. The parameters listed in **Table 12.1** are for the naturalized drainage way and its outlet to a wetland, receiving water or storm sewer.

Naturalized drainage way designs must convey at least the 1-in-2 year storm event with non-erosive velocities (Claytor et al, 1996) and within the parameters listed in **Table 12.1**. Where longitudinal slopes exceed 1%, drop structures should be used to reduce flow velocities and maintain flat grades. Water quality treatment through filtration by vegetation may be possible in some instances and is dependent on the site. Modelling of each individual site must be completed by designers to demonstrate function of the facility.

Other considerations for design and adaptation of naturalized drainage ways to ensure safety and long term functionality in the Edmonton climate and soils are as follows:

- design and locate facilities for pedestrian access and provide safety measures appropriate for expected flow depths and velocities;
- design vertical profile of vegetation located along roadways or near intersections to prevent impedance of driver visibility;
- select vegetation to be able to structurally withstand moderate flow velocities and erosive forces of design events;
- select vegetation for the facility base to withstand and thrive in conditions of near constant inundation;

- select vegetation for side slopes to withstand cycles of drought and brief inundation;
- select salt tolerant species for plantings along roadways (Appendix A);
- size facilities receiving road runoff containing salts to prevent salt induced injury to plants and soils as per Appendix D; and
- design soil amendments in roadside facilities to buffer high salt loadings.

The plan view, details and profiles of any naturalized drainage ways must be included on design drawings as indicated in **Table 12.2**.

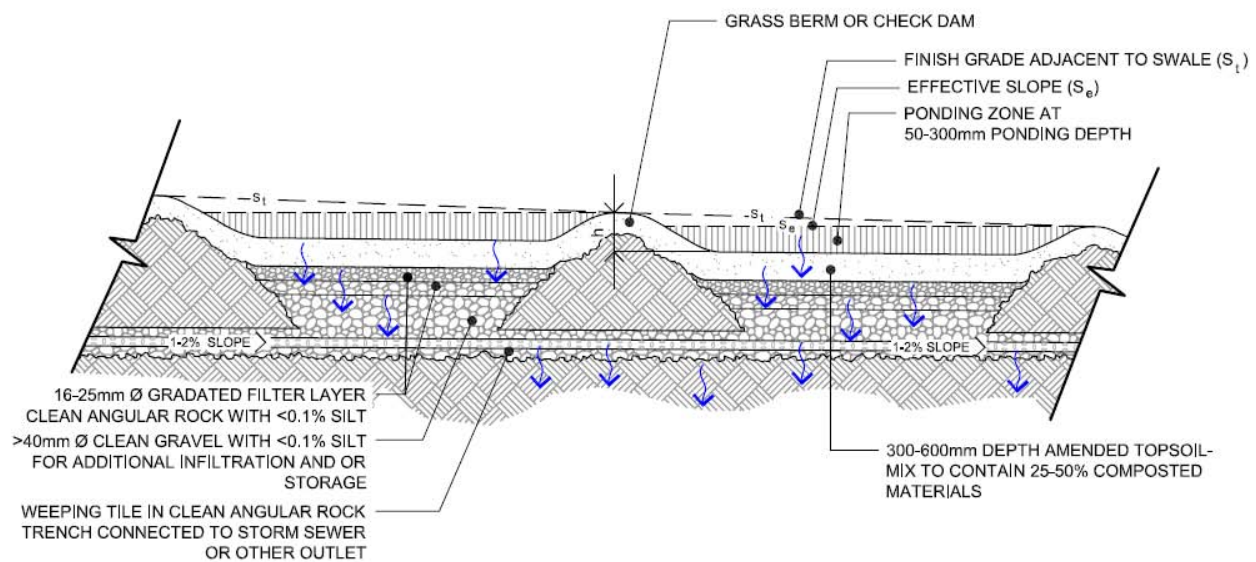


Figure 12.1 Longitudinal View of Naturalized Drainage Way with Check Dams

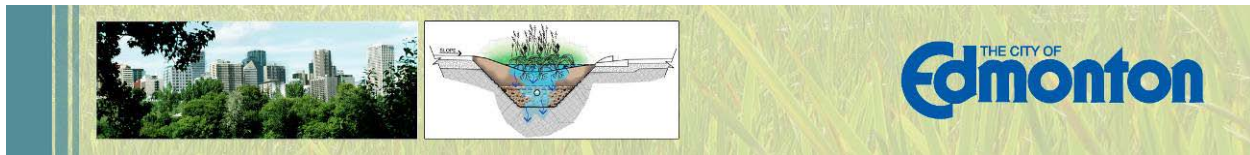


Table 12.1
Naturalized Drainage Way Parameters and Guidelines

Reported Parameters	Description and Recommendation
Contributing Area	≥1 ha
Baseflow	Near continual baseflows resulting from return flows from residential or commercial water uses in contributing catchments, or proximity to water table
Design Discharge	Safely convey Q_2 event with non-erosive velocity (0.6 m/s to 1.5 m/s, depending on vegetation and soil type); Q_{10} and Q_{100} not to exceed rates defined in Master Stormwater Drainage Plan
Flow-Through Velocity	Determine flow through capacity (maximum flow without re-suspending and flushing trapped pollutants) using hydraulic modelling; non-erosive velocities 2-year, 5-year, 10-year, 25-year and 100-year design events
Flow Depth	0.6 m to 1.2 m during a 2-year design event
Ponding Depth	0.15 m during a 2-year design event
Media Layers	Growing media: (amended soil) 300 mm to 650 mm depth able to support dense vegetation
Vegetation	Grasses and dense vegetation (100% coverage at establishment – 2-years) on drainage way slopes and within wetland zones along drainage way
WSE in Design Storms	Show that HWL in 100-year return period storm events do not compromise adjacent structures
Captured Volume	Volume of water retained through ponding and surface infiltration during the 2-year design event; additional volume captured during larger events if applicable
Emptying Time	Duration of water quality volume ponding following design events is 24 hrs; however baseflow ponding may extend beyond this time period and designs requiring this characteristic must be made accordingly
Geometry	Site specific to take advantage of existing topography and natural water features; typically trapezoidal or parabolic; provide cross-section detail with dimensions labelled
Side Slopes	3:1 (H:V) or flatter preferred (max 2:1)
Longitudinal Slope	Determine effective slope (>0.1%) for the 2-year design event using Manning's equation with initial $n=0.035$ and at maturity $n=0.08$; slopes >1% require grade control structures to flatten longitudinal slopes to less than 0.5% between grade control structures
Groundwater Buffer	Where appropriate, groundwater table may be in continual or intermittent contact with facility to sustain wetland vegetation
Structural Buffer	Facility located ≥3 m from building foundations
Planting Plan	Velocity tolerance for the 2-year design event flow; emergent plantings to be resistant to intermittent inundation and prolonged drought; wetland plantings appropriate where bottom is expected to receive continual baseflows

(UDFCD, 2008; MSSC, 2005; COP, 2004b; Claytor et al, 1996; Caraco et al, 1997)

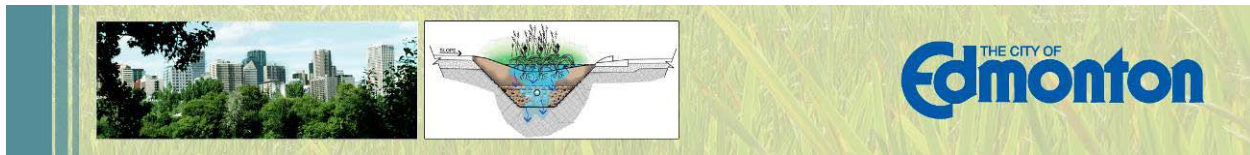


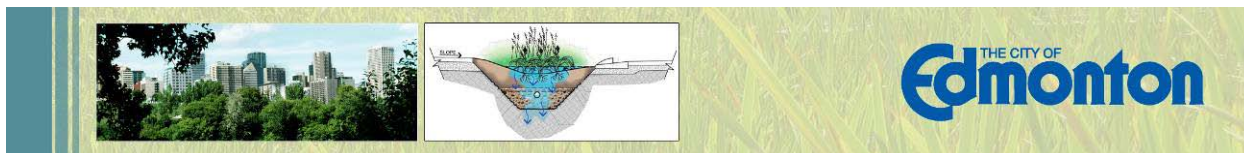
Table 12.2
Naturalized Drainage Way Drawing Details

Parameter	Plan	Detail	Profile	Description
Inlet	x	x		Shown on plan view and typical detail provided (pipe daylight, curb cut, flow spreader, ribbon curb, OGS): inverts; sizes; slopes; and, materials
Materials		x	x	Material specifications(soil, drainage material, drain pipes, geotextile), depth, hydraulic conductivity
Slope	x	x	x	Side slopes, longitudinal slope, effective slope, check dams or drop structures, flow disconnection curtains
Outlets		x		Spill elevation, catchbasin type and grate, weir, inlet control device (ICD)
Catchment	x			Delineated catchment area directed to naturalized drainage way, including daylighted pipe catchment
Surface area	x			Dimensions outlined on drawings and stated in report; setbacks from property line and structures
Depth		x		Ponding depth and water surface elevation during design storm and maximum prior to spill
Flow Arrows	x			From contributing area; within drainage way and wetland zones; overland spill route
Inundation	x			Extent of inundation during design storms (HWL)
Erosion control	x	x		Located at all inlets until site stabilized; outlets if overland spill
Landscaping	x	x		Detailed planting plan and succession plan if required, for drainage ways and wetland zones

(COP, 2004b; Claytor et al, 1996)

12.2 Operation and Maintenance

Operational requirements to keep maintenance of naturalized drainage ways to a minimum include street sweeping, soil testing in high pollution areas and removal of organic matter and sediment. The schedule for operation, maintenance and replacement activities for naturalized drainage ways is in **Table 12.3**. Similar to grass swales, naturalized drainage ways should be inspected quarterly during establishment (first 2 years) and semi-annually thereafter, with spot inspections conducted after severe storm events. Visual inspection during spring break-up is important to mitigate flooding due to ice blockage. If the drainage way is receiving water from roadways or parking lots to which de-icing

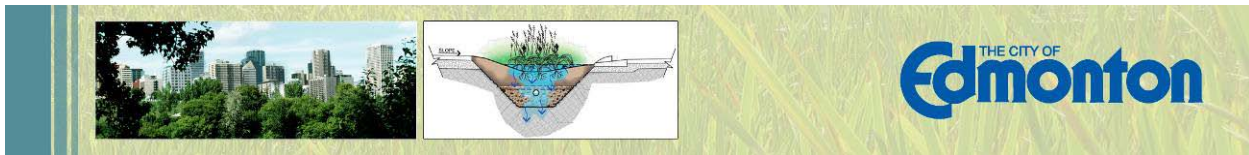


compounds are applied, soil testing is recommended annually to monitor salt content.

Table 12.3
Naturalized Drainage Way Operation, Maintenance and Replacement Schedule

Operation Activities	Scheduling
Inspect for sedimentation (identify source), erosion, plant health, and soil condition	Semi-annually (spring, fall)
Irrigation	During establishment (as required)
Street sweeping to prevent sedimentation	Semi-annually (spring, fall)
Strategic application of de-icing material on adjacent roadways	Winter
Avoid piling snow into facility unless specifically designed for this purpose	Winter
Soils testing in areas with high levels of contaminants	Bi-annually
Maintenance Activities	
Weed control	Monthly
Mow grass, if applicable, and remove clippings, minimum length (100-250 mm) no shorter than maximum design flow depth	Monthly (May-October)
Litter and debris removal from inlets, flow paths and vegetation	Quarterly
Prune vegetation to prevent debris build-up	Annually
Removal of accumulated sediment, repair source if possible	Annually (spring) or when sediment depth >100 mm
Erosion repair of soils, splash pad, rip rap	Annually (spring)
Prevent Ice blockage	Inspection during spring break-up
Replacement Activities	
Plants/grass (unhealthy or dead >10%)	As indicated in inspection (1-10 years)
Mulch, if applicable, replenish or replace	As indicated by inspection (1-3 years)
Soils	As indicated by contaminant / infiltration testing (2-20 years)

(UDFCD, 2008; Caraco et al, 1997)



<http://www.peachygreen.com/wp-content/uploads/2011/03/cistern.jpg>

13.0 RAINWATER HARVESTING FOR RE-USE

13.1 Description

Rainwater is drops of freshwater that fall as precipitation from clouds. Rainwater harvesting is the collection and conveyance of rainwater from a building roof to storage in a rain barrel or a cistern for re-use in irrigation or approved non-potable uses. **Figure 13.1** shows a schematic of a rainwater harvesting system with a buried cistern. Key components of such a system include the roof surface, gutters and downspouts, roof washer to remove contaminants, cistern, and pumping and piping system. **Table 13.1** lists and details these components.

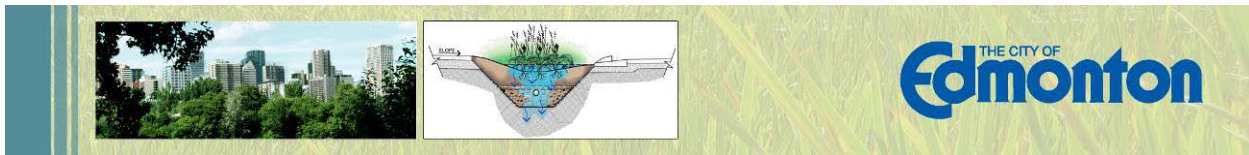
Above ground cisterns may include:

- rain barrels that receive unfiltered runoff from downspouts and are not connected to automatic irrigation systems;
- rooftop capture cisterns which provide irrigation pressure through gravity;
- above grade bladders which may be located in tight spaces and an external pump to provide irrigation pressure; or
- cisterns incorporated into a heated building allowing year round water use for non-potable purposes.

Above ground cisterns are easily implemented. However, care must be taken to prevent damage and leakage due to winter freeze/thaw cycles. These cisterns require both an overflow and a drain to allow for winterization and for facility cleaning. Underground cisterns require cleanout ports or manhole access, depending on the cistern design. Concrete cisterns must be winterized to prevent cracking and subsequent leaking due to the winter freeze/thaw cycle. Buried cisterns may also be made of plastic void crates able to withstand freeze/thaw cycling but requiring periodic vacuum cleanout as part of maintenance activities.

13.2 Application

Depending on the jurisdiction, rainwater can be used for outdoor irrigation, toilet flushing and washing clothes. Re-use sources and



applications are governed by federal and provincial legislation (Health Canada, 2007; Government of Alberta, 2010). In Alberta, rainwater re-use for irrigation is widely accepted and re-use for toilet flushing is becoming more common.

Topography, land use and location all have impacts on rainwater harvesting system design and performance. Rainwater harvesting using a rain barrel typically does not require anything more than directing a downspout into a water storage container and then manually drawing water for irrigation.

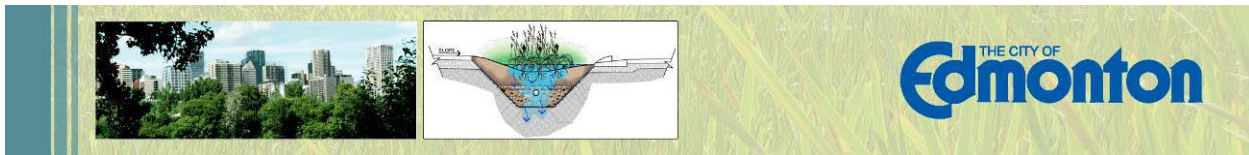
Rooftop cisterns are likely to capture less rainwater due to structural limitations; however, gravity based distribution to a re-use site is possible. Buried cisterns require pumping but store more water (TRCA, 2009) and should be located in native soils. If installation in a fill slope is necessary, both geotechnical and structural engineering design are required. Buried cistern overflows should be located with consideration for the foundation location. Lot grading, both adjacent to and downstream of the buried cistern overflow, should be designed to avoid flooding, ponding or soil saturation. Tanks should be water tight and installed at least 3 metres from building foundations (TRCA, 2009). The location of utilities and services must be considered when placing buried cisterns to avoid conflicts.

Rainwater should only be harvested from roof surfaces. Avoid harvesting rainwater from vehicular or pedestrian areas, surface water runoff or standing water to prevent introduction of contaminants such as salts, bacteria and metals (COP, 2004a). Due to the minimal water quality treatment available with rainwater harvesting, it is best paired with additional LID-BMP facilities when pollutant loading targets must be met.

13.3 Design Considerations

Unique site characteristics must be considered in the rainwater harvesting system design based on professional knowledge and judgement. Cisterns must be designed and installed by qualified professionals, according to the manufacturer's instructions.

The following recommendations and criteria are provided to aid in the design of rainwater harvesting and re-use installations:



- The volume of rainwater that may be collected from a roof surface must be determined for each unique application based on the roof footprint or exterior roof area (ft^2 or m^2). A roof surface is generally about 75% efficient in collecting rainwater due to evaporation, abstraction and leakage, so the volume available for capture from a roof surface can be calculated using the following formula:

$$V_{rw} = \frac{0.75 * RA * D_{rw}}{1000}$$

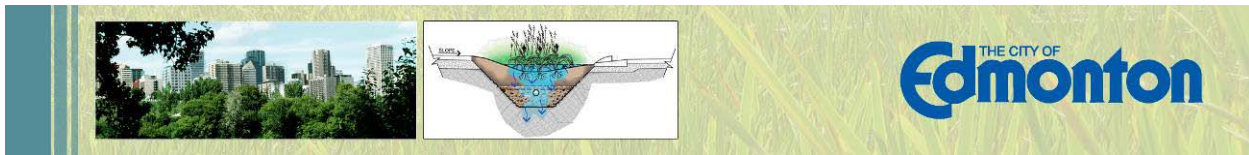
Where:

V_{rw} = Volume of available rainwater for capture (m^3)

RA = Roof area (m^2)

D_{rw} = Average annual rainfall depth (mm)

- The volume available for capture from a rooftop may exceed, meet or fall short of seasonal demand requirements based on bi-weekly rainfall patterns, size of the cistern and other water uses. Careful sizing of the cistern is required, by a qualified irrigation or engineering professional, to ensure the size and costs of installation are appropriate for the capture volume and non-potable demands.
- A cistern may be connected to a potable water source, such as municipal water, for top-up in the event that demand exceeds captured volumes. The potable water top-up must have backflow prevention measures in place.
- Cistern overflows must be directed away from building foundations to avoid flooding or damage to the foundation during large events.
- The roof washer (first flush diverter) should be designed to divert the first 0.5 mm of runoff during an event away from the storage facility to avoid clogging or contamination. As a result treatment of the diverted water does not occur unless the diverted water is directed to another LID-BMP facility in a treatment train approach.
- account for frost depth and freeze / thaw cycles when specifying depth and type of outdoor cisterns;
- confirm compliance with the Alberta Building Code; and
- consider timing of seasonal water availability and demands using continuous precipitation modelling for determining the



optimal cistern size.

- Cisterns located within a building envelope must be included on drawings submitted for the building permit. Buried cisterns should be installed in native soils whenever possible to ensure subsurface stability (TRCA, 2009). Due to the capture and retention function of rainwater harvesting systems, natural soil testing is required only for buried systems.
- Other inspection and testing activities recommended to be completed during and following construction include: (1) a plumbing inspection to ensure its compliance with CSA B128 and City of Edmonton by-laws; and (2) leak testing of cistern and irrigation piping before commissioning. Rainwater and greywater have different sources and therefore different requirements and limitations for re-use in Canada.

To ensure long term operational success of these installations, the facility's physical and performance parameters as listed in **Table 13.2** must be considered and included in the design.

13.4 Operation and Maintenance

Operational requirements include inspecting gutters and leaf screens, roof washers, filters, pumping and piping systems, and the cistern itself for leaks and sedimentation. The schedule for operation, maintenance and replacement activities for cisterns is in **Table 13.3**. Filter and screen inspections are recommended monthly from April to September, and after a severe storm event. This table is provided as a minimum recommendation, as the schedule for these activities may vary depending on cistern type, location and the manufacturer's recommendations.

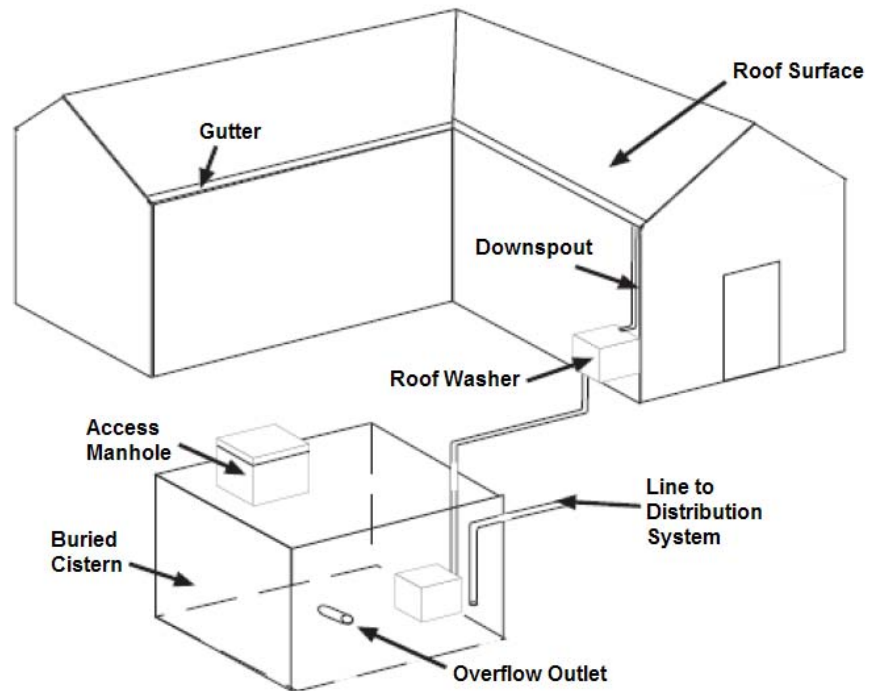


Figure 13.1 Rainwater Harvesting System Schematics (adapted from Rupp, 1998)

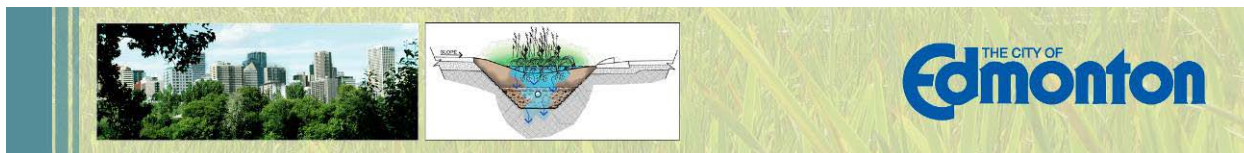


Table 13.1
Rainwater Harvesting System Components

Components	Description
Gutter Screen (Leaf Screen)	Prevents large debris and leaves from entering roof gutters
Rainwater Conveyance	System of gutters, downspouts and pipes (generally plastic) to carry water from roof to cistern
Roof Washer (First Flush Diverter)	Directs first 0.5 mm of rainwater volume, containing higher pollutant loads, away from cistern
Filter	Removes smaller debris, particulates and bacteria from rainwater prior to entry into cistern; often included in roof washer
Cistern	Watertight tank or void space connected to roof downspouts and re-use outlets
Cistern Overflow	Outlet pipe to surface or subsurface drain for use when cistern volume is exceeded
Pump	Submersible or surface pump to pressurize irrigation or plumbing
Delivery Conveyance	Irrigation and non-potable water pipes, marked in purple as per CSA B128, with appropriate signage ("Do Not Drink") at hose bibs or faucets
Potable Water Top Up	Pipes connected as per CSA B128, with backflow prevention to prevent contamination of potable water source
Level Indicator	Level indicator (float or other sensor) to trigger potable system top up when cistern volume drawn down

(Kloss, 2008; CRDWS, 2007)

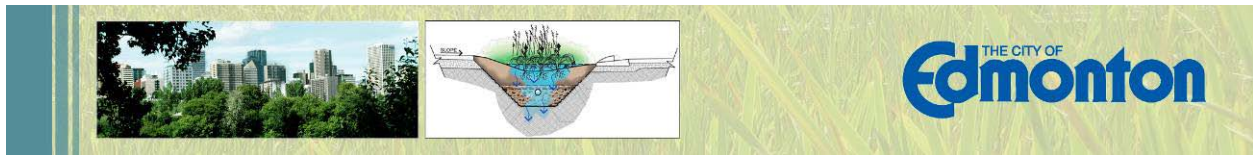


Table 13.2
Rainwater Harvesting System Design Parameters and Guidelines

Design Parameters	Description
Gutter Screen	Maximum screen size: 10 mm
First Flush Diversion	Volume: 0.5 mm * roof area; spill directed away from building foundation
Filter	Materials (type and depth of layer); treatment capacity (particle size and pollutants removed); maintenance schedule
Cistern	Location: protected from direct sunlight, (sub)surface; volume, material specifications, overflow elevation; access port or manhole
Expected Demand	Automatic or manual withdrawal, expected rate of withdrawal, expected purpose for re-used water
Potable Connection	(Optional) expected volumes and pattern of use; method of initiating top-up (manual / automatic)
Pump	Specification, type and location (submerged or external)

(Kloss, 2008; CRDWS, 2007)

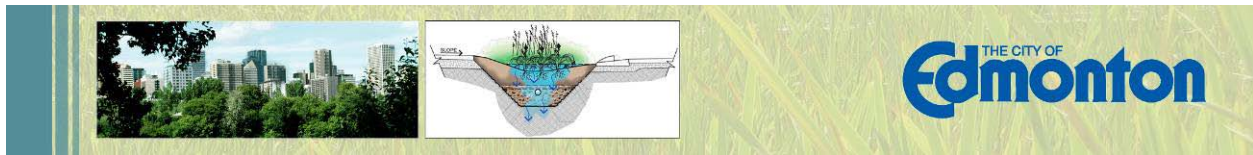
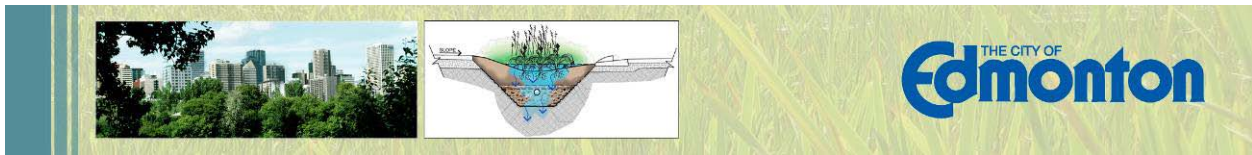


Table 13.3
Cistern Operation, Maintenance and Replacement Schedule

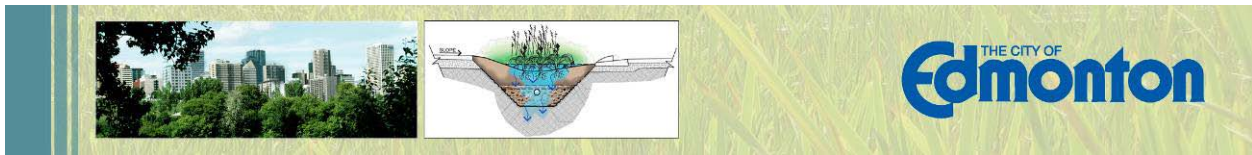
Operation Activities	Scheduling
Inspect cistern, pipes and pump for leaks, clogging	Quarterly
Inspect filters	Monthly
Inspect roof gutter screens	Quarterly
Irrigation hook-up and winterization	Semi-annually (spring, fall)
Maintenance Activities	
Litter, leaves and debris removal	Quarterly, as required
Prune nearby vegetation to avoid debris accumulation	Annually
Repair leaks and cracks	Semi-annually (spring, fall)
Filter cleaning	Semi-annually (spring, fall)
Flush inlet and outlet pipes	Annually (spring)
Vacuum / flush cistern to remove sedimentation	Annually or when accumulation >25 mm
Replacement Activities	
Large shrub / tree removal	As indicated in inspection to prevent root penetration (10-20 years)
Filter	As indicated in inspection (10-100 yrs)
Cistern	As indicated in inspection (25-100 yrs)
Pipes	As indicated in inspection (25-100 yrs)

(COP, 2004a; City of Tucson, 2005)

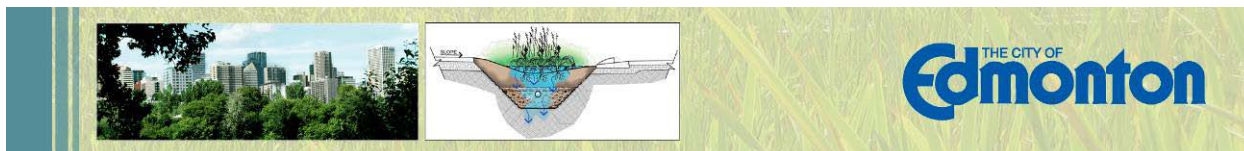


14.0 GLOSSARY

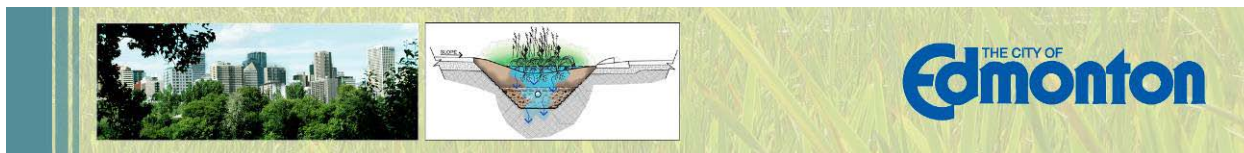
Term	Definition
A Horizon	Surface mineral (topsoil) horizon
Absorption	The physical uptake of water or dissolved chemicals by soils or organisms such as microbes or plant roots
Abstraction Potential	Ability of the landscape to retain runoff in surface storage on vegetation (leaves) and minor depressions (puddles) and through infiltration
Antecedent Conditions	Soil moisture level prior to a rainfall event
B Horizon	Enriched mineral horizon
Biodegradation	Decomposition of any material by micro organisms
Biology	Study of living organisms
Brownfield	Abandoned or under-used commercial or industrial land available for re-development
C Horizon	Undisturbed mineral horizon
Cation	Positively charged ion
De-Icing Activities	Salt and sand application to roadways during the winter to prevent ice build-up and provide traction
Depression Storage	Water retained in puddles and other surface depressions of the ground
Design Event	Runoff depth, simulated with an event-type model, for a storm likely to occur with a return period such as 1-in-10 years or 1-in-100 years
Detention (Stormwater)	Water volume contained in a facility and released to the storm sewer network at a slower rate than the event runoff rate
Disconnected Impervious Areas	Impervious surfaces, such as roofs, driveways, parking lots, that are designed to drain to vegetated surfaces or LID-BMP facilities
Ecology	Study of organisms, their habitat and their interactions with the environment
Erosion	The mechanical process of wearing or grinding something down (as by particles washing over it)
Evaporation	Process by which liquid water converts to water vapour by energy from heat or air movement



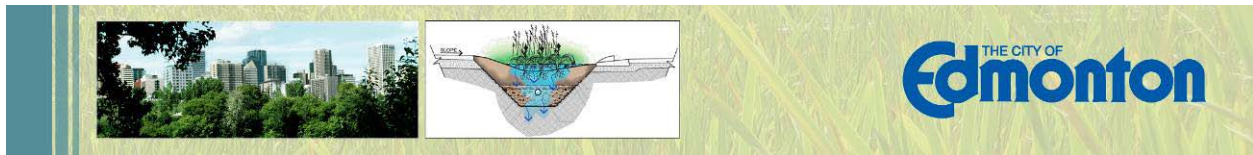
Term	Definition
Expansive Soils	Soils that contain water-absorbing minerals and expand as they take on water
First Flush	During a rain event, the initial surface runoff from impervious surfaces which contains elevated pollutant loads accumulated during the preceding dry period
Fluvial	Relating to rivers and streams
Greenfield	Land that has not been previously developed
Groundwater Recharge	Replenishment of existing natural groundwater aquifers from surface water or precipitation
Holistic	Considering the importance of the whole system and the interdependence of its parts, including ecology, biology, hydrology, environment, sustainability, economics, growth, etc.
Hydraulic Conductivity	The rate at which soil allows water to move through it
Hydrologic Cycle	Natural cycle of water from the atmosphere, to precipitation, to runoff, infiltration and groundwater recharge, to evaporation and transpiration back into the atmosphere
Hydrology	Study of the movement, distribution and quality of water throughout the Earth and its atmosphere
Impervious Surfaces	Prevent water from passing through or penetrating into the sub-soils
Indigenous Vegetation	Plants that are native to a specific locale
Infiltration	Process by which water penetrates into soil from the surface or upper layers
Interception	Rainwater held by plants as the water falls onto leaves, stems and branches
Invasive Species	Non-indigenous species, or non-native plants or animals that adversely affect the habitats and bioregions they invade economically, environmentally, and/or ecologically
Level Spreader	Stormwater outlet designed to convert concentrated runoff to sheet flow
Major System	Overland flow route designed to handle 1 in-100 year storm event flows and volumes



Term	Definition
Minor System	Stormwater sewers designed to accommodate 1-in-5 year storm event flows
Non-Point Source	Pollutants or stormwater flows entering a facility or waterbody through overland sheet flow rather than through a specific discharge location (point source)
Noxious Weed	An invasive species of plant that has been designated by local or federal authorities as one that is injurious to agricultural and / or horticultural crops, natural habitats and/or ecosystems, and/or humans or livestock
Off-Line Facilities	Stormwater is directed from the primary flow path for retention and / or enhanced treatment
Open Soils	Soils that have high infiltration rates and convey water into deeper layers of soil or to groundwater aquifers
Ornamental Vegetation	Vegetation typically grown in for aesthetic (flowers, fruit, etc.) Purposes
Passive Recreation	Emphasizes the open-space aspect of a park and involves a low level of development, including picnic areas and trails
Ph	Degree of acidity
Pre-Development Hydrology	Amount of water contributing to runoff and other stages of the hydrologic cycle prior to incorporation of impervious area (development) on the site
Rainwater	Drops of fresh water that fall as precipitation from clouds
Retention (Stormwater)	Water volume captured in a facility and released to groundwater or the atmosphere through the hydrologic cycle instead of to the storm sewer network
Retrofit	Installation of new technology or features (i.e. Lid-bmp's) to existing developments
Riparian	On, of or relating to the banks of a natural course of water
Runoff	The portion of rainfall that is not abstracted by interception, infiltration, or depression storage
Sedimentation	The act or process of depositing sediment
Sheet Flow	Slow, shallow stormwater runoff over the land surface

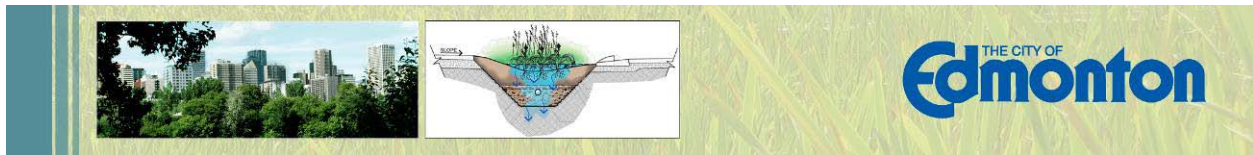


Term	Definition
Source Control	Facilities distributed throughout a site to capture and treat stormwater runoff from small catchment areas
Stormwater	Precipitation during a storm event that does not absorb into the soil and runs off into surface water bodies or stormwater management facilities
Subdivision Of Land	The division of a lot, tract, or parcel of land into two or more lots, plots, sites, or other divisions of land for the purpose, whether immediate or future, of sale or of building development
Tight Soils	Soils resistant to infiltration
Time Of Concentration (Tc)	The time it takes for surface runoff to travel from the farthest point of the watershed to the outlet
Transpiration	The process of releasing water vapour through surface pores; typically refers to vegetation
Treatment Train	LID-BMP's placed in series to improve water quality treatment so that each successive cell receives cleaner water than the previous one
Turbidity	Cloudiness or opacity in the appearance of water caused by suspended solids or particles
Urban Heat Island	An area, such as a city or industrial site, having consistently higher temperatures than surrounding areas because of a greater retention of heat, as by buildings, concrete, and asphalt
Urbanization	Physical growth of an urban area resulting in the conversion of pervious surfaces with impervious ones
Water Quality Capture Volume	The storage needed to capture and treat the runoff from 90% of Edmonton's average annual rainfall.
Water Quality Sonde	Device in the logging assembly that senses and transmits water quality data

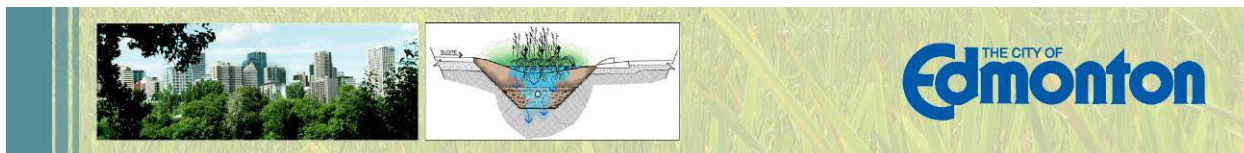


15.0 REFERENCES

- Alaska Department of Environmental Conservation.** 2009. *Alaska Storm Water Guide*. Alaska Department of Environmental Conservation, Division of Water. Anchorage, AK.
- Alberta Environment (AENV).** 2010. *Evaporation Data*.
http://www3.gov.ab.ca/env/water/GWSW/quantity/learn/what/CLM_climate/CLM1_metdata.html. Accessed October 2011.
- Alberta Low Impact Development Partnership.** 2010. <http://alidp.org/>. Accessed August 2010.
- Alberta Soil Information Centre.** 2001. *AGRASID 3.0: Agricultural Region of Alberta Soil Inventory Database (Version 3.0), Soil Layer File*. Edited by J.A. Brierley, T.C., Martin, and D.J. Spiess. Agriculture and Agri-Food Canada, Research Branch; Alberta Agriculture, Food and Rural Development, Conservation and Development Branch. Available from Alberta Soil Information Centre.
- Alberta Soil Survey.** 1962. Soil Survey of Edmonton Sheet (83-H). Report No. 21, by W.E. Bowser, A.A. Kjearsgaard, T.W. Peters, and R.E. Wells. University of Alberta, Bulletin No. SS-4.
- AMEC.** 2009. *The Metropolitan Government of Nashville and Davidson County – Green Infrastructure Master Plan*. Metropolitan Council. Nashville, TN.
- AMEC.** 2010. *The Armature – Low Impact Development Conceptual Drainage Design Report*. City of Edmonton, Edmonton, AB.
- Andriashek, L.D.** 1988. *Quaternary Stratigraphy of the Edmonton Map Area, NTS 83H*. Open File Report #198804. Alberta Research Council. Edmonton, Alberta.
- Bauder, T.A., Waskom, R.M., Davis, J.G.** 2007. *Irrigation Water Quality Criteria, Crop Series No. 0.506*. Colorado State University Cooperative Extension, Fort Collins, CO.
- Boumans, J.H., et al.** 1977. *Reclamation of Salt Affected Soils in Iraq – Soil Hydrological and Agricultural Studies*. International Institute for Land Reclamation and Improvement, Wageningen, Netherlands.
- Canadian Standards Association (CSA).** 2007. *Design and Installation of non-potable water systems / Maintenance and field testing of non-potable water systems*. CAN/CSA-B128.1-06/CAN/CSA-B128.2-06. National Standards of Canada, Mississauga, ON.
- Canadian Water and Wastewater Association (CWWA).** 2008. *Research Highlights, Rainwater Harvesting and Grey Water Re-use, Technical Series 03-100*. Canadian Mortgage and Housing Corporation. Ottawa, ON.
- Capital Regional District Water Services (CRDWS).** 2007. *Water Conservation Technology – Rainwater Harvesting in Greater Victoria*. Capital Regional District Water Services. Victoria, BC.



- Caraco, D. and R. Claytor.** 1997. *Stormwater BMP Design Supplement for Cold Climates*. Center for Watershed Protection, Ellicott City, MD.
- Center for Neighborhood Technology.** 2010. *The Value of Green Infrastructure; A Guide to Recognizing Its Economic, Environmental and Social Benefits*.
- Center for Watershed Protection (CWP).** 2007a. *National Pollutant Removal Performance Database Version 3*. CWP, Ellicott City, MD.
- City of Edmonton (COE).** 2004. *Volume 5, Landscaping. Design and Construction Standards*. March 2004. City of Edmonton, Edmonton, AB. <http://www.edmonton.ca/city_government/planning_development/city-design-construction-stand.aspx>. Accessed April 2010.
- City of Edmonton (COE).** 2006. *Drainage Services Stormwater Quality Strategy*. January 2006. City of Edmonton, Edmonton, AB. <http://www.edmonton.ca/attractions_recreation/documents/StormwaterQuality06.pdf>. Accessed March 2010.
- City of Edmonton (COE).** 2008a. *Sewers Use Bylaw No. 9675*. Dec 10, 2008. City of Edmonton, Edmonton, AB. <<http://www.edmonton.ca/business/documents/C9675.doc>>. Accessed March 2010.
- City of Edmonton (COE).** 2008b. *Bylaw 14600 - Community Standards Bylaw*. February 13, 2008. City of Edmonton, Edmonton, AB. <http://www.edmonton.ca/bylaws_licences/CityGov/C14600.doc>. Accessed March 2010.
- City of Edmonton (COE).** 2008c. *Your guide to planting trees and shrubs on city property*. City of Edmonton, Edmonton, AB. <http://www.edmonton.ca/environmental/documents/guide_to_planting_trees_on_city_property.pdf>. Accessed May 2010.
- City of Edmonton (COE).** 2008d. *Surface Drainage Bylaw No. 11501*. Dec 10, 2008. City of Edmonton, Edmonton, AB. <<http://www.edmonton.ca/business/documents/C11501.doc>>. Accessed November 2010.
- City of Edmonton (COE).** 2009. *Design and Construction Standards, Volume 3, Drainage*. January 2009. City of Edmonton, Alberta. <http://www.edmonton.ca/city_government/planning_development/city-design-construction-stand.aspx>. Accessed March 2010.
- City of Edmonton (COE).** 2009b. *Sewers Bylaw No. 9425*. Nov 24, 2009. City of Edmonton, Edmonton, AB. <<http://www.edmonton.ca/business/documents/C9425.doc>>. Accessed Nov 2010.
- City of Portland (COP).** 2004a. *ENB-15.71 – Rainwater Harvesting Systems for Interior Use or Combined Interior and Exterior Use – ICC – RES/34/#1 & UPC/6/#2*. City of Portland, Portland, OR. <<http://www.portlandonline.com/auditor/index.cfm?a=81417&c=38527>>. Accessed February 2010.
- City of Portland (COP).** 2004b. *ENB-4.01 - Stormwater Management Manual - Revision #3*. Environmental Services City of Portland Clean River Works, September 2004. City of Portland, Portland, OR.



<<http://www.portlandonline.com/auditor/index.cfm?a=12548&c=28044>>. Accessed February 2010.

City of Toronto, 2009. *Toronto Municipal Code Green Roofs Chapter 492*. City of Toronto, Toronto, ON.

City of Toronto. 2010. Green Roof Bylaw. City of Toronto, Toronto, ON. <http://www.toronto.ca/greenroofs/policy.htm>. Accessed October 2010.

City of Tucson. 2005. *City of Tucson Water Harvesting Guidance Manual, October 2005. Ordinance Number 10210*. Ed. A.A. Phillips. City of Tucson, Department of Transportation, Stormwater Management Section, Tucson, AZ. <<http://www.tucsonaz.gov/ocsd/business/water/>>. Accessed April 2010.

Claytor, R.A., and T.R. Schueler. 1996. *Design of Stormwater Filtering Systems*. Center for Watershed Protection, Ellicott City, MD and Chesapeake Research Consortium, Inc. Solomons, MD.

Collins, Paul. "Green Roofs and Earth Sheltered Buildings." <http://construction.ntu.ac.uk/staffwebs/greenroofs/aboutNoPics.htm>. Accessed September 16, 2011.

Denver Regional Council of Government (DRCOG). 1983. *Urban Runoff Quality in the Denver Region*. Denver, CO.

Diniz, E. 1980. *Porous Pavement Phase 1 – Design and Operational Criteria*. EPA-600/2-80-135. US Environmental Protection Agency Municipal Environmental Research Laboratory Office of Research and Development. August 1980. Cincinnati, OH.

ECONorthwest. 2007. *The Economics of Low Impact Development: A Literature Review*.

Energy, Mines and Resources Canada. 1981. *The National Atlas of Canada 5th Edition, Canada, Frost-Free Period*. Geographical Services Directorate, Surveys and Mapping Branch, Department of Energy, Mines and Resources, Ottawa, ON.

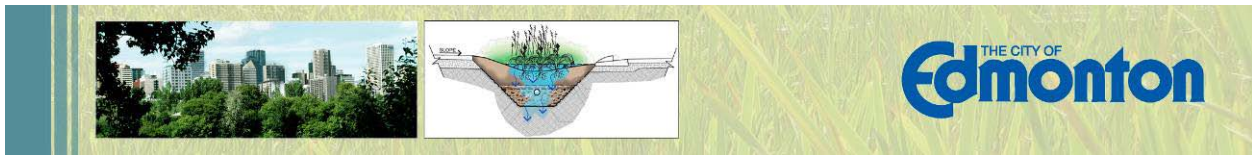
England, G. 2009. *The Pollutant Removal Efficiency Conundrum*. Stormwater – The Journal for Surface Water Quality Professionals. October 2009.

Environment Canada (EC). 2010. *Canadian Climate Normals 1971-2000, Edmonton City Centre Airport*. <http://climate.weatheroffice.gc.ca/climate_normals/>. Accessed May 2010.

Environment Canada (EC). 2010b. *Annex C Annual Report from City of Edmonton – Roadway Maintenance for 2010 (Submitted to Environment Canada under Annex C of the Canadian Environmental Protection Act (1999) Code of Practice for the Environmental Management of Road Salts)*. City of Edmonton, Edmonton, AB.

Environment Canada and Health Canada (EC). 2001. *Canadian Environmental Protection Act, 1999 – Priority Substances List Assessment Report – Road Salts*. Minister of Public Works and Government Services, Gatineau, PQ.

Fipps, Guy. 2003. *Irrigation Water Quality Standards and Salinity Management Fact Sheet B-1667*. Texas Agricultural Extension Service, Texas A&M University System, College



Station, TX. <<http://agnewsarchive.tamu.edu/drought/DRGHTPAK/SALINITY.HTM>>. Accessed August 2010).

Goom, S. 2003. *Green Roofing the Canadian Centre for Pollution Prevention*. Prepared for the Canadian Centre for Pollution Prevention, Sarnia, ON.

Government of Alberta. 2010. *Reclaimed Water Working Group*. <<http://www.municipalaffairs.gov.ab.ca/1171.cfm>>. Accessed April 2010.

Greater Vancouver Regional District (GVRD). 2005. *Stormwater Source Control Design Guidelines 2005 – Final Report*. Greater Vancouver Sewerage & Drainage District, Vancouver, BC.

Grieve, C.M., S. Wu, S.R. Grattan and A. Harivandi. 2007. *Tolerance of plants to salinity and to specific ions* In: K. Tanji (ed.) *Salt Management Guide for Landscape Irrigation with Recycled Water in Coastal Southern California*. Chapter 5, 1-60.

Gunderson, J. 2008. *Pervious Pavements – New findings about their functionality and performance in cold climates*. Stormwater, September 2008.

Health Canada. 2007. *Canadian Guidelines for Household Reclaimed Water for Use in Toilet and Urinal Flushing – draft for consultation*. Working Group on Household Reclaimed Water of the Federal-Provincial-Territorial Committee on Health and the Environment, Ottawa, ON.

Hun-Dorris, T. 2005. *Advances in Porous Pavement – Different types of materials and continuing research offer more options*. Stormwater. March-April 2005.

Hunt, W.F., and Lord, W.G. 2006. *Bioretention Performance, Design, Construction and Maintenance*. *North Carolina Cooperative Extension Service Bulletin*. Urban Waterways Series. AG-588-5. North Carolina State University, Raleigh, NC.

Kloss, C. 2008. *Managing Wet Weather with Green Infrastructure - Municipal Handbook – Rainwater Harvesting Policies EPA-833-F-08-010*. US Environmental Protection Agency, Low Impact Development Center. December 2008.

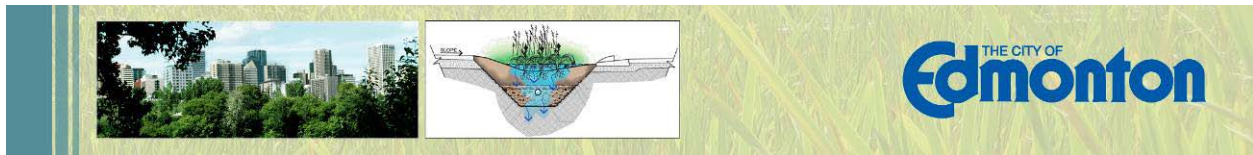
Kristopher H. 2008. *Winter Performance Assessment of Permeable Pavements: A comparative study of porous asphalt, pervious concrete and conventional asphalt in a northern climate*. Master thesis. University of New Hampshire, Durham, New Hampshire, USA.

Low Impact Development Center (LIDC). 2003. *Drainage – Bioretention Specification*. Low Impact Development Center, Beltsville, MD. <http://lowimpactdevelopment.org/epa03/biospec.htm>. Accessed December 2010.

Maisonneuve, Joan. 2011. *Heaving Walk Out Patios and Decks*. <http://www.phbia.com/documents/HeavingPatiosandDecksMay26.ppt>. Professional Home Builders' Institute of Alberta, Calgary, AB.

Massachusetts Department of Environmental Protection (MDEP). 1997. *Stormwater Management. Volume Two: Stormwater Technical Handbook*. MDEP, Boston, MA.

McKeague J.A., C. Wang, and G.M. Goen. 1986. *Describing and interpreting the macrostructure of mineral soils – a preliminary report*. Tech. Bull. 1986-2E. LRRI



Contribution No. 84-50. Land Resource Research Institute, Agriculture Canada, Ottawa, ON. pp.47.

Minnesota Stormwater Steering Committee (MSSC). 2005. *Minnesota Stormwater Manual – Version 2*. Minnesota Pollution Control Agency, St. Paul, MN.

National Research Council of Canada. 2006. *Alberta Building Code*. Second Release Approved 2009 by the Building Technical Council of the Safety Codes Council. National Research Council of Canada, Ottawa, ON.

Natural Regions Committee. 2006. *Natural Regions and Subregions of Alberta*. Compiled by D.J. Downing and W.W. Pettapiece. Government of Alberta. Pub. No. T/852.

Neithalath, N., R. Garcia, J. Weiss and J. Olek. 2005. *Tire-Pavement Interaction Noise: Recent Research on Concrete Pavement Surface Type and Texture, 8th International Conference on Concrete Pavements, Compendium of Papers CD-ROM*. Colorado Springs, Colorado, August 14-18, 2005.

New Mexico State University. 1996. New Mexico Climate Center Irrigation Scheduling Model Information. Department of Agronomy and Horticulture. Las Cruces. New Mexico. USA. <<http://weather.nmsu.edu/models/irrsch/soiltype.html>>. Accessed June 2010.

O'Brien & Company. 2009. *Low Impact Development (LID) Guidance Manual; A Practical Guide to LID Implementation in Kitsap County, Version 1.2*. Kitsap Home Builders Foundation, Bremerton, WA.

Peck, S. and Kuhn, M. 2003. *Design Guidelines for Green Roofs*. Ontario Association of Architects and CMHC, ON.

Perry, M. 2003. *Green Roofs Offer Environmentally Friendly Alternative*. Plant Engineering: August 2003.

Pitt, R. 2005. *Module 3b: Small Storm Hydrology and Why it is Important for the Design of Stormwater Control Practices*. Department of Civil and Environmental Engineering. University of Alabama, Tuscaloosa, AL.

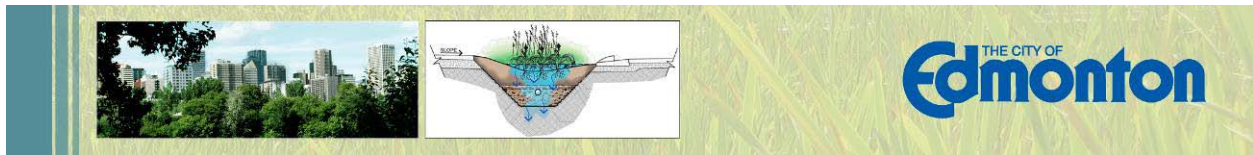
Pitt R. and R. Bannerman. 2009. *Soil amendments to enhance stormwater treatment*.

Province of Alberta. 2009. *Environmental Protection and Enhancement Act – Wastewater and Storm Drainage Regulation 119/93*. <http://www.qp.alberta.ca/574.cfm?page=E12.cfm&leg_type=Acts&isbncln=9780779735495>. Accessed March 2010.

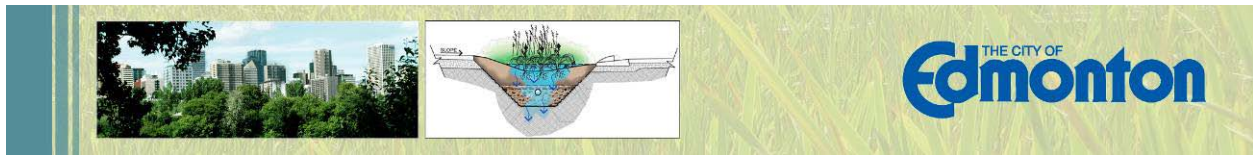
Province of Alberta. 2009. *Water Act – Water (Ministerial) Regulation 205/98*. <http://www.qp.alberta.ca/574.cfm?page=w03.cfm&leg_type=Acts&isbncln=9780779745005>. Accessed March 2010.

Puget Sound Action Team (PSAT). 2005. *Low Impact Development Technical Guidance Manual for Puget Sound*. Washington State University Pierce County Extension, Olympia, WA.

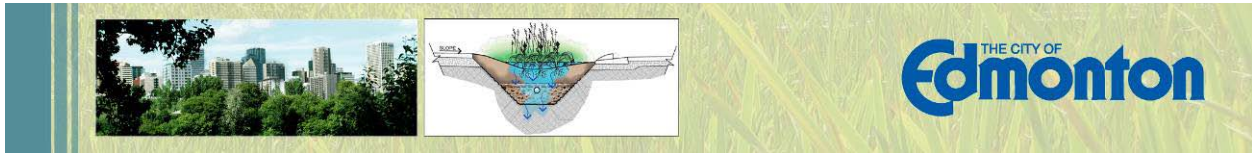
Riverkeeper. 2007. *Sustainable Raindrops: Cleaning New York Harbor by Greening the Urban Landscape*. <http://www.riverkeeper.org/wp-content/uploads/2009/06/Sustainable-Raindrops-Report-1-8-08.pdf>. Accessed November 2011.



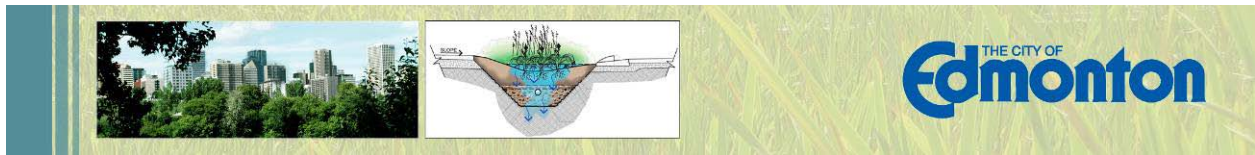
- Robert R.** 2009. *Water Quality and Hydrologic Performance of a Porous Asphalt Pavement as a Stormwater Treatment Strategy in Cold Climate*. Journal of Environmental Engineering EEENG-553R1. University of New Hampshire, Durham, NH, USA.
- Roseen, R.M., Ballesterio, T.P., Houle, J.J., Avellaneda, P., Briggs, J., Fowler, G., Wildey, R.** 2009. *Seasonal Performance Variations for Storm-Water Management Systems in Cold Climate Conditions*. Journal of Environmental Engineering, 135:3.
- Rupp, G. and B. Cichowski.** 2006. *Rainwater Harvesting Systems for Montana*. Montguide, Montana State University Extension. Bozeman, MT. (Originally published in 1998, revised 2006).
- Schueler, T.** 1987. *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban Best Management Practices*. MWCOG. Washington, D.C.
- Shelton, J.E.** 1991. *Using Municipal Solid Waste Compost*. Publication AG-439-19. North Carolina Cooperative Extension Service, NC. (<http://www.soil.ncsu.edu/publications/Soilfacts/AG-439-19>). Accessed 2010
- Southeast Michigan Council of Governments (SEMCOG).** 2008. *Low Impact Development Manual for Michigan, A Design Guide for Implementers and Reviewers*. Southeast Michigan Council of Governments. Detroit, MI.
- Southeastern Wisconsin Regional Planning Commission (SWRPC).** 1991. *Costs of Urban Nonpoint Source Water Pollution Control Measures – Technical Report Number 31*. Southeastern Wisconsin Regional Planning Commission. Waukesha, WI.
- Spectrum Technologies Inc.** 2010. *Water holding capacity by soil type*. <http://www.specmeters.com/pdf/water_holding_capacity_chart.pdf>. Accessed June 2010.
- Stephens, K., P. Graham and D. Reid.** 2002. *Stormwater Planning: A Guidebook for British Columbia*. B.C. Ministry of Water, Land and Air Protection (MWLAP). British Columbia.
- Stewart, R.E. and H.A. Kantrud.** 1971. *Classification of Natural Ponds and Lakes in the Glaciated Prairie Region*. Bureau of Sport Fisheries and Wildlife, U.S. Fish and Wildlife Service, Washington, D.C., USA. Resource Publication 92. 57 pp.
- Stormwater Managers Resource Center (SMRC).** 2010. *Stormwater Management Fact Sheet: Porous Pavement*. <www.stormwatercenter.net>. Accessed May 2010.
- Texas Agricultural Extension Service.** 1998. *Irrigation Water Quality Standards and Salinity Management*. In: Texas Drought Management Strategies. The Texas A&M University System. College Station, TX.
- The Watershed Academy.** 2010. *Designing LID to Work: Lessons Learned from North Carolina*. Watershed Academy Webcast, December 2010.
- Toronto and Region Conservation Authority (TRCA) and Credit Valley Conservation Authority (CVCA).** 2009. *Low Impact Development Stormwater Management Manual – Draft*, Toronto and Region Conservation Authority (TRCA) and Credit Valley Conservation Authority (CVCA), Ontario. October 2009.



- Toronto and Region Conservation Authority (TRCA) and Credit Valley Conservation Authority (CVCA).** 2010. *Low Impact Development Stormwater Management Planning and Design Guide; Version 1.0.* Toronto and Region Conservation Authority (TRCA) and Credit Valley Conservation Authority (CVCA), ON.
- United States Environmental Protection Agency (USEPA).** 1980. *Porous Pavement Phase 1 – Design and Operational Criteria.* The City of Austin, Texas with U.S. Environmental Protection Agency, Municipal Environmental Research Laboratory Office of Research and Development. Cincinnati, OH.
- United States Environmental Protection Agency (USEPA).** 1993. *Handbook: Urban Runoff Pollution Prevention and Control Planning.* U.S. Environmental Protection Agency, Office of Research and Development. Cincinnati, OH.
- United States Environmental Protection Agency (USEPA).** 1999a. *Storm Water Technology Fact Sheet – Bioretention (EPA 832-F-99-012).* United States Environmental Protection Agency, Office of Water. Washington, DC.
- United States Environmental Protection Agency (USEPA).** 1999b. *Storm Water Technology Fact Sheet – Vegetated Swales.* United States Environmental Protection Agency, Office of Water. Washington, DC.
- United States Environmental Protection Agency (USEPA).** 2004. *Stormwater Best Management Practice Design Guide, Order No. 1C-R059-NTSX.* Office of Research and Development National Risk Management Research Laboratory – United States Environmental Protection Agency. Cincinnati, OH.
- United States Environmental Protection Agency (USEPA).** 2007. *Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices EPA 841-F-07-006.* Nonpoint Source Control Branch, Washington, DC.
- United States Environmental Protection Agency (USEPA).** 2008. *Reducing Urban Heat Islands: Compendium of Strategies; Green Roofs.* <http://www.epa.gov/heatisd/resources/compendium.htm>. Accessed September 16, 2011.
- United States Environmental Protection Agency (USEPA).** 2009. *Green Roofs for Stormwater Runoff Control EPA/600/R-09/026.* Office of Research and Development National Risk Management Research Laboratory – Water Supply and Water Resources Division. Cincinnati, OH.
- United States Environmental Protection Agency (USEPA).** 2010. *Stormwater Management Best Practices.* <http://www.epa.gov/oaintrnt/stormwater/best_practices.htm>. Updated February 2010.
- United States Environmental Protection Agency (USEPA).** 2011. http://www.youtube.com/watch?v=huO_NRn34GI. Accessed October 2011.
- University of New Hampshire Stormwater Center (UNHSC).** 2007. *2007 Annual Report.* Durham, NH.



- Urban Drainage and Flood Control District (UDFCD).** 2008. *Urban Storm Drainage Criteria Manual - Volume 3 – Best Management Practices*. Urban Drainage and Flood Control District. Denver, Colorado.
- Verma T.R., and J.A. Toogood.** 1969. *Infiltration Rates in Soils in the Edmonton Area and Rainfall Intensities*. Canadian Journal of Soil Science. Volume 49. pp 103-109.
- Water Environment Research Foundation (WERF).** 2009. BMP and LID Whole Life Cost Models (Version 2.0). www.werf.org. Accessed August 2011.
- Wayne County.** 2001. *Planning and Cost Estimating Criteria for Best Management Practices TR-NPS25.00*. Rouge River National Wet Weather Demonstration Project. Wayne County, MI.
- Winogradoff, D.A.** 2002. *Bioretention Manual*. Prince George's County, Maryland, Department of Environmental Resources, Programs and Planning Division. Prince George's County, MD.



APPENDIX A: RECOMMENDED VEGETATION FOR LID-BMP FACILITIES IN EDMONTON

APPENDIX B: SOIL AMENDMENT TOOLS

APPENDIX C: COLD CLIMATE FACILITY SIZING EXAMPLE

APPENDIX D: ROAD SALT APPLICATION EXAMPLES

APPENDIX E: COMPARATIVE MODELLING STUDY

APPENDIX A

Recommended Vegetation for LID-BMP Facilities in Edmonton

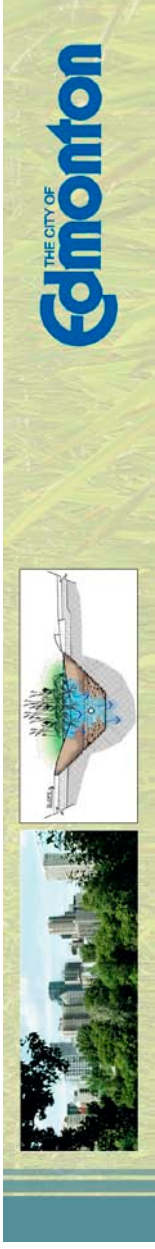


TABLE A.1
Recommended Native Plant Species for LID Facilities in Edmonton Alberta

Common Name	Scientific Name	Moisture Regime / Habitat	Morphology	Soil Preference	Soil Stabilizer	Tolerances
Woody Species (Trees & Shrubs)						
Thinleaf alder	<i>Alnus crispa</i> syn <i>Alnus viridis</i>	moist to wet sites	Shrub to small tree		Y	
River/Water Birch	<i>Betula occidentalis</i>	moist to wet sites	Tree			
Red-osier Dogwood	<i>Cornus stolonifera</i>	moist to dry; wooded to open sites	Shrub			High: salt, oil & grease, metals
Common juniper	<i>Juniperus communis</i>	medium dry to moist sites	Mounded shrub			High: oil & grease, metals; Med-High: salt
Creeping juniper	<i>Juniperus horizontalis</i>	moist to dry sites	Matted shrub			High: oil & grease, metals; Med-High: salt
Cottonwood	<i>Populus balsamifera</i>	moist to dry	Large tree			High: salt
Eastern cottonwood	<i>Populus deltoids</i>	moist to dry sites	Large tree			High: salt, oil & grease, metals
Pin cherry	<i>Prunus pennsylvanica</i>	moist to dry; shaded sites; slopes	Shrub	well drained		
Choke cherry	<i>Prunus virginiana</i>	moist to dry; shaded sites; exposed slopes	Shrub			Med-High: salt
Beaked or Bebb's Willow	<i>Salix bebbiana</i>	wet to dry sites				
Pussy Willow	<i>Salix discolor</i>	moist sites - open forests	Shrub to small tree			
Drummond's willow	<i>Salix drummondiana</i>	moist to wet sites	Shrub			
Sandbar Willow	<i>Salix exigua</i> syn <i>Salix interior</i>	moist to wet	Shrub	well drained		
Yellow Willow	<i>Salix lutea</i>	moist sites	Shrub			

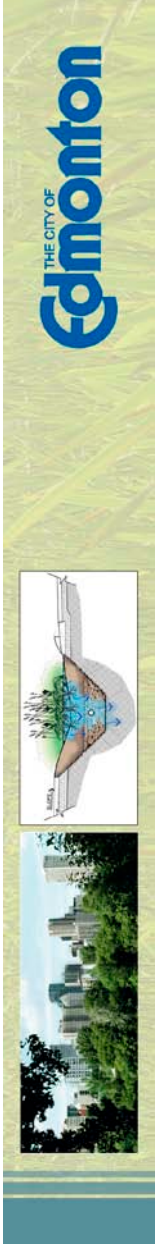


TABLE A.1 Cont'd
Recommended Native Plant Species for LID Facilities in Edmonton Alberta

Common Name	Scientific Name	Moisture Regime / Habitat	Morphology	Soil Preference	Soil Stabilizer	Tolerances
Herbaceous Species (Forbs & Grasses)						
Canada anemone	<i>Anemone canadensis</i>	moist to dry; shaded to full sun sites	Forb			
Blue joint reed grass	<i>Calamagrostis canadensis</i> syn <i>Calamagrostis scibneri</i>	moist to wet sites	Graminoid			
Water sedge	<i>Carex aquatilis</i>	moist to wet sites	Graminoid			
Awned sedge	<i>Carex atherodes</i>	wet (standing water) sites	Graminoid			
Bebb's sedge	<i>Carex bebbii</i>	moist to wet sites	Graminoid			
Long beaked sedge	<i>Carex sprengelii</i>	moist to wet; shaded to partially sunny sites	Graminoid			
Beaked sedge	<i>Carex stipata</i>	wet to standing water; shaded to partially sunny sites	Graminoid		Y	
Bottle sedge	<i>Carex utriculata</i>	wet (standing water) sites	Graminoid			
Tufted hairgrass	<i>Deschampsia cespitosa</i>	moist to wet sites	Graminoid			High: salt, oil & grease, metals
Creeping spike rush	<i>Eleocharis palustris</i>	moist to wet (standing water) sites	Graminoid			
Needle spike rush	<i>Eleocharis acicularis</i>	moist to wet (standing water) sites	Graminoid			
Fowl mannagrass	<i>Glyceria striata</i>	moist to wet sites	Graminoid	fertile loamy		
Wire rush	<i>Juncus balticus</i>	moist to wet sites	Graminoid			
Torrey's rush	<i>Juncus torreyi</i>	moist to wet sites	Graminoid	slightly acid to alkaline		
River bulrush	<i>Scirpus fluviatilis</i>	wet (standing water) sites	Graminoid			
Small flowered bulrush	<i>Scirpus microcarpus</i>	moist to wet (standing water); shaded to partially sunny sites	Graminoid			
Soft-stemmed bulrush	<i>Scirpus validus</i>	wet (still or slow moving shallow water) sites	Graminoid			
Giant bur reed	<i>Sparganium eurycarpum</i>	wet (shallow water) sites	Forb			

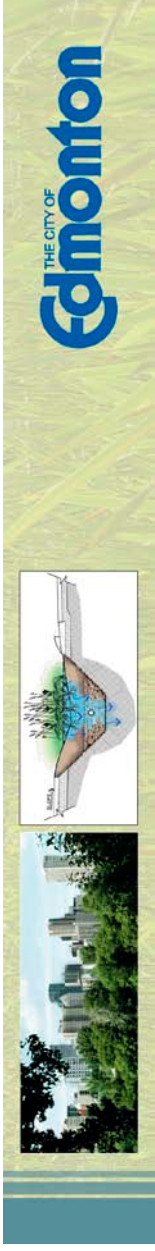


TABLE A.1 Cont'd
Recommended Native Plant Species for LID Facilities in Edmonton Alberta

Common Name	Scientific Name	Moisture Regime / Habitat	Morphology	Soil Preference	Soil Stabilizer	Tolerances
Submerged Aquatics						
Hornwort	<i>Ceratophyllum demersum</i>	open water	Not Applicable			
Spike water milfoil	<i>Myriophyllum spicatum</i> syn <i>Myriophyllum exallescens</i>	wet site - still water	Not Applicable			
Sago pondweed	<i>Potamogeton pectinatus</i>	open water	Not Applicable			
Grass Seed Mixes (Wet to Dry Sites)						
Northern wheatgrass	<i>Agropyron dasystachum</i>	dry slopes; dry open woods	Graminoid			
Western wheatgrass	<i>Agropyron smithii</i>	moist sites	Graminoid	heavy alkaline, saline		
Awned wheatgrass	<i>Agropyron trachyculum</i>	moist sites	Graminoid			
Slough grass	<i>Beckmania syzigachne</i>	wet to dry sites	Graminoid			
Blue Grama Grass	<i>Bouteloua gracilis</i>	dry sites	Graminoid			
Blue joint reedgrass	<i>Calamagrostis canadensis</i>	moist to wet sites	Graminoid			
Bebb's sedge	<i>Carex bebbi</i>	moist; open sites	Graminoid			
Red fescue	<i>Festuca rubra</i>	dry sites	Graminoid			
Tall manna grass	<i>Glyceria grandis</i>	moist to wet sites	Graminoid	non-saline, alkaline	Y	
Sweet grass	<i>Hierochloa odorata</i> syn <i>Hierochloa hirta</i> ssp. <i>Artica</i>	moist to dry; shaded to full sun sites	Graminoid			
June grass	<i>Koeleria macrantha</i>	moist to day sites	Graminoid			
Annual rye grass	<i>Lolium multiflorum</i>	moist to dry	Graminoid			
Fowl blue grass	<i>Poa palustris</i>	moist to wet sites	Graminoid		Y	
Green needle grass	<i>Stipa viridula</i>	Dry sites	Graminoid	deep, fertile with heavy clay		
* Stewart, R.E. and H.A. Kantrud. 1971. Classification of Natural Ponds and Lakes in the Glaciated Prairie Region. Bureau of Sport Fisheries and Wildlife, U.S. Fish and Wildlife Service, Washington, D.C., USA. Resource Publication 92. 57 pp.						

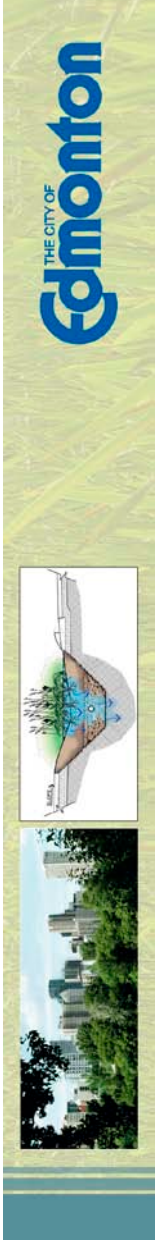


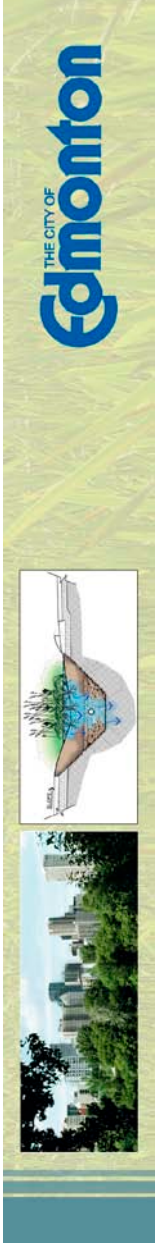
TABLE A.2
Ornamental Plants for Well Drained, Wet and Frequently Inundated Soils in the Edmonton Region¹

Common Name	Scientific Name	Moisture Regime / Habitat	Morphology	Soil Preference	Soil Stabilizer	Tolerances
Dogwood spp.						
Gold Prairie Fire Dogwood	<i>Cornus alba 'Aurea'</i>	full to part sun	Shrub			
Ivory Halo Dogwood	<i>Cornus alba 'Bailhalo'</i>	full to part sun	Shrub			salt
Bud's Yellow Dogwood	<i>Cornus sericea 'Bud's Yellow'</i>	full sun	Shrub			
Mottled Dogwood	<i>Cornus alba 'Gouchaultii'</i>	full to part sun	Shrub			
Purple Twig Dogwood	<i>Cornus alba 'Kesselringii'</i>	full to part sun	Shrub			
Siberian Coral Dogwood	<i>Cornus alba sibirica 'Coral'</i>	full to part sun	Shrub			
Arctic Fire (native) Dogwood	<i>Cornus stolonifera 'Farrow'</i>	full to part sun	Shrub	moist, well drained		
Kelsey Dwarf Dogwood	<i>Cornus sericea 'Kelsey'</i>	full to part sun	Shrub			
Willow spp.						
Coyote Willow	<i>Salix exigua</i>	full to partial sun	Shrub	dry to occasionally wet	Y	salt
Flaming Willow		full to partial sun	Shrub	dry to occasionally wet	Y	salt
Tri-Colour Willow	<i>salix integra 'Albomaculata'</i>	full to partial sun	Shrub	dry to occasionally wet	Y	salt
Shining Willow	<i>salix lucida</i>	full to partial sun	Shrub	dry to occasionally wet	Y	salt
Yellow Twig Willow		full to partial sun	Shrub	dry to occasionally wet	Y	salt
Dwarf Arctic Willow	<i>salix purpurea 'nana'</i>	full to partial sun	Shrub	dry to occasionally wet	Y	salt
Creeping Willow	<i>salix stolonifera</i>	full to partial sun	Shrub	dry to occasionally wet	Y	salt
American McKay Willow	<i>salix rigida</i>	full to partial sun	Shrub	dry to occasionally wet	Y	salt
Polar Bear Willow	<i>salix salicicola 'polar bear'</i>	full to partial sun	Shrub	dry to occasionally wet	Y	salt
Perennials, Grasses & Aquatics						
Globeflower	<i>Trollius spp.</i>	full to part sun	forb	average		
Moor Grass	<i>Molina sp.</i>	full to part sun	grass	moist to wet		
Bulbous Oat Grass	<i>Arrhenatherum elatius sp.</i>	full to part sun	grass	dry to moist		
Horsetail	<i>Equisetum sp.</i>	light shade	grass	moist		
Ribbon Grass	<i>Phalaris arundinacea sp.</i>	full to part sun	grass	wet or boggy		
Alkali Buttercup	<i>Ranunculus cymbalaria</i>		forb	moist to wet		
Bulrush	<i>Scirpus spp.</i>	full sun to light shade	aquatic	wet to moist		

¹ This list is not comprehensive and additional non-invasive species may be acceptable to LID facilities in the City of Edmonton

APPENDIX B

Soil Amendment Tools



B.1 BASIC COMPOST RECOMMENDATIONS

Compost material must meet the following five standards for use on LID facilities:

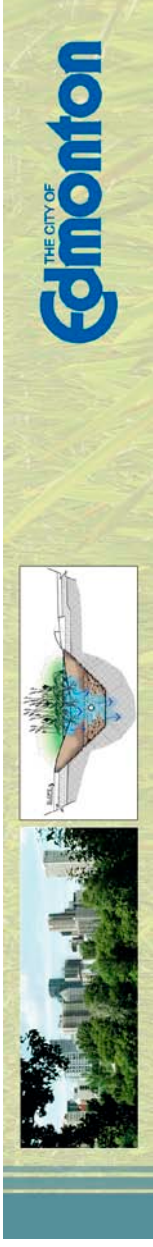
1. weed free;
2. contagion free (fungus, viral, and bacterial);
3. partly organic based;
4. organics completely composted; and
5. promote drainage and increase water holding capacity when combined with native soils.

Site specific composting calculations can be determined using **Table B.1**.

TABLE B.1
Site Specific Compost Calculator

	SBD	SOM%	FOM%	CBD	COM%	D	CR	Area	Amount	Price	Cost
	Soil Bulk Density (kg/cubic metre dry weight)	Initial soil organic matter (%)	Final target soil organic matter (%)	Compost Bulk Density (kg/cubic metre dry weight.)	Compost organic matter (%)	Depth compost is to be incorporated (mm)	Calculated compost application rate (mm)*	Area to be covered (m ²)	Calculated amount of compost to cover that area (m ³)	Price of compost (\$ per cubic metre)	Total cost for that amount of compost
Example for Planting Beds	1311	1	10	392	60	200	75	93	7.0	\$30-50	\$350
Enter site specific information											

*Calculated compost application rate (mm) formula is $SBD * (SOM\% - FOM\%) / (SBD * (SOM\% - FOM\%) - CBD * (COM\% - FOM\%)) * D$.



B.2 MODELLING PARAMETERS FOR ENGINEERED SOILS

Modelling parameters for specific soil types are provided in Table B.2. Listed parameters were developed for inclusion in the New Mexico Climate Center Irrigation Scheduling Model (New Mexico State University, 1996).

TABLE B.2
Modelling Parameters Used to Determine Water Retention Rates by Field Soil Types

Soil Texture	Field Capacity Mass Based (g/g) %	Permanent Wilting Point Mass Based (g/g) %	Average Bulk Density (g/ml)	Final Intake Rate (mm/hr)	a*	b** (mm/day) ^{1/2}	Soil Evaporation (Stage II Evaporation Coefficient) (mm/day ^{1/2})	Saturated Water Capacity/Pore Space (ml/ml)
Clay	35.1	17.2	1.26	1.9	0.21	5.67	6.09	52.4
Clay Loam	26.4	12.5	1.35	4.7	0.23	6.14	5.03	48.9
Loam	22.3	10.2	1.40	10.0	0.20	7.02	4.69	47.4
Loamy Sand	11.6	5.1	1.58	60.2	0.23	8.87	2.96	40.2
Sand	9.1	3.9	1.63	90.5	0.31	8.92	2.14	38.6
Sandy Clay	23.1	11.3	1.44	6.4	0.23	6.40	3.98	45.5
Sandy Clay Loam	20.0	9.5	1.47	10.3	0.19	7.25	4.04	44.5
Sandy Loam	13.9	6.2	1.53	20.7	0.15	8.40	3.70	42.5
Silt	33.2	14.9	1.16	4.4	0.23	6.06	6.67	56.4
Silty Clay	31.2	15.0	1.28	1.8	0.20	5.66	5.81	51.7
Silty Clay Loam	32.1	15.1	1.24	2.6	0.22	5.76	6.30	53.2
Silty Loam	27.6	12.5	1.28	5.1	0.23	6.25	5.62	51.8

* a – intake function multiplicative coefficient (cm/min)

* b – intake function exponent

Note: Infiltration is based on a power function of the form:

$$F = a \cdot t^b$$

where F is cumulative infiltrated water (cm/min);

a is an empirically determined coefficient (cm/min);

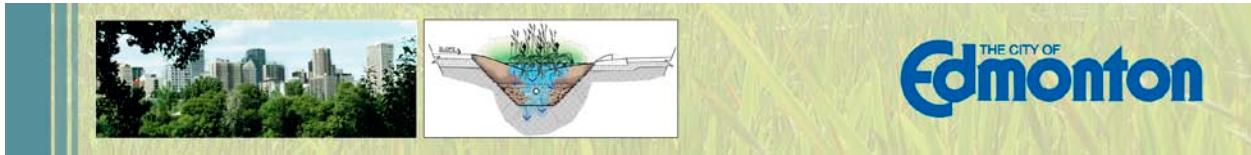
b is an empirically determined exponent; and,

t is time (in minutes).

Final intake values are determined from Campbell's infiltration model by the flux in after saturation is reached.

APPENDIX C

Cold Climate Facility Sizing Example



Facility Sizing Examples

Example 1: Sizing an LID-BMP Facility for Cold Climate Conditions

Assumptions:

Watershed area	0.5 ha
Impervious area fraction	100%
Average annual snowfall	123.5 cm
Average daily max January temp	-7.3 degrees Celsius
Average annual precipitation	365.7 mm
% of snow hauled from site	0%
Sublimation	insignificant
Pre-winter soil conditions	moderate moisture

$$M = 10\% \cdot S - L_H - L_S - L_{WM}$$

where M = moisture in snowpack (mm)

S = annual snowfall (cm)

L_H, L_S, L_{WM} = losses to hauling, sublimation and winter melt, respectively (mm).

STEP 1 Determine if oversizing is necessary.

Average annual precipitation is less than 1/2 of average annual snowfall and snowfall is greater than 900mm, oversizing is required.

STEP 2 Determine the annual losses from sublimation and snow plowing.

Loss from snow hauling based on 20% removal from site:

$$L_H = 20\% \cdot 10\% \cdot (S \cdot 10 \text{ mm/cm})$$

where L_H = water equivalent lost to hauling snow offsite

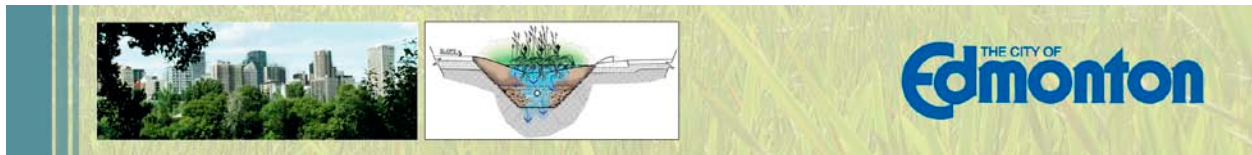
S = annual snowfall (cm)

10% = factor to convert snowfall to water equivalent

$$0 \text{ mm} = 0\% \cdot 0.1 \cdot (123.5 \cdot 10)$$

Sublimation is negligible: $L_S = 0$

In Edmonton, sublimation may be significant and should be accounted for.



STEP 3 Determine the annual water equivalent loss from winter melt events.

Using information in Step 2, moisture equivalent in snowpack remaining after hauling is:

$$S * 10 \text{ mm/cm} * 10\% - L_H = 123.5 \text{ cm} * 10 * 0.1 - 24.7 \text{ mm} = 98.8 \text{ mm}$$

Substituting into **Table C.1**, using column 2, and interpolating, the volume lost to winter melt L_{WM} , is:

$$L_{WM} = 49.4 \text{ mm}$$

TABLE C.1
Winter Snowmelt (adapted from Caraco et al., 1997)

Adjusted Snowfall Moisture Equivalent	Winter Snowmelt (January Tmax < -3.9°C)	Winter snowmelt (January Tmax < 1.7°C)
50.8 mm	25.4 mm	33.0 mm
101.6 mm	50.8 mm	68.6 mm
152.4 mm	76.2 mm	101.6 mm
203.2 mm	101.6 mm	134.6 mm
254 mm	127 mm	170.2 mm
304.8 mm	152.4 mm	203.2 mm

STEP 4 Calculate final snowpack water equivalent, M.

$$M = 10\% * S - L_H - L_S - L_{WM}$$

$$M = 0.1 * 123.5 \text{ cm} * 10 \text{ mm/cm} - 0 \text{ mm} - 0 \text{ mm} - 49.4 \text{ mm}$$

$$M = 74.1 \text{ mm}$$

STEP 5 Calculate the snowmelt runoff volume, R_s .

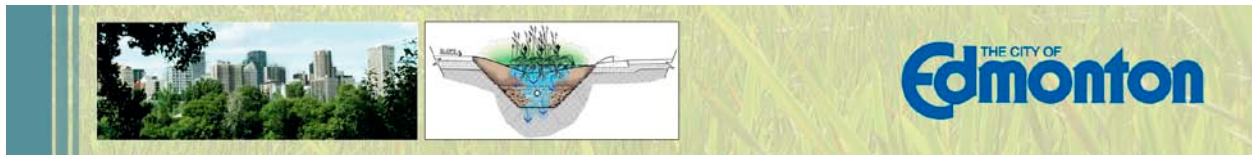
$$R_s = (100\% - I) * (M - \text{Inf}) + I * M$$

where I = percent impervious area contributing

Inf = infiltration (mm), assuming average moisture (20 mm)

$$R_s = (100\% - 100\%) * (74.1 \text{ mm} - 20 \text{ mm}) + 100\% * 74.1 \text{ mm}$$

$$R_s = 74.1 \text{ mm}$$



STEP 6 Determine the annual runoff volume, R.

Use the Simple Method (Schueler, 1987) to calculate rainfall runoff:

$$R = 0.9 \cdot (0.05 + 0.9 \cdot I) \cdot P$$

where P = annual rainfall (mm)

$$R = 0.9 \cdot (0.05 + 0.9 \cdot 1) \cdot 365.7 \text{ mm}$$

$$R = 312.7 \text{ mm}$$

*Simple Method based on 25.4 mm rainfall which is close to the 1-in-2 year event of 26.6 mm so the simplifying assumptions of the original analysis (Schueler 1987) were used.

<http://www.stormwatercenter.net/monitoring%20and%20assessment/simple%20meth/simple.htm>

STEP 7 Determine the runoff volume to be treated, T.

$$T = (R_s - 0.05 \cdot R) \cdot A \cdot 10$$

where A = contributing area, ha

$$T = (74.1 \text{ mm} - 0.05 \cdot 312.7 \text{ mm}) \cdot 0.5 \text{ ha} \cdot 10$$

$$T = 292 \text{ m}^3$$

STEP 8 Size the BMP.

The volume treated by the base criteria would be the larger of:

(1) Water Quality Volume:

$$WQ_v = (0.05 + R_{WQ}) \cdot A \cdot 10$$

R_{WQ} = the water quality event runoff depth

where $WQ_v = (0.05 + 0.9 \cdot 1) \cdot 26.6 \text{ mm} \cdot 0.5 \text{ ha} \cdot 10$

$$WQ_v = 126.4 \text{ m}^3$$

(2) Cold Climate Volume:

$$V_{cc} = 0.5 \cdot T \quad \text{therefore this is the volume used to size the BMP}$$

$$V_{cc} = 146 \text{ m}^3$$

Sites required to accommodate the full snowpack melt volume on the surface will required dedication of a significant portion of the land to LID facilities. Cold climate sizing should only be used for sites where overflow from LID facilities cannot be accommodated safely in the minor and major storm systems and where overflow from the facilities will cause property damage or become a danger to public safety.

APPENDIX D

Road Salt Application Examples



TABLE D.1

Roadside LID Facility Design to meet Salt Leaching Requirements

Average Winter precipitation snow water equivalent (SWE) depth
Average Spring / Summer / Fall precipitation depth

111 mm
366 mm

Assume collector / arterial roadways in Edmonton receive the same salt application per square metre. Total salt tonnage used (2010): 14629.8 tonnes (0.2 kg/m²).

Road Type	Lane km maintained	Lane Width (m)	Salt Load (tonnes/lane km)	Summer Rainfall (m ³ /lane km)
collector	5853	11.5	2.5	4209
arterial		14.5		

Winter salt load to roadside per lane kilometre on collector (assumed crowned roadway directing 1/2 of runoff to roadside):

$$\frac{0.2 \text{ kg/m}^2 * (5.75\text{m} * 1000\text{m})}{(111\text{mm} * 5.75\text{m} * 1000\text{m})} = 1.8 \text{ kg/m}^3 \text{ or, } 1800 \text{ mg/L}$$

Winter salt load to roadside per lane kilometre on collector (assumed crowned roadway directing 1/2 of runoff to roadside):

Land Use	Runoff Coefficient ¹	Winter Runoff Depth ² (mm)	Summer Runoff x Depth ² (mm)	TDS runoff concentration ³ (mg/L)
asphalt / concrete pavement	0.95	105	348	1800 (winter) ⁴ /374 (summer)
mid-density residential	0.5	56	56	374
commercial	0.6	67	220	296
industrial	0.6	67	220	168
undeveloped/natural	0.1	11	37	678

¹City of Edmonton, 2009

²using rational method

³DRCOG, 1983; Greenwood Village, 2010.

⁴Edmonton road salt estimate (winter) (Environment Canada, 2010b)

Maximum allowable winter salt loading without loss in fescue yield

Maximum allowable summer salt loading

1000 mg/L

680 mg/L

includes 40% factor of safety
(Texas Agricultural Extension Service, 1998)
matching background average observed concentrations
(DRCOG, 1983)

Allowable salt loadings are based on the assumption that LID facilities designed to receive untreated road runoff will be planted with salt tolerant plantings such as native grasses and plantings indicated in Appendix A.



Example 1: Salt loading in a 2m Swale along a collector roadway with an appropriately designed contributing area:

Contributing area, including swale	Swale Area		0.20 ha		2.20 ha	
Contributing Land Use	Area (ha)	Winter Runoff Volume (m ³)	Winter TDS / Salt Mass (mg)	Summer Runoff Volume (m ³)	Summer TDS / Salt Mass (mg)	
roadway	0.58	610	1100	2000	750	
sidewalk	0.15	160	60	520	190	
residential	0.59	330	120	1100	410	
commercial	0.59	390	120	1300	380	
industrial	0.00	0.0	0.0	0.0	0.0	
undeveloped/natural	0.10	11	7.5	37	25	
swale	0.20	22	15	73	50	
TOTAL	2.20	1500	1400	5000	1800	

Winter loading to swale

930 mg/L

Winter TDS / salt Mass
Winter Runoff / Precip Volume

Summer loading to swale

360 mg/L

Summer TDS / salt mass
Summer Runoff / Precip Volume

Example 2: Salt loading in a 2m Swale along a collector roadway with an improperly designed contributing area:

Contributing area, including swale	Swale Area		0.20 ha		1.20 ha	
Contributing Land Use	Area (ha)	Winter Runoff Volume (m ³)	Winter TDS / Salt Mass (mg)	Summer Runoff Volume (m ³)	Summer TDS / Salt Mass (mg)	
roadway	0.58	610	1100	2000	750	
sidewalk	0.15	160	60	520	190	
residential	0.00	0.0	0.0	0.0	0.0	
commercial	0.00	0.0	0.0	0.0	0.0	
industrial	0.18	120	20	380	64	
undeveloped/natural	0.10	11	7.5	37	25	
swale	0.20	22	15	73	50	
TOTAL	1.20	920	1200	3000	1100	

Winter loading to swale

1300 mg/L

Winter TDS / salt Mass
Winter Runoff / Precip Volume

Summer loading to swale

370 mg/L

Summer TDS / salt mass
Summer Runoff / Precip Volume

Contributing area adjustments required

Within target loading values

SWALE EXAMPLE

PLANTER EXAMPLE



Example 3: Salt loading in a Box Planter receiving runoff from a parking lot with salt application within an appropriately designed contributing area:

Planter Area
Total contributing area

0.20 ha
1.00 ha

Contributing Land Use	Area (ha)	Winter Runoff Volume (m ³)	Winter TDS / Salt Mass (mg)	Summer Runoff Volume (m ³)	Summer TDS / Salt Mass (mg)
parking lot	0.25	270	490	880	330
sidewalk	0.04	42	16	140	52
residential	0.00	0.0	0.0	0.0	0.0
commercial	0.25	170	50	560	170
industrial	0.25	170	29	560	94
undeveloped/natural	0.00	0.0	0.0	0.0	0.0
planter	0.20	22	15	73	50
TOTAL	1.00	670	600	2200	700

Winter loading to planter

Winter TDS / salt Mass
Winter Runoff / Precip Volume

900 mg/L

Within target loading values

Summer loading to planter

Summer TDS / salt mass
Summer Runoff / Precip Volume

320 mg/L

Within target loading values

Example 4: Salt loading in a Box Planter receiving runoff from a parking lot with salt application within an improperly designed contributing area:

Planter Area
Total contributing area

0.02 ha
1.00 ha

Contributing Land Use	Area (ha)	Winter Runoff Volume (m ³)	Winter TDS / Salt Mass (mg)	Summer Runoff Volume (m ³)	Summer TDS / Salt Mass (mg)
parking lot	0.95	1000	1800	3300	1200
sidewalk	0.03	36	13	120	45
residential	0.00	0.0	0.0	0.0	0.0
commercial	0.00	0.0	0.0	0.0	0.0
industrial	0.00	0.0	0.0	0.0	0.0
undeveloped/natural	0.00	0.0	0.0	0.0	0.0
planter	0.02	2.2	1.5	7.3	5.0
TOTAL	1.00	1000	1800	3400	1200

Winter loading to planter

Winter TDS / salt Mass
Winter Runoff / Precip Volume

1800 mg/L

Contributing area adjustments required

Summer loading to planter

Summer TDS / salt mass
Summer Runoff / Precip Volume

350 mg/L

Within target loading values

APPENDIX E

Comparative Modelling Study

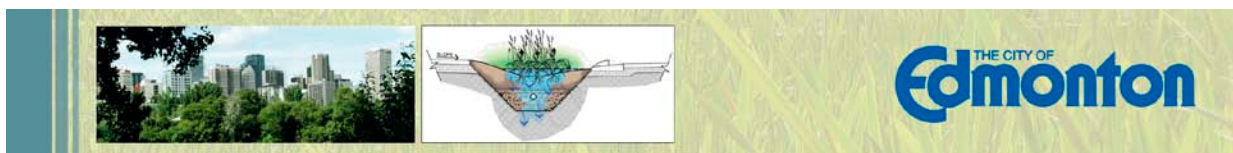


TABLE OF CONTENTS

	PAGE
1.0 INTRODUCTION.....	1
1.1 About the Comparative Modelling Study	1
1.2 Limitations of the Study Report	1
2.0 HYDROLOGIC MODELLING CONSIDERATIONS.....	2
2.1 Conventional versus LID-BMP	2
2.1.1 Small Storm Hydrology Concepts	3
2.1.2 Water Quality Capture Volume	4
2.2 Hydrologic Abstractions	7
2.2.1 Interception and Depression Storage.....	8
2.2.2 Infiltration	8
2.2.3 Evapotranspiration.....	8
2.3 Design Rainfall.....	9
3.0 MODELLING LID-BMP FACILITIES.....	11
3.1 Model Review	11
3.2 Adopted Model (EPA SWMM5).....	14
3.3 LID-BMP Facilities Representation	14
3.4 LID-BMP Control Placement.....	18
4.0 NEIGHBOURHOOD MODELLING COMPARISONS.....	23
4.1 Stormwater Servicing Concepts.....	24
4.1.1 Conventional Neighbourhood Concept	24
4.1.2 LID-BMP Neighbourhood Concept.....	25
4.2 Model Construction	29
4.2.1 Catchment Areas	29
4.2.2 Hydrologic Response Parameters	29
4.2.3 Conventional Conveyance Systems.....	33
4.2.4 LID-BMP Conveyance Systems.....	34
4.2.5 Storage Systems (Ponds)	35
4.2.6 LID-BMP Stormwater Management Facilities (Controls)	36
4.3 Model Application and Results	37
4.3.1 Single Rainfall Events.....	37
4.3.2 Continuous Long Term Rainfall.....	43
4.3.3 Flow Durations (Potential Erosion Impacts)	51
4.3.4 Treatment Efficiency of LID-BMP Scenario	53
5.0 LIFE CYCLE COST ANALYSIS.....	55
5.1 Total Costs.....	56



5.1.1	Capital Costs	56
5.1.2	Design, Permitting and Contingency Costs	57
5.1.3	Operation and Maintenance (O&M) Costs	57
5.1.4	Land Costs	58
5.2	Inflation and Regional Cost Adjustments.....	58
5.3	Comparison of Alternatives	59
5.4	Discussion of Life Cycle Costs	60
6.0	CONCLUSIONS.....	61
6.1	Conceptual Models	61
6.2	Seasonal Volume Reduction	61
6.3	Detention Storage	61
6.4	Flow Durations.....	61
6.5	Treatment Efficiency	62
7.0	REFERENCES.....	63

LIST OF TABLES

Table 2.1	Comparative Summary of LID-BMP Stormwater Management Concepts Impacting Hydrologic Design	3
Table 2.2	Design Basis – Rainfall / Level of Service	9
Table 3.1	Model Review: Summary of Capacity to Model Various Hydrologic Processes	12
Table 3.2	Model Review: Summary of Suitability to Model LID-BMP Systems	13
Table 3.3	Layers Representation for Typical SWMM LID-BMP Controls.....	17
Table 4.1	Percent Imperviousness of Different Land Uses in Conventional Development Site Plan	24
Table 4.2	Percent Imperviousness of Different Land Uses in LID-BMP Development Site Plan	26
Table 4.3	Depression Storage and Overland Flow Surface Roughness.....	32
Table 4.4	Green-Ampt Model Infiltration Parameters	32
Table 4.5	Average Monthly Evaporation Data at City Centre Airport.....	33
Table 4.6	Conventional Neighbourhood Conveyance (Pipe) Elements	34
Table 4.7	Conventional Neighbourhood Stormwater Pond Minimum Required Area (Footprint)	36
Table 4.8	LID-BMP Neighbourhood Stormwater Pond Minimum Required Area (Footprint)	36
Table 4.9	Summary of LID-BMP Neighbourhood Concept – LID-BMP Facilities and Associated Model Parameters	38
Table 4.10	Characteristics of Modelled Single Storm Events	39
Table 4.11	Summary of 2-year Rainfall Event Runoff Results.....	39
Table 4.12	Summary of 5-year Rainfall Event Runoff Results.....	40
Table 4.13	Total Observed Seasonal (April through October) Rainfall Depth (mm)	44
Table 4.14	Total Computed Seasonal (April through October) Rainfall Depth (mm)	45
Table 4.15	Computed Seasonal (April through October) Peak Runoff (m ³ /s)	47

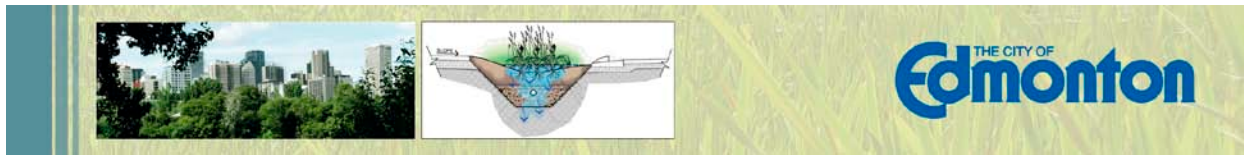
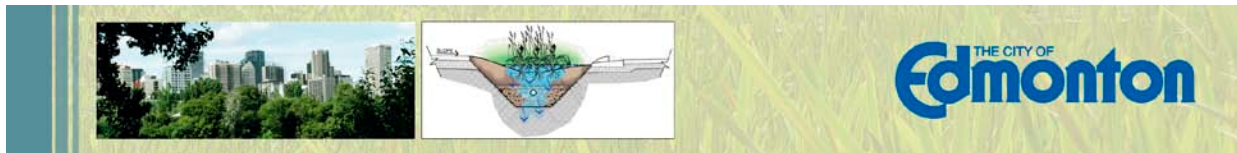


Table 4.16	Comparison of Computed Total Flow Durations (hrs) for Channel Forming Discharge ($Q_{2-YR} = 0.05 \text{ m}^3/\text{s}$).....	53
Table 4.17	Treatment Efficiency on Flows Passing Through LID-BMP Controls	54
Table 5.1	Base Capital Costs (Without Land Costs) for Commonly Used LID-BMPs	57
Table 5.2	Representative Annual O&M Costs of Different Types of Stormwater LID-BMPs	58
Table 5.3	Costs Summary	59

LIST OF FIGURES

Figure 2.1	Rain Event Histograms for Edmonton Area Rainfall	6
Figure 2.2	Hydrologic Processes Concept	7
Figure 3.1	Conceptual Section of a Typical LID-BMP Facility.....	17
Figure 3.2	Options for Placement of LID-BMP Controls: Option 1 – LID-BMP Control Displacing a Portion of a Subcatchment Option 2 – Single LID-BMP Control Occupying Entire Catchment	19
Figure 3.3	Comparison of Total Inflow (Runon) Hydrographs for: Option 1 – LID-BMP Control Displacing a Portion of a Subcatchment, and Option 2 – Single LID-BMP Control Occupying Entire Catchment	22
Figure 4.1	Conventional Neighbourhood Concept Plan.....	27
Figure 4.2	LID-BMP Neighbourhood Concept Plan.....	28
Figure 4.3	Conventional Neighbourhood SWMM Model Layout Screenshot	30
Figure 4.4	LID-BMP Neighbourhood SWMM Model Layout Screenshot	31
Figure 4.5	2-year Rainfall Runoff Hydrographs from Development to Creek.	41
Figure 4.6	5-year Rainfall Runoff Hydrographs from Development to Creek.	42
Figure 4.7	1960-1993 Seasonal Total Rainfall and Computed Runoff (Expressed as Total Depth over Development Area)	49
Figure 4.8	1980-2010 Seasonal Total Rainfall and Computed Runoff (Expressed as Total Depth over Development Area)	50



1.0 INTRODUCTION

1.1 About the Comparative Modelling Study

This report presents the results of a comparative modelling exercise conducted to assess and compare the hydrologic characteristics of a conventional and Low Impact Development (LID) neighbourhood stormwater servicing design.

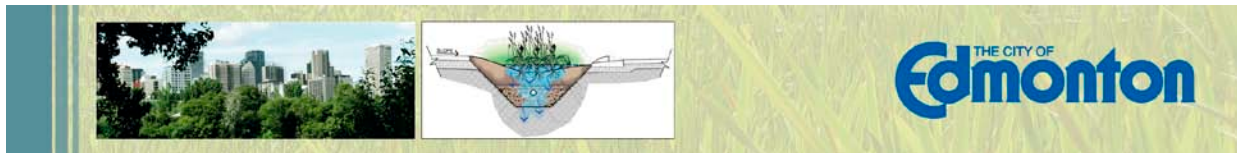
This modelling study informs those interested in modelling LID-BMP systems by introducing important hydrologic considerations for modelling, a brief assessment of the applicability of a variety of common modelling tools and a modelling example using a widely accepted public domain modelling tool that is well suited to simulating LID-BMP components.

1.2 Limitations of the Study Report

This document does not provide a prescriptive approach to modelling LID-BMP facilities. The stormwater management system servicing a particular development site is unique and has specific characteristics that require thoughtful consideration during the conceptual modelling and design stages.

The techniques and procedures for modelling LID-BMP systems are not well established. Those tasked with modelling these systems should complement their experience of modelling conventional systems with an awareness of the hydrologic processes important to LID-BMP systems. Determining the level of detail required for a suitable analogue requires discretion of an experienced modeller that is knowledgeable on the hydrologic considerations relevant to LID-BMP systems.

The United States Environmental Protection Agency (EPA) stormwater management model (SWMM5) was adopted for application in this particular study. However, the City does not promote, endorse, or specifically recommend any particular model as a preferred tool.



2.0 HYDROLOGIC MODELLING CONSIDERATIONS

The following provides context for the hydrologic modelling considerations in simulating LID-BMPs. Modelling LID-BMPs does not require a paradigm shift in the approach to hydrologic modelling. However, it does warrant revisiting some fundamental hydrologic considerations to ensure adequate representation of the most significant physical processes. The recent emphasis on control of total pollutant loadings has also introduced new hydrologic aspects to consider during the development of models that represent LID-BMPs.

2.1 Conventional versus LID-BMP

The approach to managing water quantity differs between conventional and LID-BMP stormwater management. The conventional stormwater management approach is to maintain peak runoff rates to pre-development conditions associated with a specified design storm event or to capacity of downstream facilities. The design event is associated with a large infrequent storm event such as the 5 year or 100 year return period storm. The conventional approach does not control storms that are more frequent than the design event.

The peak runoff rate is usually predetermined by:

- capacity of the downstream receiving stream / system (engineered or natural);
- pre-development conditions; or
- an applicable stormwater management plan criterion.

Design Event –
Hypothetical rainfall event used for design. The magnitude and duration of the design event is usually based on observed historical data.

Design of LID-BMP based stormwater management systems considers frequent events. These smaller, more frequent storms represent the vast majority of rainfall events in terms of both the number of rain events and the total runoff volume. While the LID-BMP approach controls runoff peaks it also addresses stormwater runoff volume. The conventional approach to stormwater management rarely gives consideration to total runoff volume control.

Table 2.1 provides a comparative summary of key concepts that impact hydrologic design of conventional and LID-BMP based stormwater management systems.

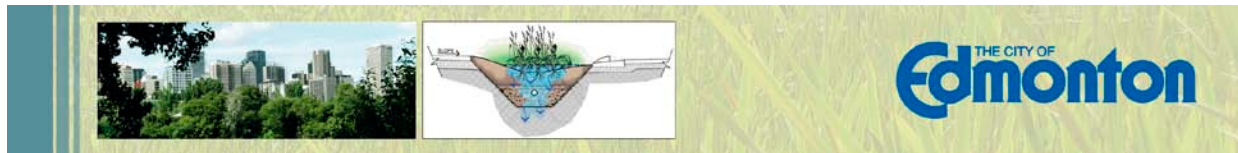


TABLE 2.1
Comparative Summary of LID-BMP Stormwater Management
Concepts Impacting Hydrologic Design

Conventional Stormwater Management	LID-BMP Stormwater Management
Centralized end-of-pipe control.	Distributed source control.
Collect and convey stormwater quickly away from site.	Integrate LID-BMP facilities throughout site to provide retention and treatment near source. Consider stormwater as a valuable resource for use on site.
Most stormwater management facilities designed to control peak outflow rates to predevelopment peak. Duration of peaks at and below outlet control rates increase.	LID-BMP facilities control total volumes, reduce peak outflows for all storms, and reduce duration of peak outflows.
Water quality controlled at end-of-pipe facilities.	Water quality controlled throughout site. Small storms treated by retention of stormwater near source.

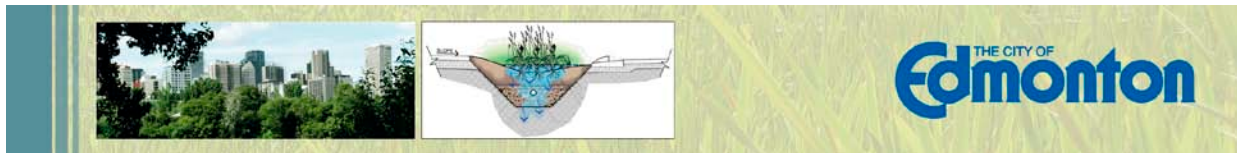
Interception – rainwater held by plants as the water falls onto leaves, stems and branches.

2.1.1 Small Storm Hydrology Concepts

The following provides a brief introduction to the concepts of small storm hydrology. A more comprehensive review of these concepts is provided by Pitt (2005) and in the US EPA *Stormwater Best Management Practice Design Guide* (USEPA, 2004).

The addition of regulatory requirements on total pollutant loadings has introduced new aspects to traditional hydrologic design considerations. These new aspects are largely the result of an increased emphasis on the importance of runoff resulting from smaller, more frequent, rainfall events. The smaller more frequent events (less than 2 year return period) tend to dominate hydrologic design of systems aimed at improving water quality. These smaller storms generate most of the annual runoff from an urban watershed. Thus, systems designed to capture and provide treatment for the more frequent smaller storms provide a significant reduction in total annual pollutant loadings.

For a given rainfall event, the total precipitation is abstracted by interception, depression storage, infiltration and evapotranspiration.



Depression Storage –
*water retained in puddles
 and other surface
 depressions of the ground.*

Antecedent Moisture –
*soil moisture level prior to a
 rainfall event.*

Continuous Simulation –
*modeling using
 precipitation records over a
 number of years in order to
 account for: antecedent
 conditions; seasonal
 variations; and inter-event
 processes.*

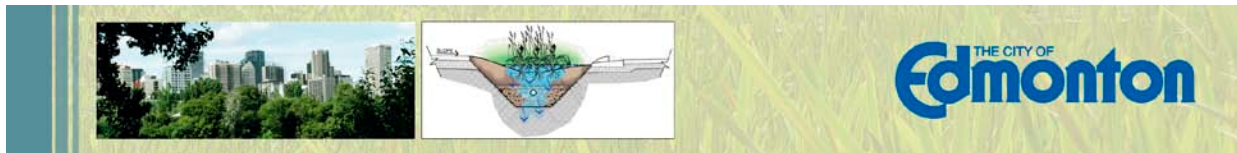
The remaining, excess precipitation ultimately runs off to receiving water bodies. For large rain events, only a small portion of the total rainfall is abstracted and most runs off. However, for small rain events, the percentage of rainfall abstracted in a natural landscape can be very significant. Therefore, a better accounting of the abstraction processes is required to accurately assess systems designed to accommodate small storms. Accounting of runoff resulting from rain events can be done using a hydrologic model.

The computational procedures used to estimate or compute runoff for large storms are well established. Tools used to simulate runoff resulting from small storms must provide for more detailed accounting of the abstraction processes that are often neglected in large storm simulation. Existing tools may provide the means to accurately capture these hydrologic processes; however, greater attention should be given to methods accounting for abstractions. Further, the antecedent moisture conditions prior to an event are of greater importance when considering small storms. Therefore, it is recommended to conduct continuous simulations to assess performance of systems designed to accommodate small storms.

2.1.2 Water Quality Capture Volume

Runoff generated by small storms carry the bulk of total pollutant loading to the receiving water body because the vast majority of the total runoff volume (that transports pollutants) is generated from these smaller storms. LID-BMP facilities, designed to capture these smaller storms, will provide treatment to runoff resulting from all small storms and treatment to the first portion of larger storms. This provides treatment for a significant portion of the total annual runoff.

The water quality capture volume provides a practical means for establishing an appropriate hydrologic design basis for LID-BMP systems. Analysis of the long-term rainfall record provides guidance on selecting an appropriate water quality capture volume. The capture volume is effectively represented by rainfall depth since it is not possible to specify a finite volume as runoff volume will vary with catchment size and characteristics. An analysis of Edmonton rainfall data was conducted to determine an appropriate rainfall depth that is representative of the water quality capture volume.



95th Percentile Storm – 95% of all storms are less than or equal to the 95th percentile storm.

First Flush – during a rain event, the initial surface runoff from impervious surfaces which contains elevated pollutant loads accumulated during the preceding dry period.

Local rain gauge data were analyzed to characterize rainfall within the Edmonton Area. A simple statistical analysis was applied to the rainfall event data set to better understand the distribution of rainfall events in terms of depth. **Figure 2.1** presents a summary of the distribution of rainfall events corresponding to each of three Environment Canada stations in the Edmonton area. A fourth distribution (“All Stations Combined”) provides the distribution for the collective rainfall event population for all data sets. All data were normalized by the total rainfall depth over the period of record. A cumulative total percentage of all events was plotted to determine the depth of the 95th percentile storm, which was between 22 mm and 28 mm, depending on the station.

The initial runoff from larger storms is significant in that it picks up and carries pollutants that are washed off impervious surfaces (e.g., pavements). This initial volume is commonly referred to as the *first flush*. In practice, many jurisdictions specify a depth of rainfall (typically 2.5 cm or 1 inch) to capture the first flush component (USEPA, 2004). The amount of pollutants carried by the first flush depends on a variety of factors including:

- the pollutants available for wash off;
- the time between storm events;
- the storm characteristics; and
- characteristics of the subwatershed

It is interesting to note that the City of Edmonton 2-year, 4-hour design storm depth of 25.6 mm well approximates both the 95th percentile storm of all rain gauges and a commonly used first flush capture requirement of 25 mm. For design purposes, it may be practical to define a water quality capture volume equivalent to the City’s existing 2-year rainfall design event. This provides a familiar design event size and distribution that is consistent with existing drainage design standards.

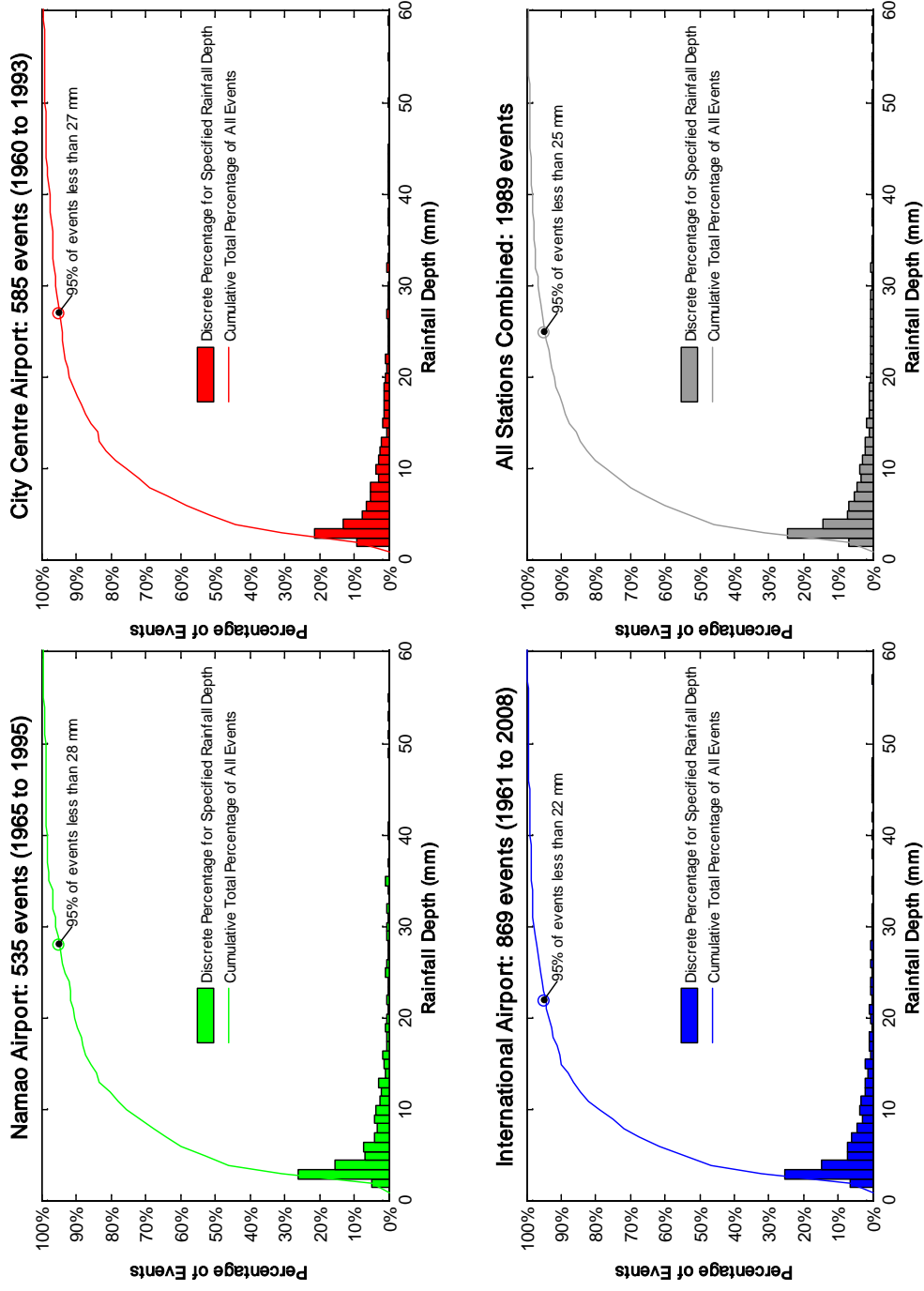
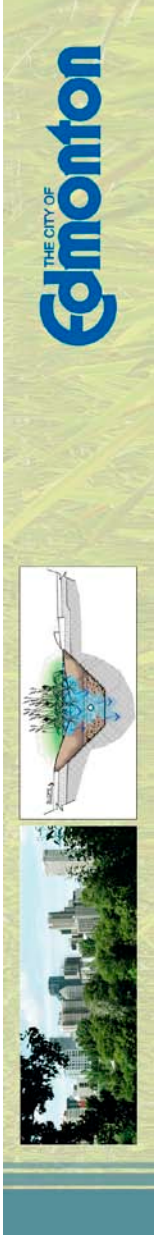


Figure 2.1 Rain Event Histograms for Edmonton Area Rainfall

2.2 Hydrologic Abstractions

To successfully model LID-BMPs it is important to represent all significant hydrologic abstractions for both small and large storms. The relative importance of hydrologic abstractions is greater for small storms than for large storms. It is also important to represent those processes that continue between rainfall events. **Figure 2.2** provides an illustrative concept of precipitation (rainfall), surface runoff, and hydrologic abstractions within the LID-BMP footprint and upstream areas serviced by the LID-BMP. The salient hydrologic abstraction processes are described in the following sections.

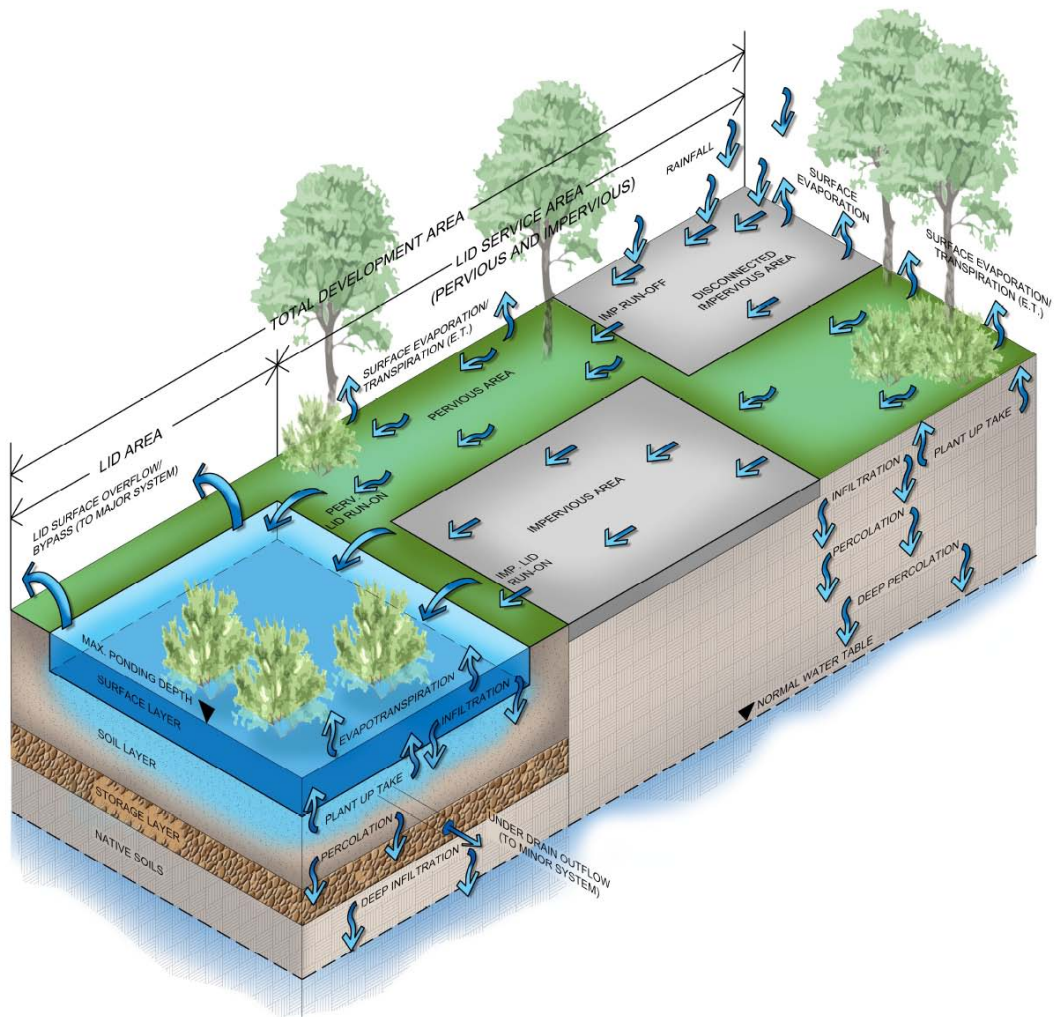
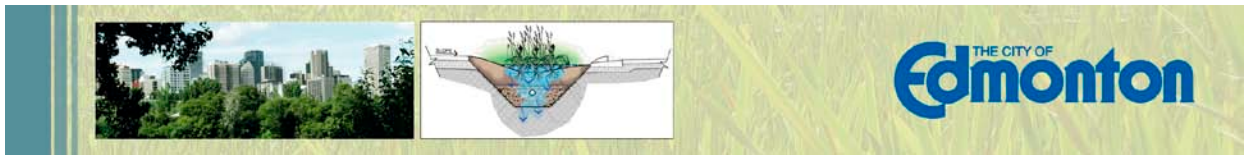


Figure 2.2 Hydrologic Processes Concept



2.2.1 Interception and Depression Storage

Interception describes the process by which rainfall is abstracted by vegetation or other forms of cover above the ground. Depression storage is the process by which rainfall is retained in surface depressions and small puddles on the ground. These two hydrologic abstractions are similar in that water is retained by absorption or returned to the atmosphere by evaporation. A practical approach to modelling these abstractions is to combine them into a single parameter describing depression storage.

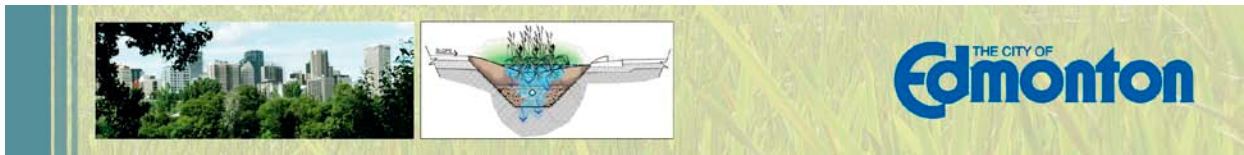
2.2.2 Infiltration

Infiltration describes the process where rainfall is abstracted by seeping into the ground through the soil surface. After water enters the soil matrix it will continue to move through interstitial spaces by forces of gravity and differential pressures (e.g., capillary or advective action). The rate at which water infiltrates depends on several factors including: soil type, antecedent moisture, organic matter, rainfall intensity, vegetation cover and depth to groundwater table. Deep infiltration describes water movement through deeper soils and percolation refers to water moving vertically down into aquifers. Infiltration represents a significant portion of total hydrologic abstraction.

2.2.3 Evapotranspiration

Evapotranspiration (ET) is a term that includes the combined effect of evaporation of water from surfaces (vegetative, soil, and free water) and transpiration of water by plants. It is the process by which all water is converted to vapour and returned to the atmosphere. Water in the soil can be taken up by plants and returned by ET.

ET rates are influenced by meteorological factors (solar radiation, air temperature, vapour pressure and wind speed) and the nature of the evaporating surface. The amount of ET during a rain event is comparatively small and is often neglected when estimating runoff due to a single rainfall event. However, the effect of ET becomes significant during continuous event simulations where accounting of antecedent conditions is important. ET represents an appreciable total amount of abstraction over longer periods. It should therefore be accounted for in long term simulations.



As mentioned previously, ET rates vary depending on a variety of factors. A practical modelling approach is to use pre-determined evaporation rates based on historic local data. These rates may be represented by daily or monthly average values. A time series can also be specified when high temporal resolution evaporation data is available. Under unique circumstances, a more sophisticated approach may be required for a detailed accounting of ET.

2.3 Design Rainfall

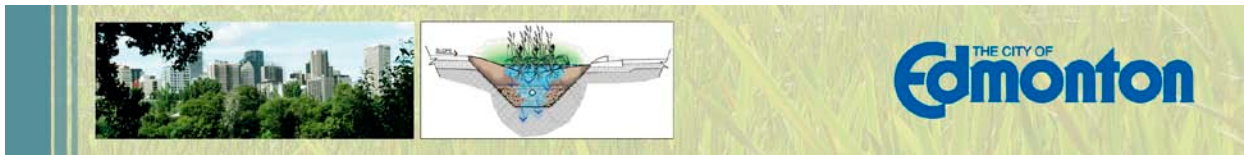
The primary input to a hydrologic model is rainfall and the primary output is runoff. The runoff volume and runoff rate present key parameters for design of conveyance systems, storage facilities, and LID-BMP facilities. The design basis for LID-BMP systems must provide a level of service consistent with City of Edmonton Design Standards. **Table 2.2** presents the design basis applicable to all stormwater management drainage systems (including systems that incorporate LID-BMP facilities).

TABLE 2.2
Design Basis – Rainfall / Level of Service

System Elements	Design Basis (rainfall return period)
Minor drainage system components servicing areas of 30 ha and less.	5 years.
Minor drainage system trunk sewers servicing areas greater than 30 ha.	5-year runoff rate plus 25%.
Major drainage system conveyance elements.	100 years.
Major drainage system storage.	Generally, designs are to be based on elements providing the volume equivalent of a 120 mm depth of water over the total catchment area. Designs are to be evaluated considering the most critical storage event as may result from selected design and historical rainfall events.

Note: Adapted from City of Edmonton Design Standards (January 2009)

The design basis provides modelling guidance on the type of rainfall event to use for assessing the hydrologic performance of a stormwater management concept. The design basis listed above

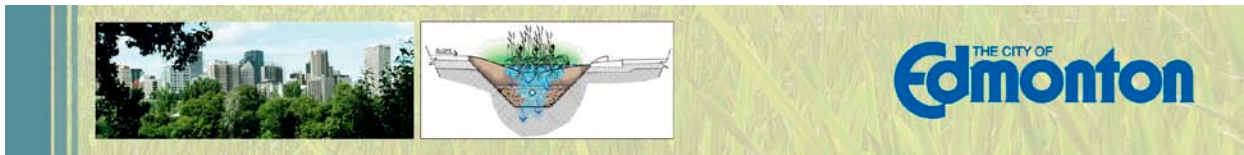


refer to single large storm events and are not well suited to assessing performance of systems that capture and treat runoff resulting from smaller more frequent events. Further, LID-BMP systems are also designed to return water back to the hydrologic cycle through processes of infiltration and evapotranspiration. Single event analysis fails to adequately capture these processes. For this comparative study, the design rainfall inputs listed below were modelled. These design rainfall series are consistent with the current design basis (**Table 2.2**) and are suitable for assessing hydrologic performance of LID-BMP systems.

- City of Edmonton 2-year 4-hour Chicago design storm;
- City of Edmonton 5-year 4-hour Chicago design storm;
- July 10-11, 1978, recorded storm;
- Continuous hourly rainfall 1960-1993 (EC City Centre Airport); and,
- Continuous 15-minute rainfall 1980-2010 (City Edmonton Rain Gauge No. 19 – near City Centre Airport).

The 2-year Chicago storm has a depth that is representative of the 95th percentile storm. The 5-year Chicago storm was used to assess the conveyance system. The 1978 recorded storm event was used to assess the major storage elements as it was found to be the most critical / extreme design event for the modelled systems presented in this study.

The continuous data series enabled assessment of long term impacts and total average annual volume reductions. The total annual volume reduction provides a reasonable approximation on the total annual pollutant loading reduction.



3.0 MODELLING LID-BMP FACILITIES

3.1 Model Review

A brief review of available hydrologic models was conducted to determine a suitable modelling tool for use in this comparative study. There are a vast number of hydrologic modelling tools available. **Tables 3.1** and **3.2** provide a listing of the models identified during the model review process. While the list is not exhaustive, it provides a representative cross section of the various hydrologic tools that one may consider for application in LID-BMP modelling. The tables provide a qualitative assessment of each model's capacity to model various hydrologic processes (**Table 3.1**) and their suitability to model LID-BMPs (**Table 3.2**). The assessments are subjective and readers are urged to further investigate the applicability of these tools to suit their needs. The tables provide a useful starting point for those unfamiliar with the variety of tools available. The following is a list of acronyms used for each model:

EPA SWMM5:	U.S. EPA Storm Water Management Model Version 5
HEC-HMS:	Hydrologic Engineering Center Hydrologic Modeling System
HSPF:	Hydrologic Simulation Program FORTRAN
LIFE:	Low Impact Feasibility Evaluation
MUSIC:	Model for Urban Stormwater Improvement Conceptualization
P8:	Program for Predicting Polluting Particle Passage through Pits, Puddles and Ponds
PGC – BMP:	Prince George's County Best Management Practice
SET:	Site Evaluation Tool
SLAMM:	Source Loading and Management Model
STORM:	Storage, Treatment, Overflow, Runoff Model
SWMHYMO:	Storm Water Management Hydrologic Model
TR:	Technical Release
WBM:	Water Balance Model
WMS	Watershed Modeling System

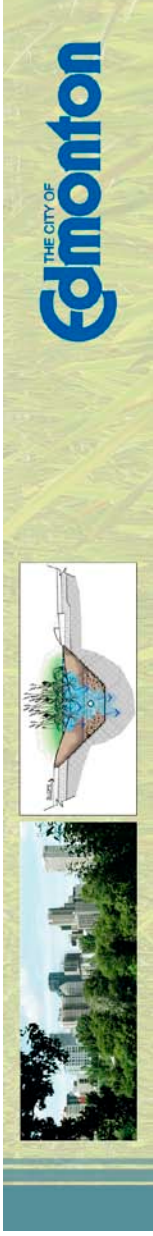


TABLE 3.1
Model Review: Summary of Capacity to Model Various Hydrologic Processes

Model	Toolbox - Features	Rainfall - Snowmelt Runoff simulation	Infiltration	Evapo - transpiration	Pollutant accumulation & washoff	Water quality simulation	Sizing of storage - treatment units
EPA SWMM 5	●	●	●	○	○	○	●
HEC-HMS	X	○	○	○	X	X	X
HSPF (RCHRES Module)	○	○	○	○	○	○	○
LIFE	●	○	○	○	○	○	
MIKE URBAN* (Mouse)	●	●	●	○	○	○	●
MUSIC	○	○	○	○	○	○	X
P8	○	○	○	○	○	○	○
PGC – BMP Module	●	○	●	●	●	●	○
RECARGA	○	○	○	○	X	X	○
SET	○	○	X	X	X	○	X
SLAMM	○	○	○	X	○	○	○
STORM	○	○	○	X	○	○	○
SUSTAIN	●	●	●	●	●	●	●
SWMHYMO	○	○	○	X	X	X	○
TR-20/TR-55	X	○	X	X	X	X	X
WBM	●	○	○	X	X	X	●
WMS	X	○	○	○	○	○	X

Notes:

- Well-suited for LID-BMP modelling.
- Less well-suited for LID-BMP modelling but maybe customized for LID-BMP modelling.
- X Not suitable for LID-BMP modelling.
- * At time of this investigation, MIKE URBAN was recently updated to include LID-BMP controls within the SWMM module.

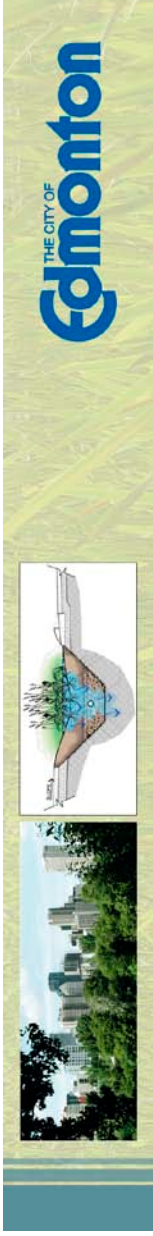
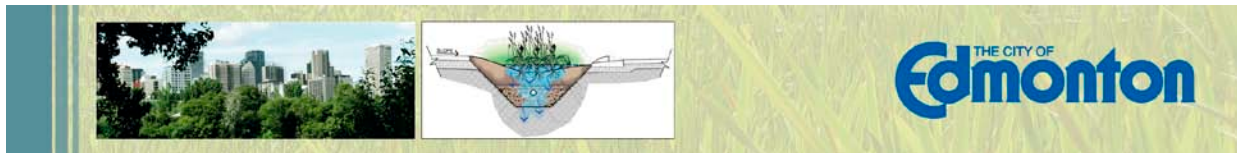


TABLE 3.2
Model Review: Summary of Suitability to Model LID-BMP Systems

Model	Single feature	Multi feature (treatment train)	Single event modelling	Continuous modelling	Overall applicability	Remarks
EPA SWMM5	●	○	●	●	●	New version of SWMM has LID-BMP controls. Requires knowledge of application.
HEC-HMS	○	○	○	○	○	Infiltration swales can be modeled with reach routing using the Muskingum-Cunge routing procedure.
HSPF (RCHRES Module)	○	○	X	○	○	Accurate representation of particular BMPs possible with skilled user.
LIFE	○	○	X	○	○	
MIKE URBAN	●	○	●	●	●	Recently updated to include LID-BMP controls within SWMM module. Integrated GIS (ESRI) user interface.
MUSIC	○	○	○	○	X	Applied mainly in Australia as a conceptual design tool.
P8	●	●	○	○	○	Limitations with hourly timestep temporal scale.
PGC – BMP Module	●	●	○	○	○	Applicable at the screening and planning levels. Not suitable for BMP design purposes.
RECARGA	○	X	○	○	X	Used only for Bioretention / rain garden sizing
SET	○	○	○	X	X	Planning / scoping level tool.
SLAMM	○	○	X	○	○	More useful as a planning tool.
STORM	○	○	X	○	○	Huge data requirements and little parameter flexibility for model calibration.
SUSTAIN	○	●	X	●	●	Version 1.0 model has some minor bugs that should be resolved in future versions. The tool is best used for network analysis and BMP sizing optimization based on continuous simulation performance.
SWMHYMO	○	○	○	○	○	
TR-20/TR-55	X	X	○	X	X	Assessment of impacts at watershed scale
WBM	●	●	X	●	○	Lack of flexibility in applied precipitation data
WMS	○	○	○	○	○	Requires high level of expertise for application.



3.2 Adopted Model (EPA SWMM5)

SWMM5 was adopted for this modelling study for, the following reasons, among others:

- facilitates inclusion of LID-BMP facilities directly into the model through built in LID-BMP control modules;
- relative ease of use;
- well established and widely used model;
- freely available public domain model;
- many commonly used and economical commercially available models with advanced utilities and interfaces are built on and or include the SWMM5 computational engine (e.g., MIKE URBAN, PCSWMM, XPSWMM);
- comprehensive supporting documentation (manuals, guides, sample applications, etc.); and
- well-supported and active online user community.

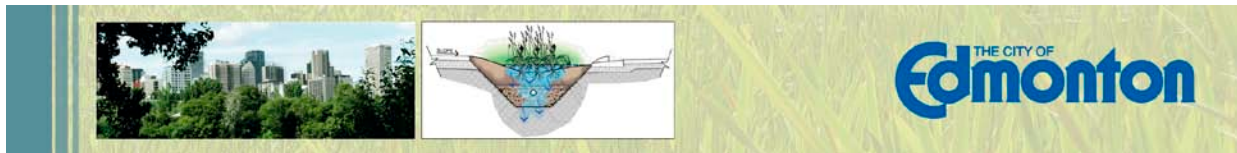
The choice of the SWMM5 model does not necessarily suggest it is the optimal tool for all applications. Other models are also appropriate for modelling LID-BMPs.

3.3 LID-BMP Facilities Representation

LID-BMP facilities are engineered to enhance the natural processes of rainfall abstraction. A particular LID-BMP facility can be conceptualized into vertical layers where each layer provides a unique function. The configuration of a particular LID-BMP facility varies and the modeller should review conceptual design sections to determine how best to simulate the hydrologic processes captured by a particular design. Models may require some level of customization to adequately describe the physical processes associated with an LID-BMP facility.

Development of a computational analogue of LID-BMP facilities presents a unique challenge to modellers. This section is provided as a starting point to assist modellers in their development of suitable computational analogues that assess the performance of these systems. It should not be interpreted as a standardized approach.

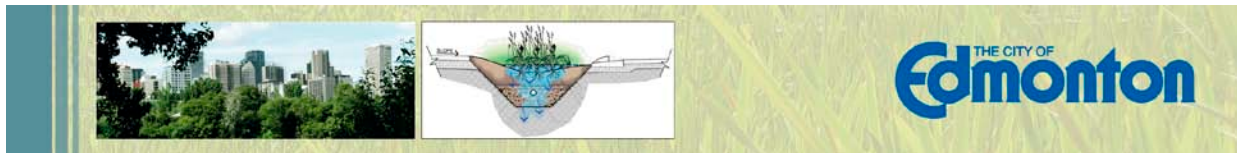
The SWMM5 model provides several built in LID-BMP control modules designed to capture the key hydrologic processes associated with typical LID-BMP facilities. Methods used by the SWMM5 model are described in this report to illustrate an approach



to modelling LID-BMP systems. This study also demonstrates an approach to modelling LID-BMP facilities that are not explicitly represented by a built in control module (i.e., vegetative swale with check dam). Much of the approach to modelling LID-BMP facilities presented in this report follows the concepts presented in SWMM model documentation. For a more detailed description the reader is referred to the most recent and complete SWMM documentation available for download on the US EPA website (<http://www.epa.gov/nrmrl/wswrd/wq/models/swmm/>).

LID-BMP controls / facilities are designed to simulate key hydrologic processes. They are conceptualized as a separate “control” that shares many of the processes attributed to a catchment. SWMM 5 can model five different generic types of LID-BMP facilities:

1. *Bioretention Cells*: surface depressions covered with mulch and planted with vegetation in an engineered soil mix placed on a gravel storage bed. They store, infiltrate and evapotranspire surface runoff. The bioretention cell LID control can be used to model rain gardens, green roofs and street planters. These are all considered variations of the bioretention unit.
2. *Infiltration Trenches*: infiltration trenches or narrow ditches filled with gravel that intercept runoff from upstream impervious areas. They provide storage volume and time for captured runoff to infiltrate the native soils below.
3. *Porous Pavement / Block Pavers*: excavated areas filled with gravel and covered with a hard porous surface (porous asphalt, concrete, or pavers). Porous pavements are characterised by high surface infiltration rates that quickly pass rainfall and surface runoff to the underlying storage layer where they infiltrate into the native soil below. Block pavers consist of modular units of paver blocks placed on a layer of sand or pea gravel overlying a storage bed. Direct rainfall and runoff infiltrate through the spaces in the blocks into the storage bed and native soils below.
4. *Rain Barrels / Cisterns*: capture runoff from impervious surfaces (e.g., roofs) during storm events. The captured runoff is stored prior to release or re-use during dry periods (for example, for lawn watering).
5. *Bioswales*: open channels planted with grass and other vegetation. They offer resistance to flow and allow for runoff to infiltrate into the native soils below.



Bioretention cell units, infiltration trenches and porous pavements can contain optional underdrain systems in the gravel storage beds. These are perforated pipes that convey excess water in the storage beds away to a storm sewer or other appropriate outlet. They may be applied where it is desirable to keep adjacent sub-soils dry (e.g., next to pavements) or where sub-soils have very low infiltration rates. Underdrains are required when storage beds are lined with impermeable barriers. Porous pavement systems and gravel storage beds can experience decreasing hydraulic conductivities over time due to clogging.

LID controls are represented by a stack of vertical layers whose properties are defined on a per unit area basis. During a simulation, SWMM performs a moisture balance of water stored within or transmitted between layers. An example of a typical LID-BMP unit, illustrating various hydrologic processes, is provided in **Figure 3.1**.

The following description of each layer is an excerpt from the SWMM User's Manual (Revised July 2010). It is provided here for convenience:

- “The *Surface Layer* corresponds to the ground (or pavement) surface that receives direct rainfall and runoff from upstream land areas, stores excess inflow in depression storage and generates surface outflow that either enters the drainage system or flows onto downstream land areas.
- The *Pavement Layer* is the layer of porous concrete or asphalt used in continuous porous pavement systems, or is the paver blocks and filler material used in modular systems.
- The *Soil Layer* is the engineered [or amended] soil mixture used in bioretention cells to support vegetative growth.
- The *Storage Layer* is a bed of crushed rock or gravel that provides storage in bioretention cells, porous pavement, and infiltration trench systems. For a rain barrel it is simply the barrel itself.
- The *Underdrain System* conveys water out of the gravel storage layer of bioretention cells, porous pavement systems and infiltration trenches (typically with slotted pipes) into a common outlet pipe or chamber. For rain barrels it is simply the drain valve at the bottom of the barrel.”

Table 3.3 summarizes the combination of these five layers used to represent typical LID-BMP control features.

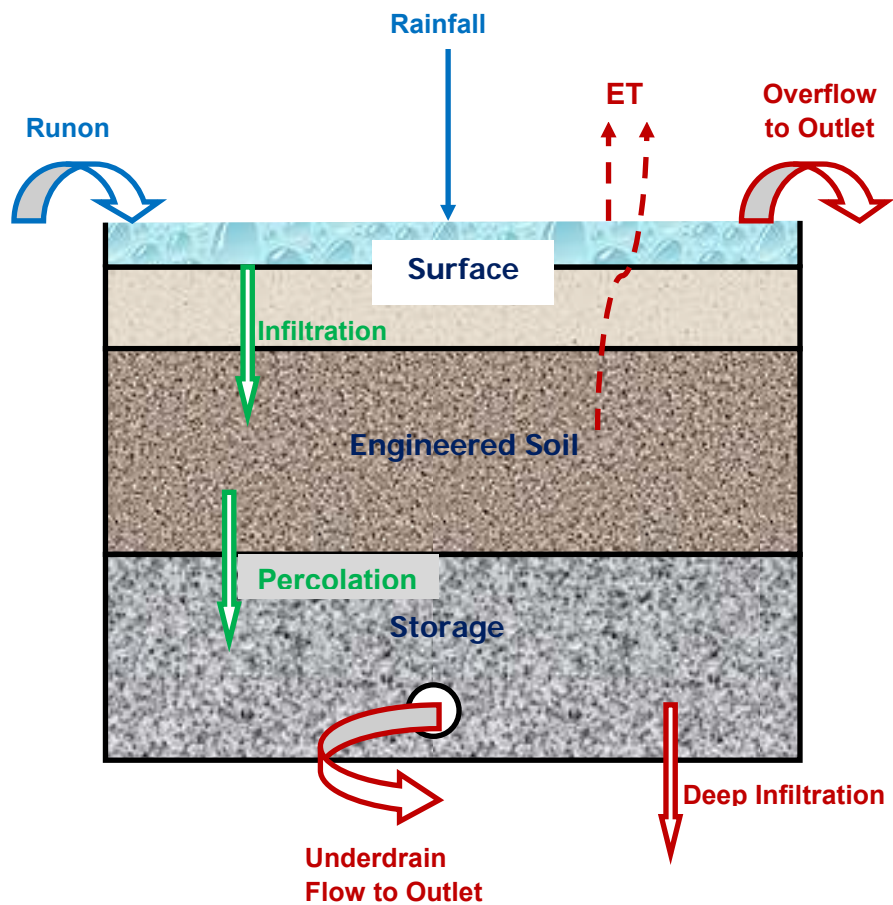
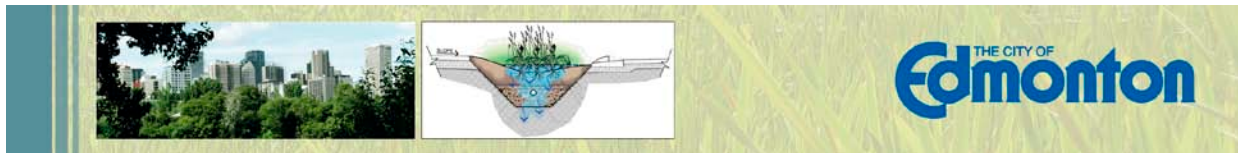


Figure 3.1 Conceptual Section of a Typical LID-BMP Facility

**TABLE 3.3
Layers Representation for Typical SWMM LID-BMP Controls**

Layer	LID-BMP Control				
	Bioretention	Porous Pavement	Infiltration Trench	Rain Barrel	Vegetative Swale
Surface	√	√	√		√
Pavement		√			
Soil	√				
Storage	√	√	√	√	
Underdrain	o	o	o	√	

Notes: √ denotes layers are required and user must apply input parameters; o denotes layers that are optional; and blank cells denote layer that are not simulated by the model for the respective LID-BMP Control (for example, bioretention does not use a pavement layer).



3.4 LID-BMP Control Placement

LID-BMP controls can be treated independently as a single unit or can represent a portion of the total footprint within a single catchment. The utilization of LID-BMP controls in a study area follows a two-step process. The first step is to create the required set of scale-independent LID-BMP controls that can be deployed in the study area. The second is to assign the desired mix of controls created in the first step to selected subcatchments. When LID-BMP controls are added to a subcatchment, the subcatchment's 'area' property is the total area of both the LID and non-LID portions of the subcatchment. However the 'percent imperviousness' and 'width' properties of the subcatchment apply only to the non-LID-BMP portion. For each LID-BMP control added to a subcatchment, the size of the control and the area of the subcatchment it treats are specified.

LID-BMP controls can be placed in a subcatchment using one of two options. One option is to place one or more controls directly within an existing subcatchment that will displace an equal amount of non-LID pervious area from the subcatchment. The other option is to create a separate subcatchment fully occupied by a single LID-BMP control. These options are illustrated in **Figure 3.2**.

For Option 1 it is important to note that runoff from *impervious areas only* is directed to the LID-BMP facility. Runoff from pervious areas reports to the catchment outlet. This approach has a limiting aspect in that the total inflow to LID-BMP units from surface runoff will be underestimated for cases where LID-BMP facilities service excess runoff from pervious areas.

Option 1 allows for the placement of multiple LID-BMP controls (of different types) within the subcatchment. However, it does not allow for the linking of controls into a "treatment train" configuration. Runoff from one LID-BMP control cannot be directed to another LID-BMP control within the catchment. All LID-BMP controls share the same outlet attributed to the catchment they reside in. The runoff to each LID-BMP control is distributed / weighted according to their area.

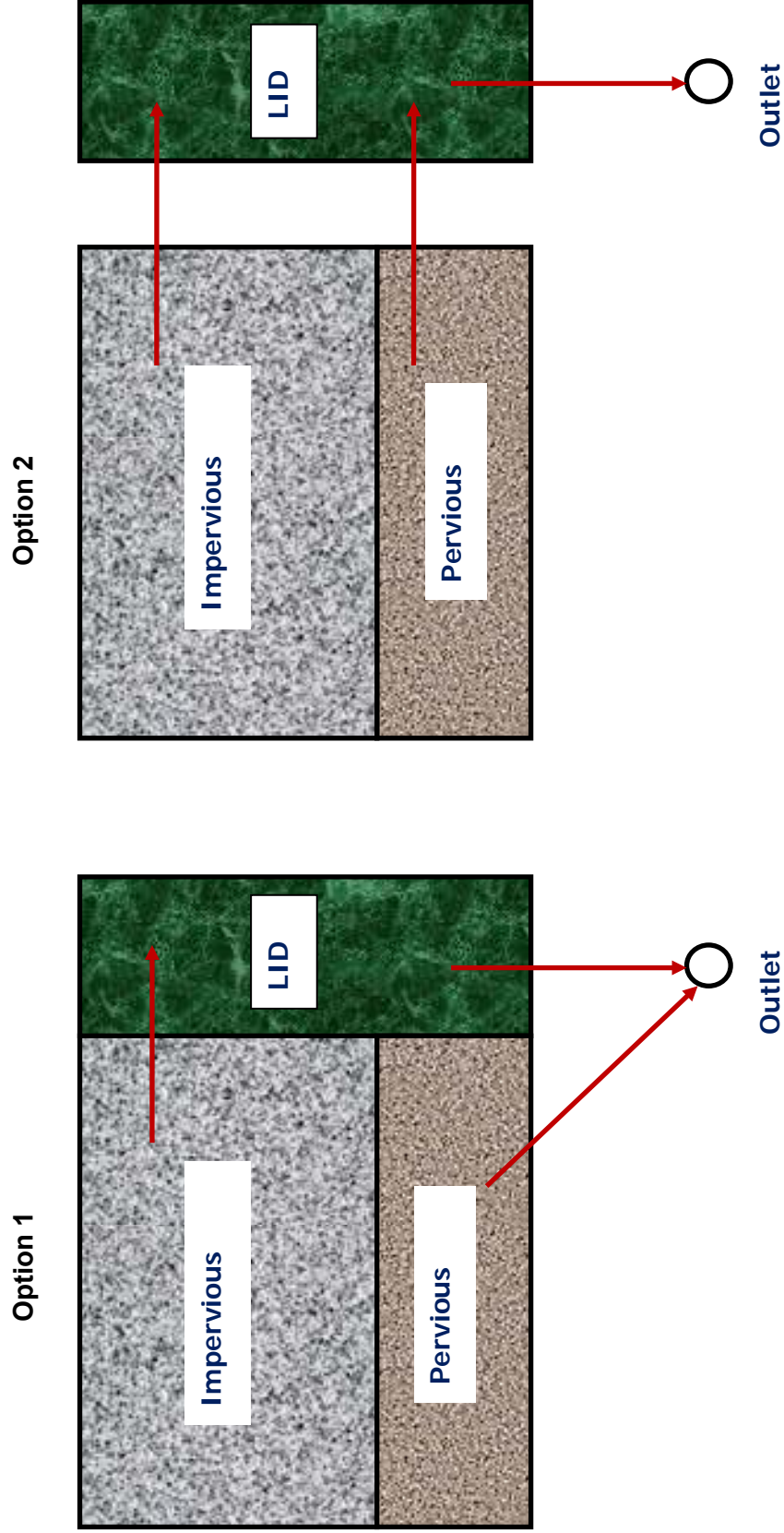
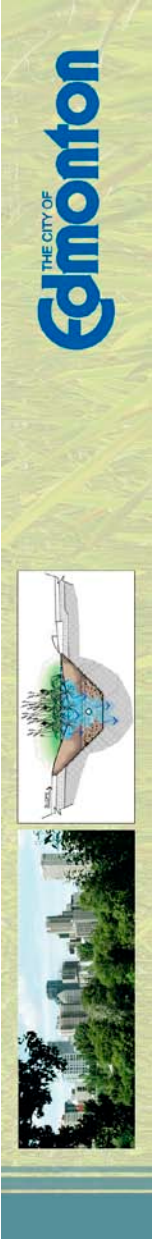
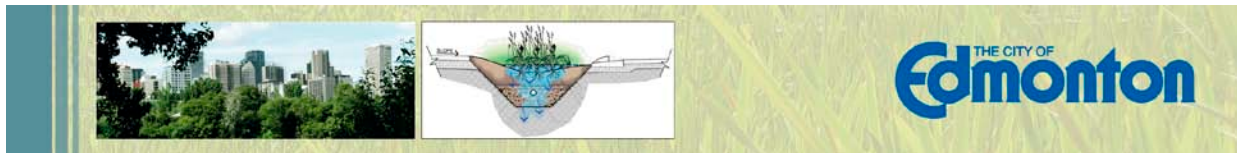


Figure 3.2 Options for Placement of LID-BMP Controls:
Option 1 – LID-BMP Control Displacing a Portion of a Subcatchment
Option 2 – Single LID-BMP Control Occupying Entire Catchment



Another important consideration to note while using Option 1 relates to the assignment of impervious areas. The impervious area assigned to a catchment defines the percent imperviousness of all areas *not* occupied by LID-BMP controls. When adding LID-BMP controls to a catchment it may be necessary to adjust the effective catchment impervious area to account for those areas displaced by the LID-BMP control.

Option 2 presents a more labour intensive approach but allows for LID-BMP controls to act in series as a treatment-train. It also enables runoff from several different catchment areas to a single LID-BMP control. When a LID-BMP control fully occupies a subcatchment, the surface properties of the LID-BMP control (including imperviousness, slope, roughness and width) override the associated subcatchment properties.

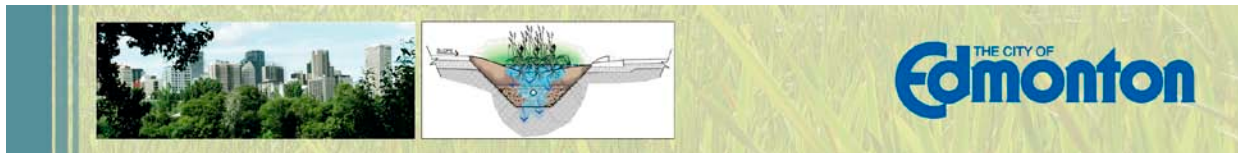
A simple test was conducted to illustrate the accounting of runoff from pervious areas by using the two options described above. **Figure 3.3** shows an example of the effect on total inflows (runoff) to LID-BMP units depending on the option of placing a single LID-BMP control within a catchment (Option 1) or as a separate catchment fully occupied by the LID-BMP control (Option 2). The 2-year Chicago design storm event was used for this illustrative test. The test represents a 1 hectare site with runoff control provided by a bioretention unit occupying 7% of the site area. The pervious area of the site is characterized by silt loam soils with a hydraulic conductivity of 6.6 mm/hr.

Inflow hydrographs are expressed in terms of millimetres per hour over the LID-BMP control surface area. Inflow includes both runoff from contributing areas and direct precipitation over the LID-BMP control. The 2-year Chicago design storm is also shown for comparison.

The results of the test are summarized by percent imperviousness as follows:

0% Impervious

For Option 1 and with 0% imperviousness, there is no runoff directed from upstream areas to the LID-BMP control and total inflow is represented solely by precipitation falling directly on the LID-BMP surface area (note that the 2-year Chicago design storm is coincident with inflow hydrograph for “Option 1 @ 0%



Impervious”). For Option 2, inflow to the LID-BMP control includes both direct precipitation and runoff from upstream pervious areas.

36% and 60% Impervious

Values of 36% and 60% imperviousness were simulated to provide plausible percent imperviousness for residential and commercial areas, respectively. As the percentage of impervious areas increases, there is a reduction in the difference between total inflows of Options 1 and 2.

100% Impervious

At 100% imperviousness the total inflow to the LID-BMP control is the same for both Options 1 and 2. Note that hydrographs for these options are coincident – “Option 1 @ 100% Impervious” is not visibly apparent as it plots directly over Option 2 @ 100% Impervious”.

For areas that are mostly impervious, the total runoff to the LID-BMP control is insensitive to the choice of Option. However, for LID-BMP controls designed to capture runoff from pervious areas, the choice of Option becomes important.

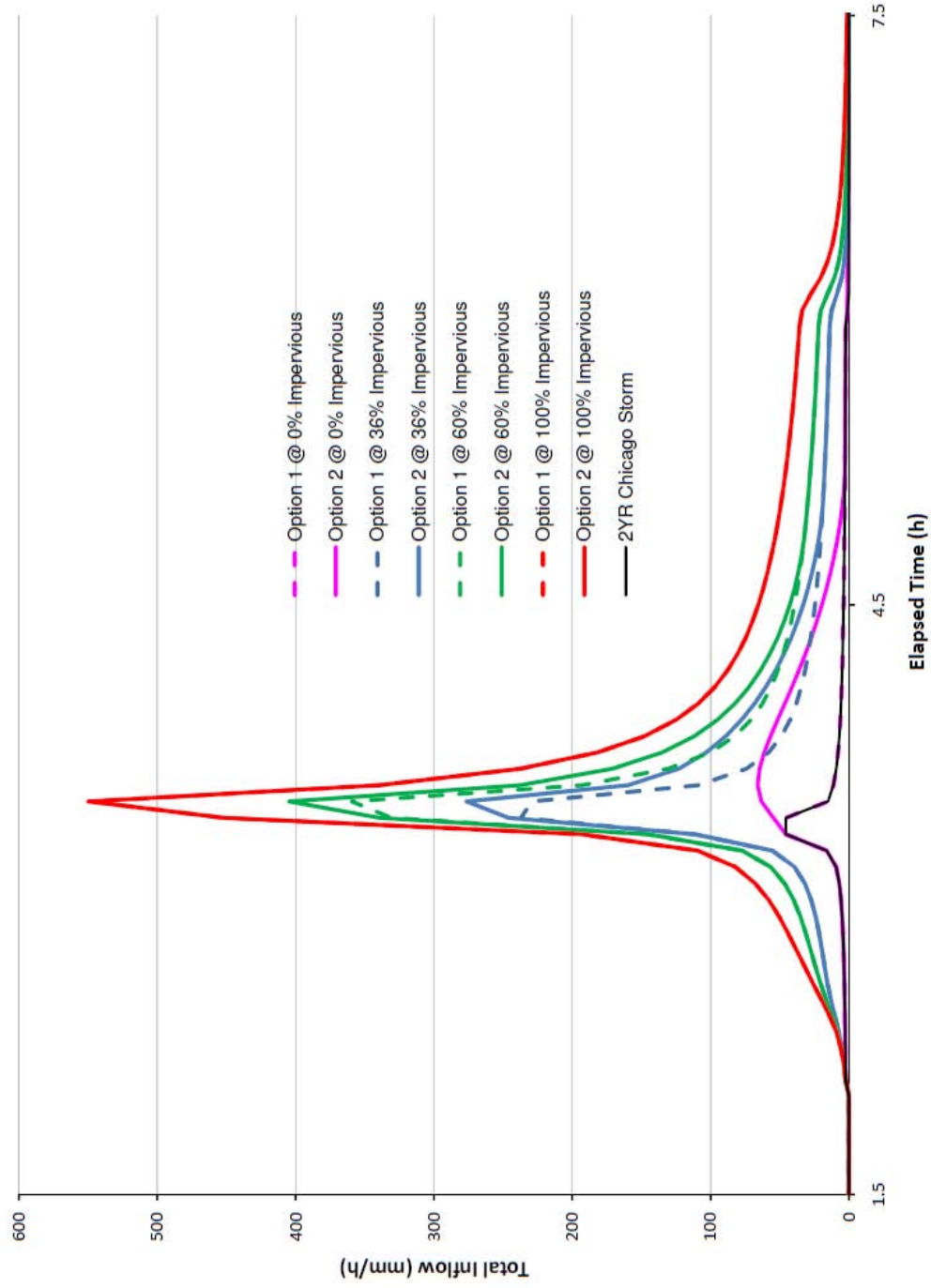
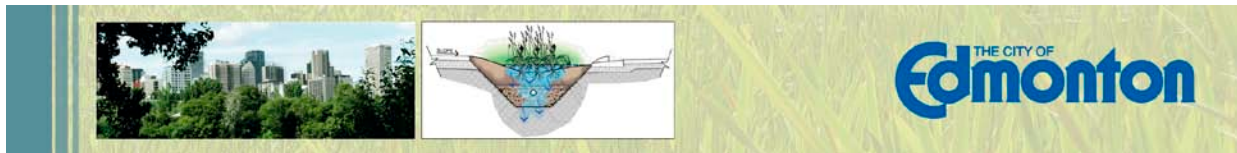


Figure 3.3 Comparison of Total Inflow (Runon) Hydrographs for: Option 1 – LID-BMP Control Displacing a Portion of a Subcatchment, and Option 2 – Single LID-BMP Control Occupying Entire Catchment



4.0 NEIGHBOURHOOD MODELLING COMPARISONS

The neighbourhood modelling comparison examines the following conditions:

- developed neighbourhood serviced by a conventional stormwater management system; and
- developed neighbourhood serviced by an LID-BMP stormwater management system.

Implementation of LID-BMP systems begins at the planning stage. Readers interested in the early stages of developing the basic stormwater management concepts are referred to the Design Guide for details on the design process / sequence for site designs. The same neighbourhoods provided as examples in the Design Guide were adopted for this modelling study.

The development scenarios presented in this study represent hypothetical, yet plausible, development conditions. Stormwater management elements (including LID-BMP facilities) are provided at a concept level. This modelling study assumes that development concepts are consistent with applicable standards and criteria.

This modelling study examines Conventional and LID-BMP neighbourhood concepts as would be provided to the modeller by the planner / designer. Often the modeller is presented with a concept and then tasked with constructing an appropriate hydrologic / hydraulic analogue of the conceptual stormwater management system. The analogue provides a tool for assessing the hydrologic performance of the concept. In practice it may be an iterative process where modelling assists in optimizing the conceptual design. The analysis presented herein provides the results of one of perhaps several iterations. The intent is not to illustrate the full optimization process. Rather, it is to demonstrate an approach to modelling LID-BMP systems. The modelling exercise also provides an opportunity to compare the hydrologic performance of a Conventional versus LID-BMP neighbourhood stormwater servicing concept.



4.1 Stormwater Servicing Concepts

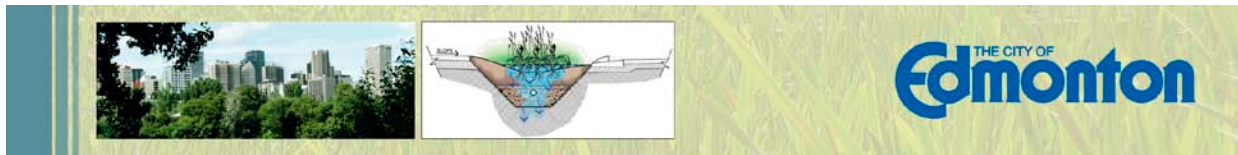
Stormwater servicing concepts were based on two conceptual plans for a Conventional and an LID-BMP neighbourhood development (**Figures 4.1 and 4.2**). The LID-BMP plan utilizes distributed stormwater management controls, providing natural filtration and retention in a localized process that works to preserve natural hydrological processes of abstraction, infiltration, evaporation, transpiration, retention and storage close to the source of runoff. The Conventional development relies on centralized, end-of-pipe stormwater management facilities to manage stormwater quantity and quality.

4.1.1 Conventional Neighbourhood Concept

The Conventional design represents a mixed use development comprising of single and multi-family residential as well as commercial development. The site has three centralized stormwater detention facilities for stormwater runoff control and treatment. Runoff is conveyed around the site by a network of storm pipes and their associated appurtenances, including manholes and catch basins. The different land uses represented in the Conventional development and their assigned percentage imperviousness are shown in **Table 4.1**.

TABLE 4.1
Percent Imperviousness of Different Land Uses in Conventional Development Site Plan

Land use	Total Area (ha)	% Impervious	Comments
Park/Open Space	4.72	18	
Institutional	4.25	24	Also includes areas denoted as Parking Lot
Low Density Residential	48.88	45	Weighted average between 'Residential' and 'Roadway'
Multi-Family	4.15	51	
Medium Density Residential	11.71	57	Weighted average between 'Multi-Family' and 'Roadway'
Commercial	4.6	60	
Stormwater Pond	2.22	100	
Total	80.53	44	Total % Impervious denotes the weighted average over entire site.



4.1.2 LID-BMP Neighbourhood Concept

Like the Conventional site design, the LID-BMP site design is a mixed-use type of development that offers a comparable mix of commercial, residential and institutional areas. The LID-BMP site design uses an integrated approach to stormwater management combining distributed LID-BMP source controls with centralized pond controls. The LID-BMP site plan has three ponds to capture and treat bypass flows, produced by large storms, from the LID-BMP source controls. Stormwater runoff is conveyed around the site using vegetative swales and a limited number of storm pipes and culverts. **Table 4.2** shows the composition of various land use types in the LID-BMP site design and their assigned percentage imperviousness.

The LID-BMP Neighbourhood Plan maintains the same housing and commercial density as the Conventional Neighbourhood Plan while providing some additional unique characteristics:

- connected green spaces throughout the site that allow stormwater capture and conveyance;
- LID-BMP facilities such as green roofs, permeable pavers, and parking lot bioretention areas;
- cisterns and residential rain gardens in select areas as a pilot initiative;
- swales with check dams as primary conveyance elements throughout neighbourhoods and a large naturalized drainage way with bioswales along its central boulevard; and
- stormwater control facilities that serve a dual purpose of storage for large events and treatment through bioretention for small events.

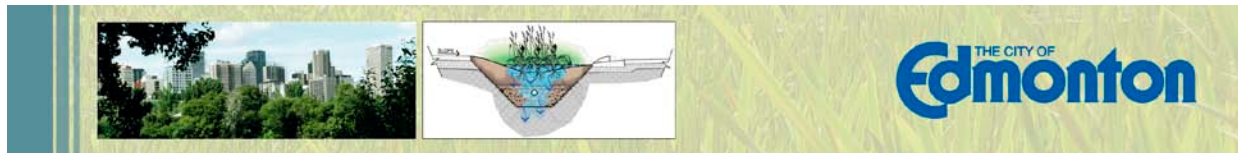


TABLE 4.2
Percent Imperviousness of Different Land Uses in LID-BMP Development Site Plan

Land Use	Total Area (ha)	Impervious (%)	LID-BMP Facility	LID-BMP Area (ha)	Comments
Bioretention Area	0.15	0	Bioretention	0.15	Dedicated bioretention areas not including ponds.
Bioretention Ponds	1.22	100	Bioretention Pond	2.10	All water reports to pond (100% impervious), infiltration modeled as storage element with bottom infiltration.
Green Roof	2.28	50	Green Roof	1.14	Assume 50% coverage on all roofs in commercial, high-density residential, and institutional areas.
Roads	12.24	85	None	0	
Commercial	2.45	70	Box Planter Pervious Paver	0.09 0.01	
High Density Residential	2.10	61	Box Planter Pervious Paver	0.03 0.03	Weighted average of pervious and impervious areas.
Medium Density Residential	4.27	51	Cistern	0.01	Weighted average of pervious and impervious areas.
Low Density Residential	38.84	36	Rain Garden	0.18	Weighted average of pervious and impervious areas.
School	2.79	30	Bioretention	0.132	Weighted average of pervious and impervious areas. Excludes areas covered by LID-BMP controls.
Pervious Grass	9.15	18			
Roadside Swales	4.22	0	Vegetative Swale	4.22	
Naturalized Drainage Way	0.45	0	Vegetative Swale	0.45	
Woodlot	0.56	10	None	0	Heavily treed area (not included as part of conventional design).
Total	80.7	43		8.5	10.5% of total area covered by LID-BMPs (including bioretention ponds).

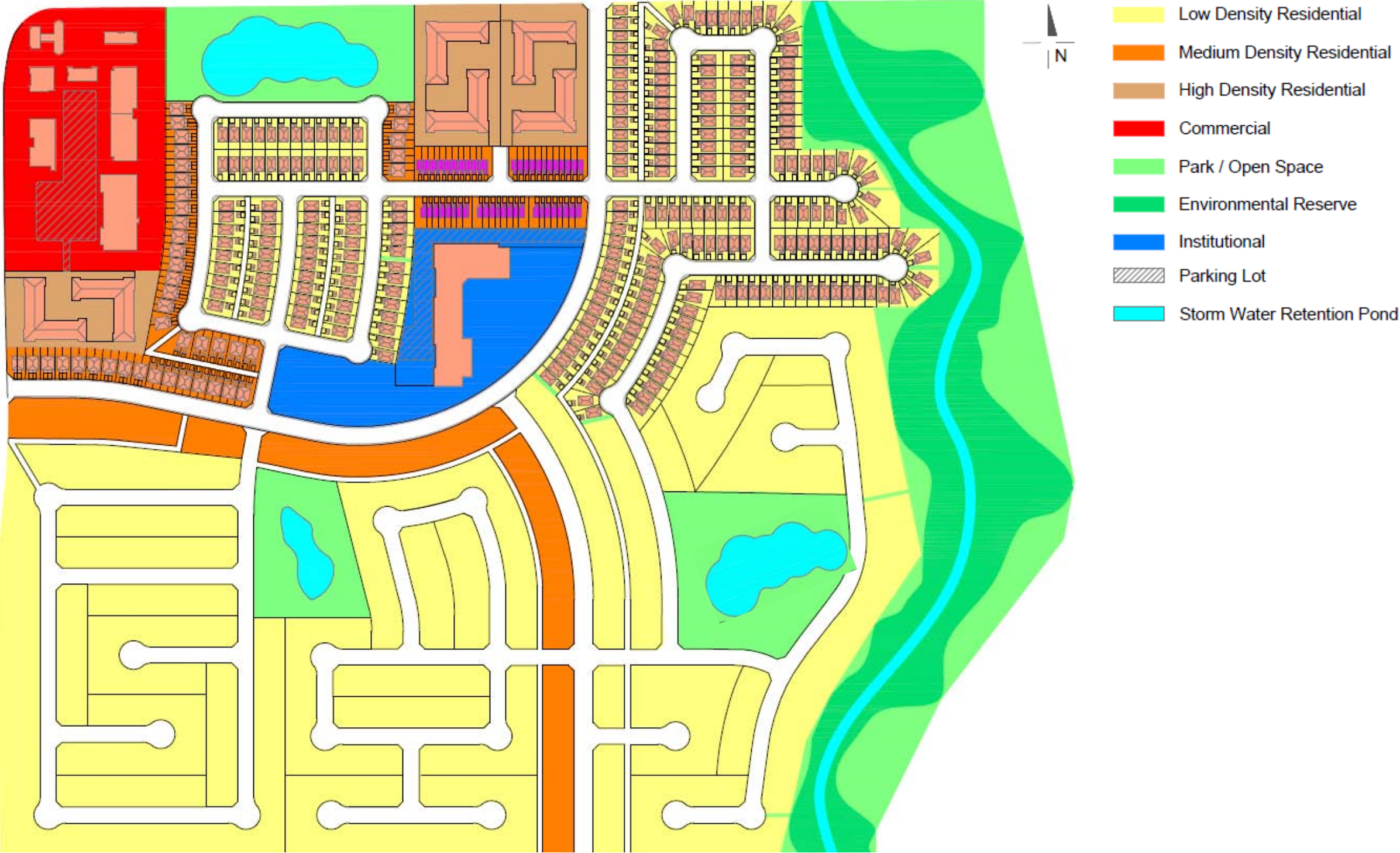


Figure 4.1 Conventional Neighbourhood Concept Plan

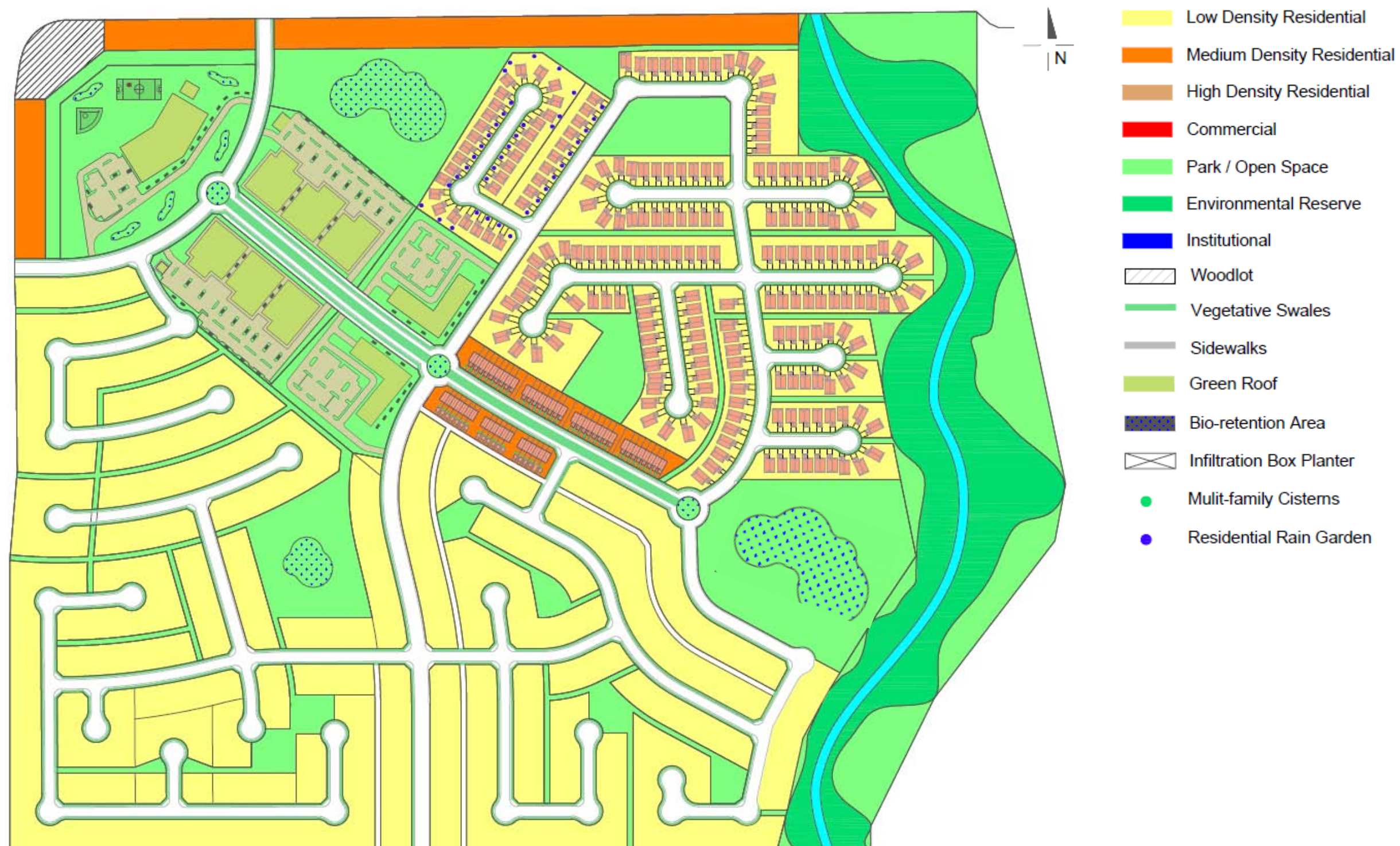
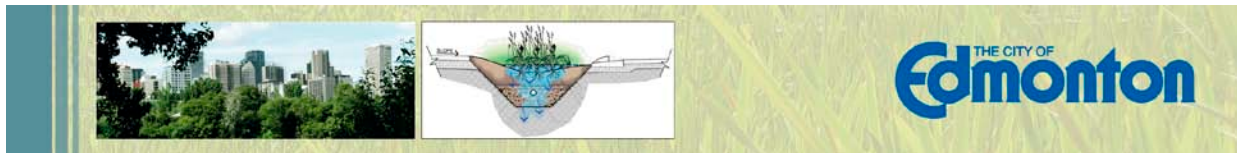


Figure 4.2 LID-BMP Neighbourhood Concept Plan



4.2 Model Construction

This section describes major components of the models for the Conventional and LID-BMP development scenarios.

Figure 4.3 and **Figure 4.4** provide model conceptual site layouts illustrating catchment areas and key stormwater management facilities represented in the Conventional and LID-BMP models, respectively. These correspond to screen shots of the models as viewed in the SWMM5 interface. A description of key elements of the model construction is provided below.

4.2.1 Catchment Areas

The total development area is approximately 80 hectares. Catchment areas were delineated according to land use, and the assumed final topography / grading. In general, the development area slopes toward the east and discharges to a creek bounding the east side of the development area. The development area does not accept runoff from adjacent land areas. The stormwater management system collects all runoff from the developed area and discharges to the creek at a controlled rate.

A summary of the catchment areas corresponding to the conventional and LID-BMP concepts is provided in **Tables 4.1 and 4.2**, respectively. Catchment areas are grouped by land use. The adopted percent of impervious area for each land use is provided in the tables. The total percent imperviousness (~40%) is comparable for both concepts.

4.2.2 Hydrologic Response Parameters

Catchment response parameter values were selected to be representative of local Edmonton conditions. The same catchment response parameters were used for the Conventional and LID-BMP models. **Table 4.3** provides a range of typical values and the selected parameter value for catchment surface properties (depression storage and overland flow roughness).

07/10/1978 20:05:00

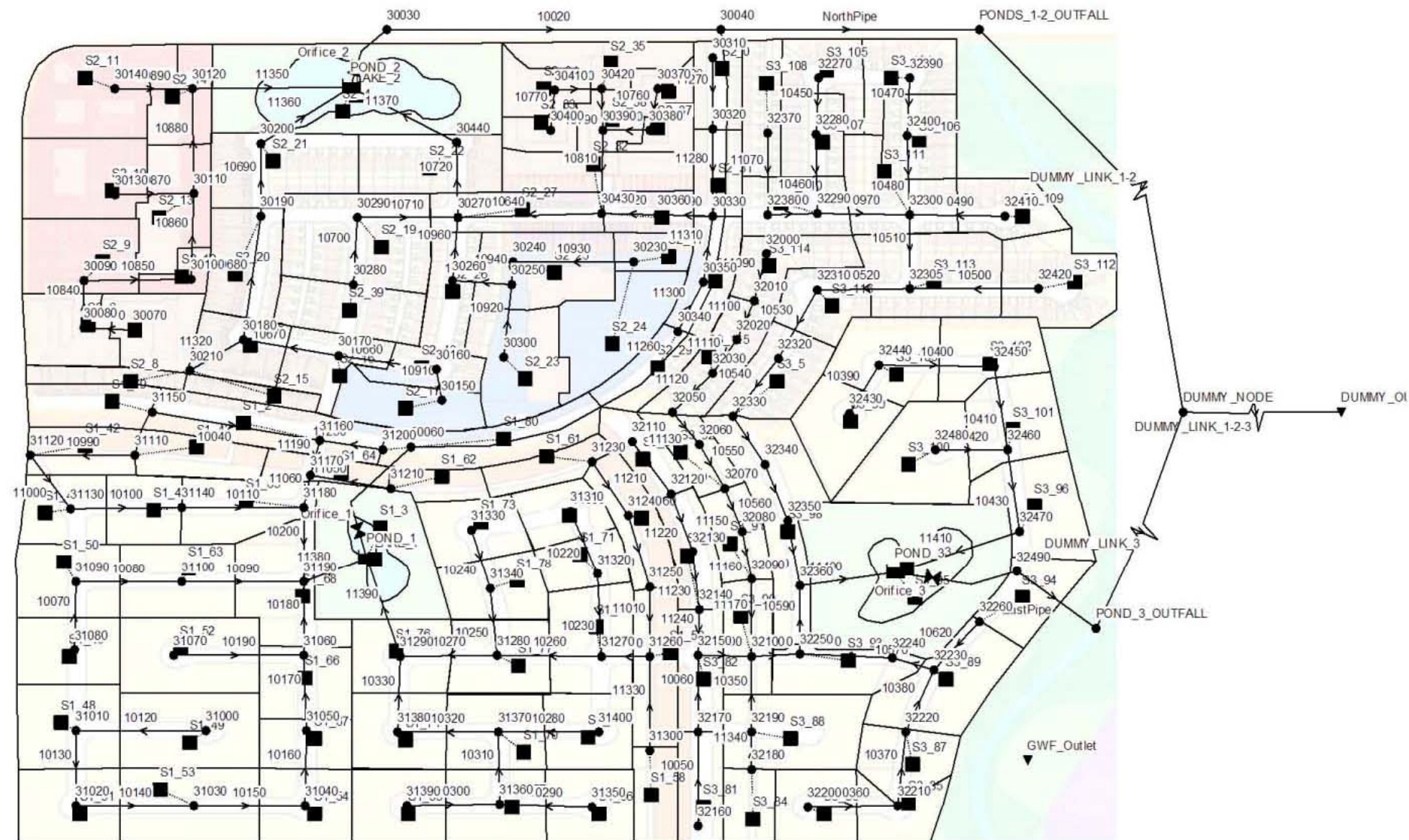


Figure 4.3 Conventional Neighbourhood SWMM Model Layout Screenshot

07/10/1978 20:05:00

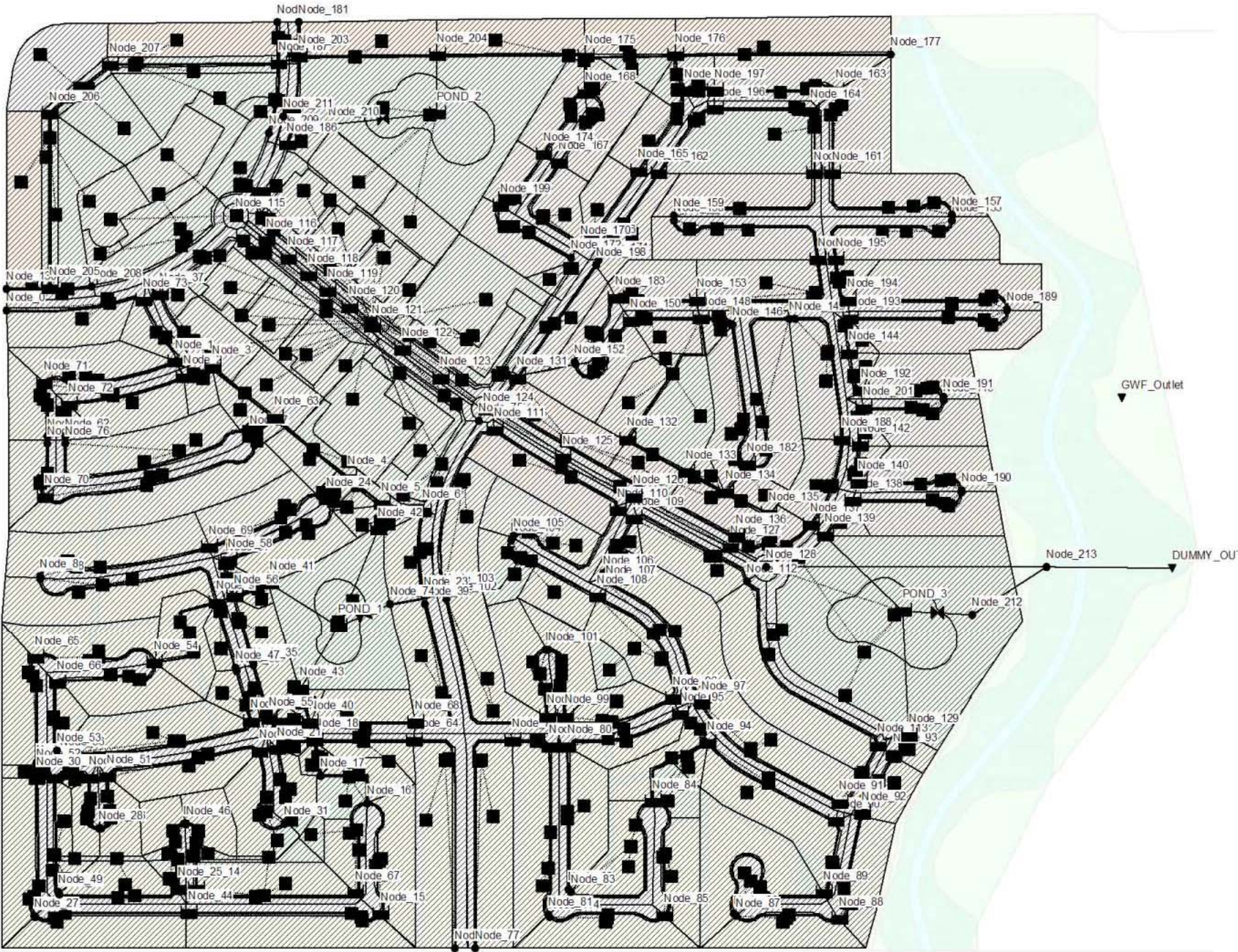


Figure 4.4 LID-BMP Neighbourhood SWMM Model Layout Screenshot

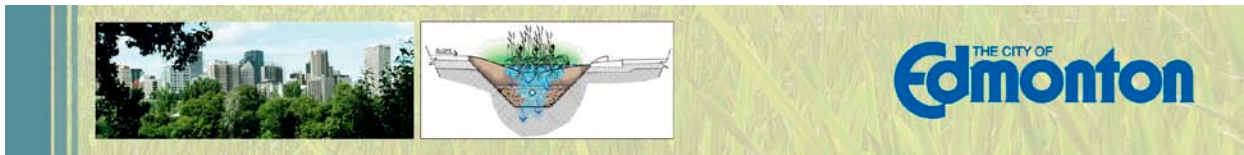


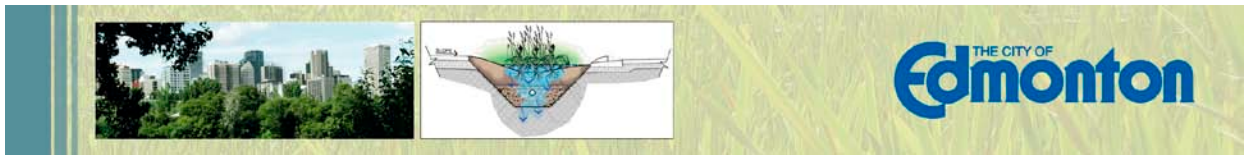
TABLE 4.3
Depression Storage and Overland Flow Surface Roughness

Parameter		SWMM Parameter Name	Typical Range	Selected Value	Remarks
Depression Storage (mm)					
	Pervious areas	Sperv	2.5 - 7.6	2.5	Low permeable soils considered representative of Edmonton area soils.
	Impervious areas	Simp	1.3 - 2.5	0.5	Representative of Edmonton conditions.
Manning's n for overland flow					
	Pervious areas	Nperv	0.05 - 0.80	0.15	Short grasses (lawns).
	Impervious areas	Nimp	0.011-0.024	0.015	Representative of Edmonton conditions.

Pervious area infiltration was based on the Green-Ampt infiltration method. This infiltration model was selected for practical considerations as certain components in the SWMM model (e.g., LID-BMP Controls and Storage Elements with infiltration) are limited to the Green-Ampt model. This allowed for consistency in the infiltration method used across all model elements. **Table 4.4** summarizes the modelled infiltration parameters. Typical ranges of values are provided for comparison.

TABLE 4.4
Green-Ampt Model Infiltration Parameters

Parameter	SWMM Parameter Name	Typical Range	Selected Value	Remarks
Soil capillary suction (mm)	Suction	49 - 320	170	Silt Loam (low permeable soil)
Soil saturated hydraulic conductivity (mm/hr)	Conduct	0.25 - 120	6.6	Silt Loam (low permeable soil)
Initial soil moisture deficit	InitDef	0 - 1	0	Assume Saturated



Evapo-transpiration estimates were based on mean monthly evaporation data reported by Environment Canada for the Edmonton City Centre Airport. **Table 4.5** lists monthly evaporation data used for modelling.

TABLE 4.5
Average Monthly Evaporation Data at City Centre Airport

Month	Evaporation (mm/day)	Month	Evaporation (mm/day)
January	0	May	3.6
February	0	June	4.2
March	0.7	July	4.6
April	2.3	August	3.6
		September	1.8
		October	0.7
		November	0.1
		December	0

4.2.3 Conventional Conveyance Systems

The drainage system design for the Conventional development neighbourhood is based on a minor system design for conveyance elements and flood control for storage elements. The conveyance system is made up of a network of local and trunk sewers and manholes with enough detail for the design of the main collection system and stormwater management ponds. Catchbasins and catchbasin leads were excluded from the network for modelling purposes. The minor system is designed to handle minor rainfall events up to the 1:5 year Chicago design storm event. Model pipe geometries were sized to meet the following criteria:

- minimum pipe slope of 0.1%;
- pipes do not surcharge during 5 year design event;
- maximum velocities do not exceed 3.0 m/s; and
- minimum velocities of 0.6 m/s are achieved.

Table 4.6 provides a listing of the different sizes of storm pipes in the constructed network for the Conventional development neighbourhood.

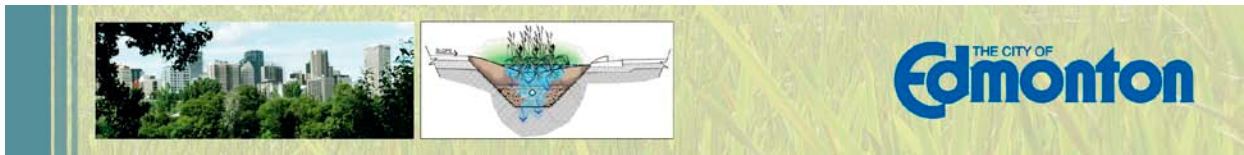


TABLE 4.6
Conventional Neighbourhood Conveyance (Pipe) Elements

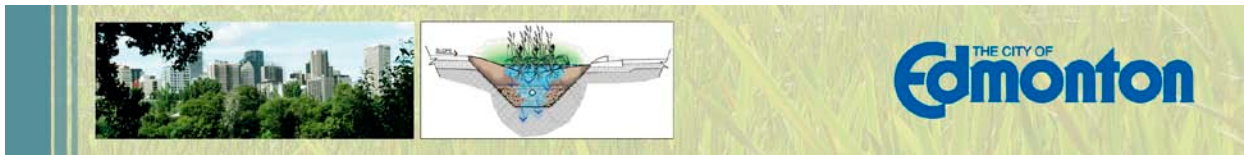
Size of Pipe (mm)	Total Length (m)
375	896
450	1790
600	3298
750	2332
900	2148
Total	10464

4.2.4 LID-BMP Conveyance Systems

The conveyance network for the LID-BMP concept is largely made up of vegetated swales with only a limited number of storm conduits. All swales were represented by trapezoidal sections with base width of 0.5 meters and side slopes of 2H:1V.

Incorporating swales as LID-BMP controls presented a unique challenge with respect to the hydraulic routing of flows through the collection network. A practical limitation for representing swales as LID-BMP controls relates to a SWMM model restriction on connectivity between model elements. That is, once flows enter the hydraulic network (e.g., manhole, storage node, pipe, etc.) they cannot be redirected back onto a catchment or LID-BMP control. For example, flows could not be routed along a vegetated swale (represented as an LID-BMP control), through a culvert and then back into a swale.

The following approach was used to overcome this limitation. First flows from a subcatchment were directed into a vegetated swale (represented as an LID-BMP control). Then, flows from the vegetated swale were sent into a SWMM “Conduit” (represented by an open channel cross section). By this approach, a more appropriate representation of the hydraulic routing was achieved. The exception to this approach was for swales directly connected to the central naturalized drainage way. Runoff from these nearby swales was directed into the naturalized drainage way (represented by an LID-BMP control).



This approach also helped to reduce some of the limitations associated with the hydraulic routing of flows along vegetated swales represented by an LID-BMP control. Some simple tests were conducted to examine the difference between how flows are routed through swales represented by an LID-BMP control (“LID swale”) versus flows through swales defined by a hydraulic element or “conduit” (“conduit swale”). Tests on representative vegetated swale segments found that flows routed through LID swales produced peaks that were approximately 20% lower than for flow routed through a conduit swale.

Further, the adopted approach for routing flows through swales enabled the simulation of check dams. Small, 200 mm high, check dams were introduced at the end of each major swale segment. The check dams were simulated by storage nodes with infiltration. The storage upstream of each check dam was determined by a depth area relationship based on the corresponding ditch geometry.

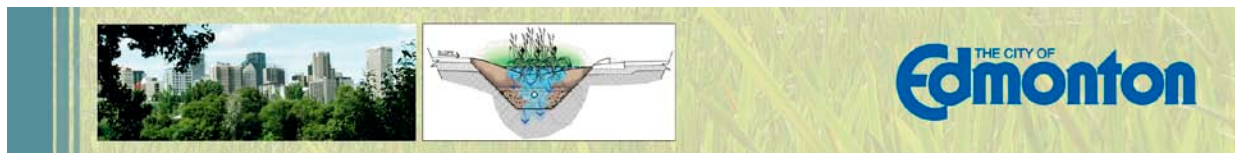
For the modelling exercise, all LID swales were assigned a constant slope of 0.5%. Runoff from these swales was then directed into conduit swales that had slopes more representative of surface grades. The average slope of the conduit swales was 0.6%.

4.2.5 Storage Systems (Ponds)

For both the Conventional and LID-BMP models, stormwater management ponds were represented as cylindrical storage units with outflows controlled by a circular orifice. Criteria applied for sizing ponds to handle the most critical design rainfall event – the July 10–11, 1978 storm event recorded at the Edmonton Municipal Airport - were:

- maximum allowable storage depth of 3.0 m;
- maximum allowable peak discharge to creek of 4.0 m³/s (based on a maximum unit peak rate of 5.0 L/s/ha); and
- adequate drawdown of pond levels to achieve 90% of active storage volume within 96 hours.

The cross-sectional area of the ponds was adjusted until these criteria were met. This area provides a guide on the minimum footprint required to accommodate each pond. Required pond



areas for the Conventional model are summarized in **Table 4.7**. Required pond areas for the LID-BMP model are summarized in **Table 4.8**. Total footprint required for the storage ponds for the modelled LID-BMP concept was approximately 80% of that required for the Conventional concept.

TABLE 4.7
Conventional Neighbourhood Stormwater Pond Minimum Required Area (Footprint)

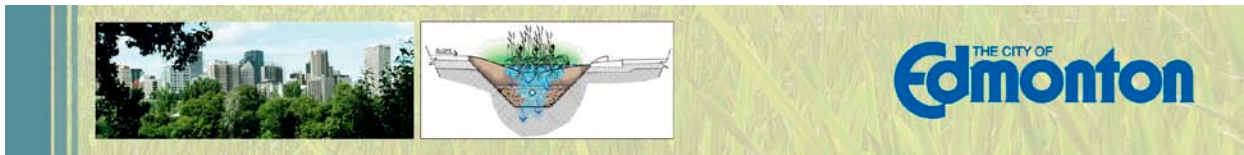
Pond	Uniform Cross-Sectional Area (m ²)
POND 1	7,960
POND 2	7,040
POND 3	7,410
Total	22,410

TABLE 4.8
LID-BMP Neighbourhood Stormwater Pond Minimum Required Area (Footprint)

Pond	Uniform Cross-Sectional Area (m ²)
POND 1	4,550
POND 2	3,670
POND 3	10,090
Total	18,310

4.2.6 LID-BMP Stormwater Management Facilities (Controls)

Table 4.9 provides a summary of the LID-BMP controls used in the LID-BMP neighbourhood concept plan. The LID-BMP properties are defined on a per unit area basis. The placement of controls were opportunistic in nature, utilizing existing building roof tops for green roof applications, landscaped areas for rain gardens and planned parking lots for porous pavement applications. The total area represented by all the SWMM LID-BMP controls is equal to 6.44 ha (8% of the total site area). Bioretention ponds (simulated as storage



elements with infiltration) offer an additional 2.1 ha (2.6% of total area). Therefore, the total footprint of LID-BMPs occupies approximately 11% of the development area.

4.3 Model Application and Results

4.3.1 Single Rainfall Events

Single design storm event simulations were conducted to assess the performance of stormwater management systems during and immediately after short periods of rainfall. These simulations test the hydraulic design capacities of minor system components for conveyance when small storm events are applied. The July 10-11, 1978 storm event recorded at the Edmonton Municipal Airport was used for sizing stormwater management facilities. **Table 4.10** provides a summary of characteristics of the single design storm events used for model simulations.

Table 4.11 and **Table 4.12** provide a summary of computed peak runoff rates and volumes for the 2-year and 5-year rainfall events, respectively.

Figure 4.5 and **Figure 4.6** provide a comparison of runoff hydrographs discharging to the creek for the 2-year and 5-year rainfall events, respectively.

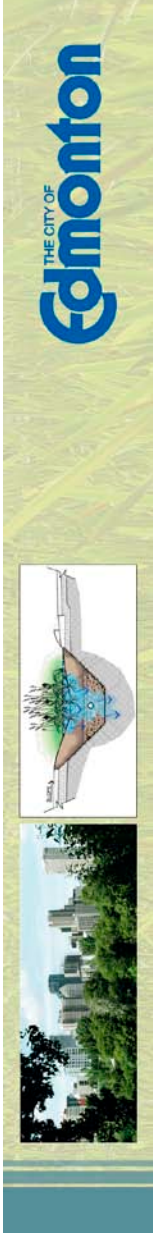


TABLE 4.9
Summary of LID-BMP Neighbourhood Concept – LID-BMP Facilities and Associated Model Parameters

Layer	Layer Properties	LID-BMP Facility Modeled as SWMM LID-BMP Control						
		Bio-retention	Rain Garden/Box Planter	Permeable Pavement	Vegetative Swales	Naturalized Drainage Way	Green Roof	Cistern
		Bio-retention cell (BC)	Bio-retention cell (BC)	Porous Pavement (PP)	Vegetative Swale (VS)	Vegetative Swale (VS)	Bio-retention cell (BC)	Rain Barrel (RB)
Surface	StorHt (mm)	150	150	25	2000	1000	25	not applicable
	VegFrac	0	0	0	0	0	0	not applicable
	Rough	0	0	0.03	0.035	0.035	0	not applicable
	Slope	0	0	1	0.5	0.5	0	not applicable
	Xslope	not applicable	not applicable	not applicable	2	3	not applicable	not applicable
Pavement	Thick (mm)	not applicable	not applicable	150	not applicable	not applicable	not applicable	not applicable
	Vratio	not applicable	not applicable	0.15	not applicable	not applicable	not applicable	not applicable
	FracImp	not applicable	not applicable	0	not applicable	not applicable	not applicable	not applicable
	Perm (mm/h)	not applicable	not applicable	500	not applicable	not applicable	not applicable	not applicable
	Vclog	not applicable	not applicable	0	not applicable	not applicable	not applicable	not applicable
Soil	Thick (mm)	500	500	not applicable	not applicable	not applicable	150	not applicable
	Por	0.44	0.44	not applicable	not applicable	not applicable	0.58	not applicable
	FC	0.11	0.11	not applicable	not applicable	not applicable	0.34	not applicable
	WP	0.05	0.05	not applicable	not applicable	not applicable	0.04	not applicable
	Ksat (mm/h)	30	30	not applicable	not applicable	not applicable	64	not applicable
Storage	Kcoeff	10	10	not applicable	not applicable	not applicable	5	not applicable
	Suct (mm)	61	61	not applicable	not applicable	not applicable	75	not applicable
	Height (mm)	300	10	300	not applicable	not applicable	25	1000
	Vratio	0.66	0.66	0.66	not applicable	not applicable	0.66	not applicable
	Flit (mm/h)	1	1	1	not applicable	not applicable	0	not applicable
Underdrain	Vclog	0	0	0	not applicable	not applicable	0	not applicable
	Coeff (mm/h)	0.36	0	0.34	not applicable	not applicable	50	1.23
	Expon	0.5	0.5	0.5	not applicable	not applicable	0.5	0.5
	Offset (mm)	100	0	100	not applicable	not applicable	0	0
	Delay (h)	not applicable	not applicable	not applicable	not applicable	not applicable	not applicable	12
Total Area (ha)		0.28	0.30	0.04	4.22	0.45	1.14	0.01



TABLE 4.10
Characteristics of Modelled Single Storm Events

Storm & Duration	Total Depth (mm)	Peak Intensity (mm/hr)	Application
2-Yr 4-hr Chicago	25.5	45.6	Test performance of LID-BMP systems under frequent storm events.
5-Yr 4-hr Chicago	37.2	68.1	Test level of service for conveyance system.
July 10-11, 1978 recorded storm event at the Edmonton Municipal Airport	133.6	105.6	Used for sizing / testing performance of large stormwater management facilities (ponds).

TABLE 4.11
Summary of 2-year Rainfall Event Runoff Results

Runoff Destination	Rainfall (mm)	Service Area (ha)	Peak Inflow (m ³ /s)	Unit Peak (L/s/ha)	Runoff Volume (m ³)	Runoff Depth (mm)
Pre-Development						
Creek	25.5	80.5	0.04	0.5	1,560	1.9
Conventional Development						
Pond 1	25.5	25.5	1.70	66.7	4,129	16.2
Pond 2	25.5	28.2	1.49	52.9	3,606	12.8
Pond 3	25.5	26.9	1.37	50.9	3,731	13.9
Creek	25.5	80.5	0.14	1.7	10,793	13.4
Low Impact Development						
Pond 1	25.5	23.2	0.55	23.6	2,764	11.9
Pond 2	25.5	16.1	0.28	17.6	1,631	10.1
Pond 3	25.5	80.7*	0.63	7.7	4,044	5.0
Creek	25.5	80.7*	0.07	0.8	2,600	3.2

* Service areas for Pond 3 and Creek are same since all runoff reports to Pond 3 prior to release to Creek.

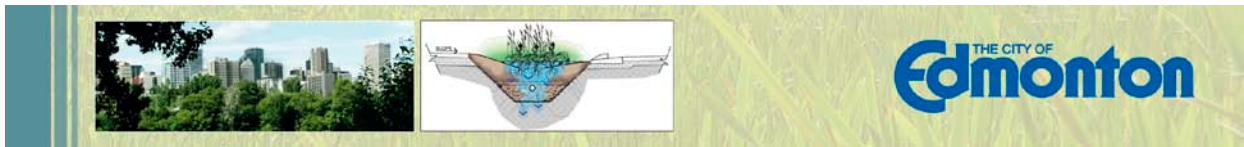


TABLE 4.12
Summary of 5-year Rainfall Event Runoff Results

Runoff Destination	Rainfall (mm)	Service Area (ha)	Peak Inflow (m ³ /s)	Unit Peak (L/s/ha)	Runoff Volume (m ³)	Runoff Depth (mm)
Pre-Development						
Creek	37.2	80.5	0.10	1.2	2,690	3.3
Conventional Development						
Pond 1	37.2	25.5	2.80	110.1	6,849	26.9
Pond 2	37.2	28.2	2.52	89.2	6,034	21.4
Pond 3	37.2	26.9	2.24	83.5	6,269	23.3
Creek	37.2	80.5	0.19	2.4	18,231	22.6
Low Impact Development						
Pond 1	37.2	23.2	1.07	46.0	4,989	21.6
Pond 2	37.2	16.1	0.64	39.7	3,106	19.3
Pond 3	37.2	80.7	1.32	16.4	7,920	9.8
Creek	37.2	80.7	0.16	1.9	9,458	11.7

* Service areas for Pond 3 and Creek are same since all runoff reports to Pond 3 prior to release to Creek.

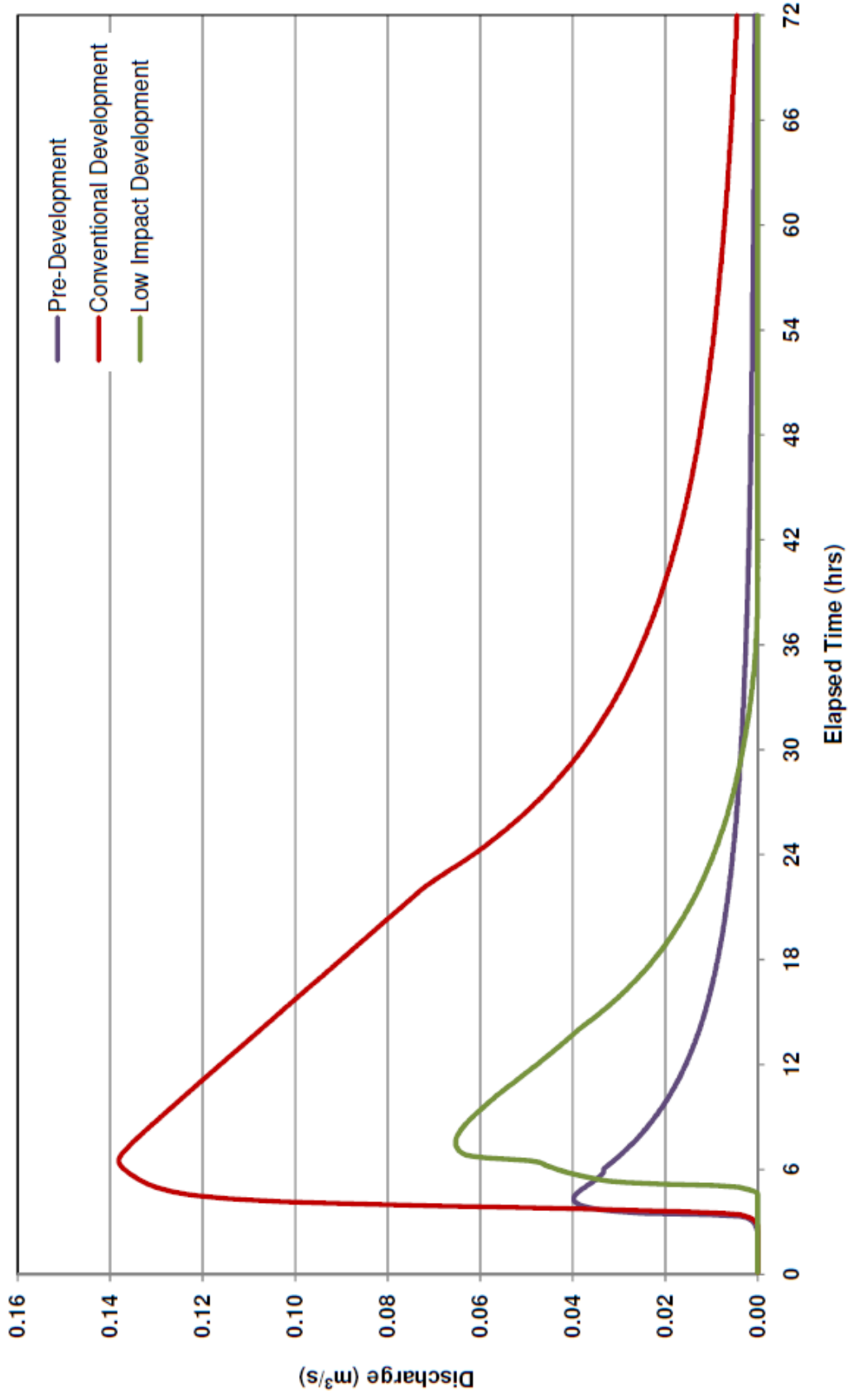
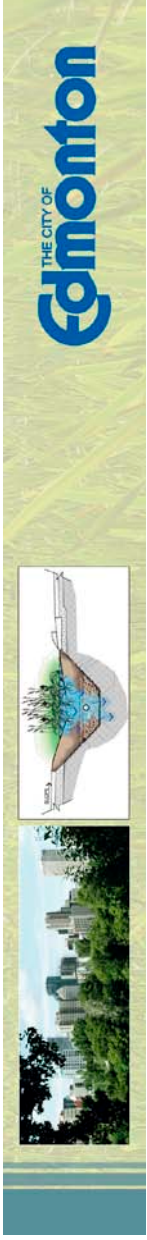


Figure 4.5 2-year Rainfall Runoff Hydrographs from Development to Creek.

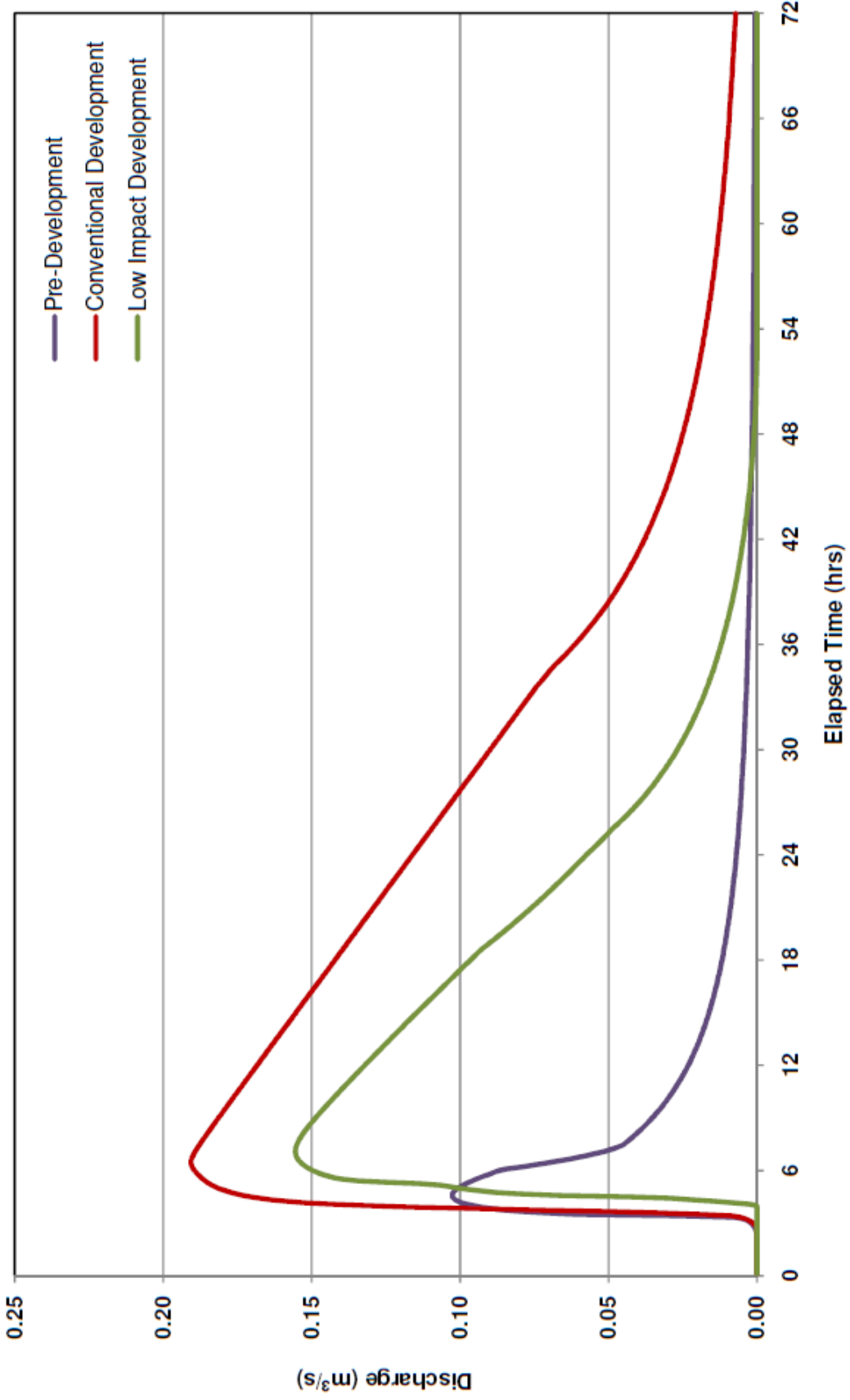
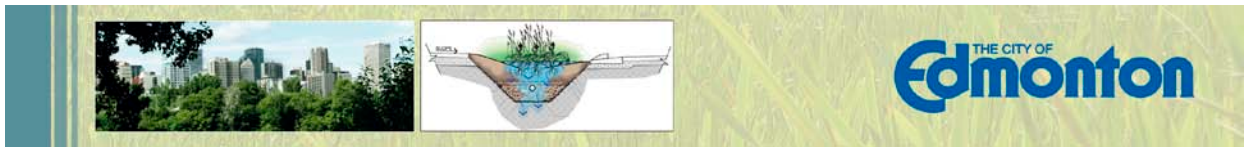


Figure 4.6 5-year Rainfall Runoff Hydrographs from Development to Creek.



4.3.2 Continuous Long Term Rainfall

Long term continuous simulation allows for consideration of:

- antecedent soil moisture conditions;
- evapo-transpiration losses;
- varying patterns of rainfall duration and intensity, variation of time between storms and changing storage conditions within the watershed; and
- impact of back-to-back storm events on capacity of storage elements and LID-BMP controls.

Infiltration capacities of soils are dependent on their moisture content. Using long term continuous simulations, effects of changing infiltration capacities on the overall water balance are taken into account.

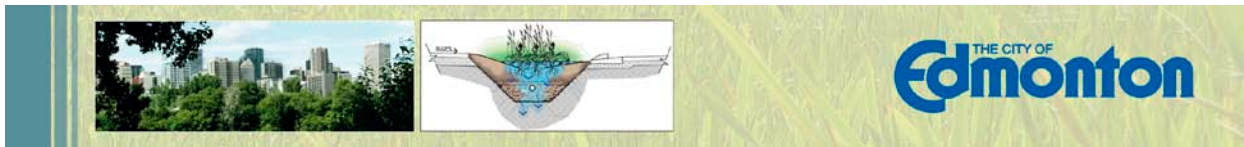
Continuous simulations were used to evaluate and compare annual runoff volumes. Seasonal rainfall time series were developed based on continuous rainfall data recorded by Environment Canada (EC) and the City of Edmonton. Rainfall data were available for the period from April through October. Two long term time series data sets were generated. The first data set was developed from EC hourly rainfall data recorded at the City Centre Airport (EC Station No. 3012208) for the period of record 1960 to 1993. The second set of long term time series was created from 5 minute rainfall data collected by the City of Edmonton at the City Centre Airport (City Rain Gauge No. 19). **Table 4.13** provides a summary of seasonal rainfall data for these two records. Seasonal rainfall based on EC daily data is provided for comparison. For most years, there is good agreement on seasonal totals between gauges. Data based on short intervals were typically less than the reported daily data. This is in part due to daily data being corrected to account for undercatch. Those years where there is poor agreement between the continuous time series data (hourly or 5-minute interval) and daily total are highlighted in the table. Poor agreement was defined, qualitatively, as differences larger than 25%.



TABLE 4.13
Total Observed Seasonal (April through October) Rainfall Depth (mm)

Rain Gauge	City of Edmonton Gauge 19	EC City Centre Station 3012208	EC City Centre Station 3012208	Rain Gauge	City of Edmonton Gauge 19	EC City Centre Station 3012208	EC City Centre Station 3012208
Recording Interval	(5 min)	(Hourly)	(Daily)	Recording Interval	(5 min)	(Hourly)	(Daily)
Year				Year			
1960		375.0	401.9	1986	342.6	352.8	386.6
1961		205.3	207.5	1987	264.8	373.4	387.9
1962		314.7	322.1	1988	439.8	455.7	476.9
1963		201.9	221.5	1989	162.6	207.9	324.9
1964		315.0	311.3	1990	222.8	343.0	363.3
1965		393.4	402.5	1991	344.2	345.2	367.5
1966		286.5	297.9	1992	186.2	176.4	197.6
1967		225.3	237.0	1993	308.2	322.2	346.6
1968		228.9	261.8	1994	362.4		429.3
1969		257.7	372.2	1995	209.8		239.7
1970		269.5	330.1	1996	333.8		401.0
1971		262.8	264.8	1997	336.8		399.8
1972		334.8	346.6	1998	346.0		423.4
1973		425.6	420.2	1999	263.0		349.8
1974		373.7	374.6	2000	251.8		333.0
1975		37.9	310.5	2001	100.2		329.4
1976		290.7	316.7	2002	64.4		149.8
1977		375.1	416.2	2003	306.2		311.2
1978		478.8	509.8	2004	372.6		376.0
1979		353.7	357.2	2005	216.6		241.7
1980	146.0	370.9	406.6	2006	325.6		375.5
1981	229.8	308.6	310.5	2007	230.0		238.5
1982	396.4	305.3	305.9	2008	233.8		235.5
1983	400.0	325.5	343.0	2009	119.8		189.0
1984	288.0	294.2	339.6	2010	306.6		349.0
1985	266.6	308.3	308.4				

Note: Highlighted cells indicate values that vary by more than 25% from seasonal totals based on reported daily data.



Tables 4.14 and **4.15** provide long term seasonal summaries of computed total runoff and seasonal peaks, respectively. **Figures 4.7** and **4.8** provide charts comparing total computed runoff volumes for the hourly long term time series (1960-1993) and 5-minute long term time series (1980-2010), respectively. Runoff depths are expressed as an equivalent depth, in mm, over the total development area. The modelled rainfall denotes the time series rainfall data input to the model (based on recorded rainfall data provided by EC and the City of Edmonton).

TABLE 4.14
Total Computed Seasonal (April through October) Rainfall Depth (mm)

Simulation Period / Season	Pre-Development Rainfall Depth (mm)		Conventional Development Rainfall Depth (mm)		Low Impact Development Rainfall Depth (mm)		% Reduction Conventional to LID-BMP	
	1980-2010	1960-1993	1980-2010	1960-1993	1980-2010	1960-1993	1980-2010	1960-1993
1960		20		157		42		73%
1961		8		74		8		89%
1962		10		112		1		99%
1963		8		78		10		87%
1964		12		114		3		97%
1965		20		155		40		74%
1966		12		107		14		87%
1967		11		92		20		78%
1968		9		81		4		95%
1969		13		99		22		78%
1970		12		105		13		88%
1971		11		95		7		93%
1972		13		124		5		96%
1973		23		169		41		76%
1974		19		152		47		69%
1975		1		12		0		100%
1976		14		118		27		77%
1977		17		141		16		89%
1978		25		201		48		76%
1979		19		146		43		71%

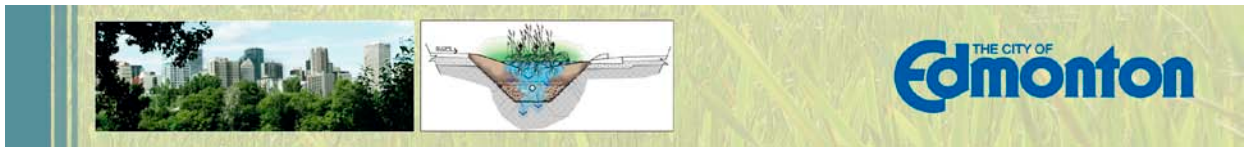


TABLE 4.14 (cont'd)
Total Computed Seasonal (April through October) Rainfall Depth (mm)

Simulation Period / Season	Pre-Development Rainfall Depth (mm)		Conventional Development Rainfall Depth (mm)		Low Impact Development Rainfall Depth (mm)		% Reduction Conventional to LID-BMP	
	1980-2010	1960-1993	1980-2010	1960-1993	1980-2010	1960-1993	1980-2010	1960-1993
1980	6	16	53	139	4	9	92%	94%
1981	13	16	99	128	27	27	73%	79%
1982	55	15	237	118	193	29	19%	75%
1983	19	17	161	136	50	49	69%	64%
1984	12	14	100	111	8	14	92%	87%
1985	9	13	92	115	9	9	90%	92%
1986	16	17	127	136	27	18	79%	87%
1987	11	19	102	157	25	49	75%	69%
1988	22	24	174	185	54	53	69%	71%
1989	3	7	48	72	0	5	100%	93%
1990	7	19	73	141	5	50	93%	65%
1991	18	19	150	150	60	54	60%	64%
1992	5	5	57	59	1	1	98%	98%
1993	13	15	112	125	15	16	87%	87%
1994	17		139		29		79%	
1995	7		68		10		85%	
1996	14		117		14		88%	
1997	14		120		17		86%	
1998	18		154		44		71%	
1999	10		93		5		95%	
2000	9		80		4		95%	
2001	4		35		2		94%	
2002	2		21		0		100%	
2003	21		136		48		65%	
2004	19		156		48		69%	
2005	6		68		0		100%	
2006	12		119		5		96%	
2007	8		78		8		90%	
2008	8		82		7		91%	
2009	3		38		1		97%	

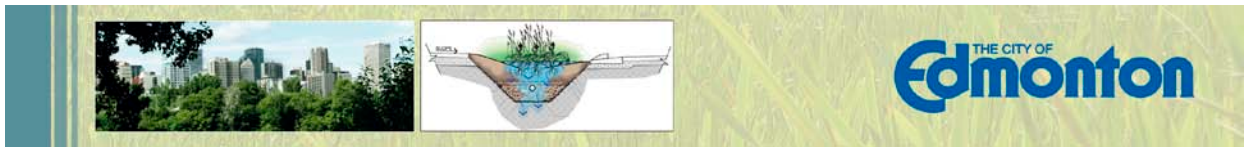


TABLE 4.15
Computed Seasonal (April through October) Peak Runoff (m³/s)

Simulation Period / Season	Pre-Development Rainfall Depth (mm)		Conventional Development Rainfall Depth (mm)		Low Impact Development Rainfall Depth (mm)		% Reduction Conventional to LID-BMP	
	1980-2010	1960-1993	1980-2010	1960-1993	1980-2010	1960-1993	1980-2010	1960-1993
1960		0.175		0.207		0.188		9%
1961		0.044		0.147		0.1		32%
1962		0.025		0.105		0.012		89%
1963		0.089		0.165		0.123		25%
1964		0.031		0.109		0.032		71%
1965		0.082		0.209		0.183		12%
1966		0.042		0.138		0.097		30%
1967		0.115		0.195		0.169		13%
1968		0.034		0.124		0.055		56%
1969		0.038		0.153		0.113		26%
1970		0.034		0.144		0.094		35%
1971		0.031		0.111		0.06		46%
1972		0.027		0.117		0.052		56%
1973		0.054		0.167		0.149		11%
1974		0.197		0.249		0.234		6%
1975		0.007		0.039		0		100%
1976		0.187		0.241		0.226		6%
1977		0.062		0.154		0.127		18%
1978		0.151		0.259		0.249		4%
1979		0.163		0.217		0.198		9%
1980	0.026	0.031	0.112	0.124	0.053	0.058	53%	53%
1981	0.242	0.207	0.244	0.231	0.231	0.213	5%	8%
1982	1.075	0.065	0.448	0.187	0.452	0.169	-1%	10%
1983	0.068	0.07	0.199	0.198	0.175	0.174	12%	12%
1984	0.027	0.033	0.117	0.118	0.04	0.092	66%	22%
1985	0.035	0.036	0.132	0.129	0.081	0.075	39%	42%
1986	0.077	0.065	0.175	0.161	0.14	0.075	20%	53%
1987	0.197	0.288	0.216	0.242	0.199	0.119	8%	51%
1988	0.073	0.082	0.218	0.228	0.199	0.229	9%	0%

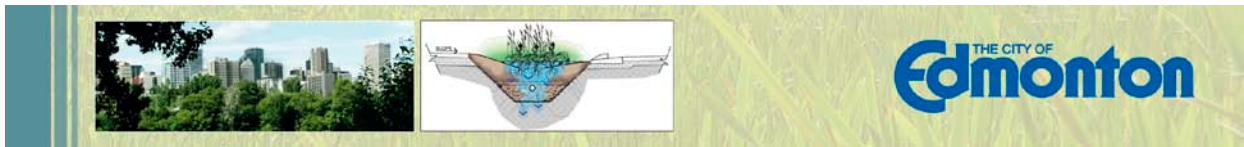


TABLE 4.15 (cont'd)
Computed Seasonal (April through October) Peak Runoff (m³/s)

Simulation Period / Season	Pre-Development Rainfall Depth (mm)		Conventional Development Rainfall Depth (mm)		Low Impact Development Rainfall Depth (mm)		% Reduction Conventional to LID-BMP	
	1980-2010	1960-1993	1980-2010	1960-1993	1980-2010	1960-1993	1980-2010	1960-1993
1989	0.012	0.044	0.081	0.139	0.006	0.214	93%	-54%
1990	0.027	0.15	0.113	0.271	0.065	0.078	42%	71%
1991	0.206	0.16	0.22	0.211	0.205	0.267	7%	-27%
1992	0.025	0.029	0.106	0.11	0.028	0.192	74%	-75%
1993	0.051	0.056	0.132	0.137	0.085	0.032	36%	77%
1994	0.104		0.175		0.144		18%	
1995	0.037		0.13		0.085		35%	
1996	0.041		0.149		0.11		26%	
1997	0.062		0.168		0.126		25%	
1998	0.09		0.179		0.172		4%	
1999	0.025		0.107		0.047		56%	
2000	0.033		0.122		0.039		68%	
2001	0.025		0.112		0.038		66%	
2002	0.013		0.073		0		100%	
2003	0.59		0.301		0.303		-1%	
2004	0.134		0.2		0.177		12%	
2005	0.016		0.085		0.005		94%	
2006	0.031		0.103		0.025		76%	
2007	0.036		0.138		0.091		34%	
2008	0.045		0.145		0.102		30%	
2009	0.021		0.102		0.015		85%	
2010	0.033		0.13		0.068		48%	

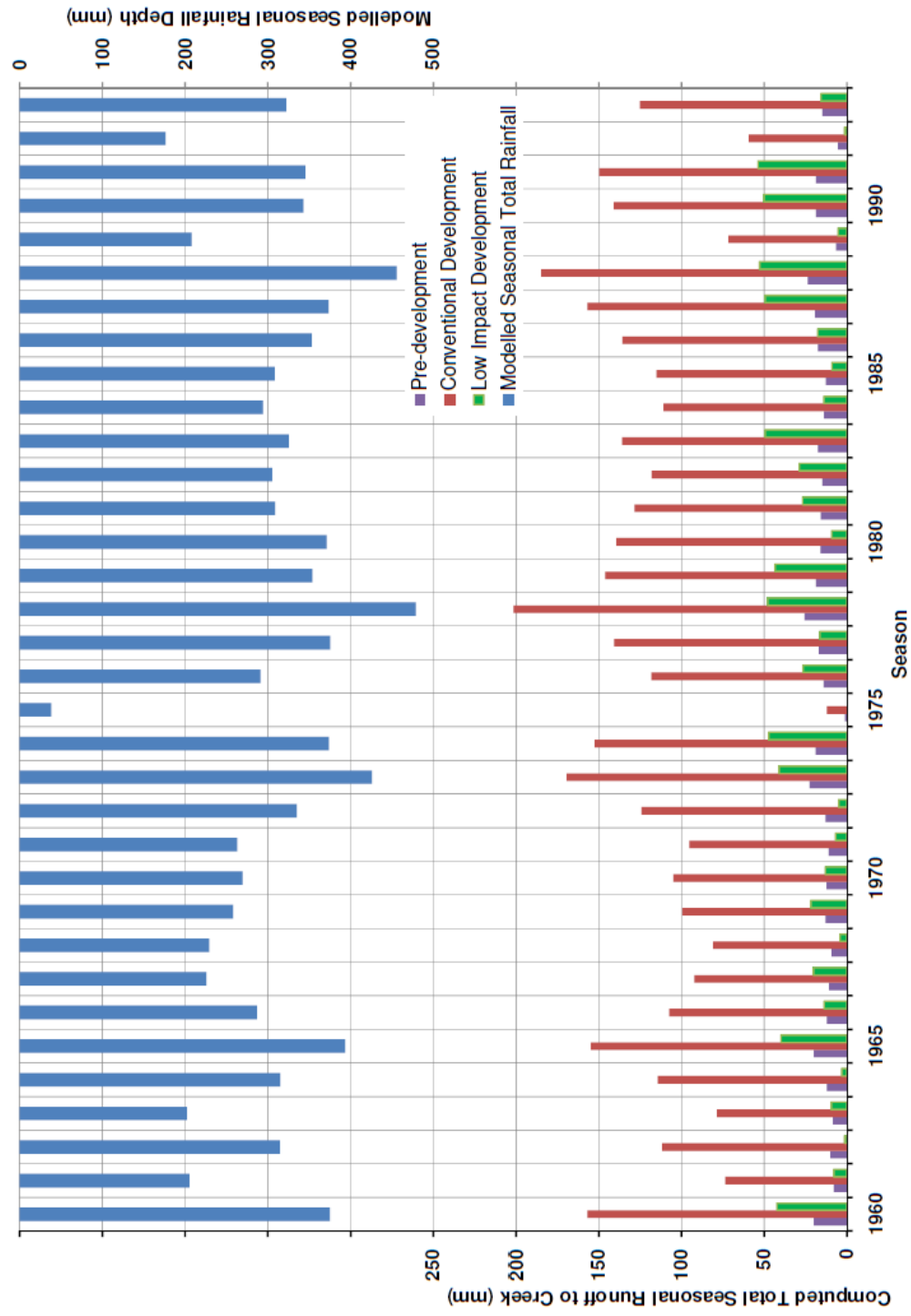
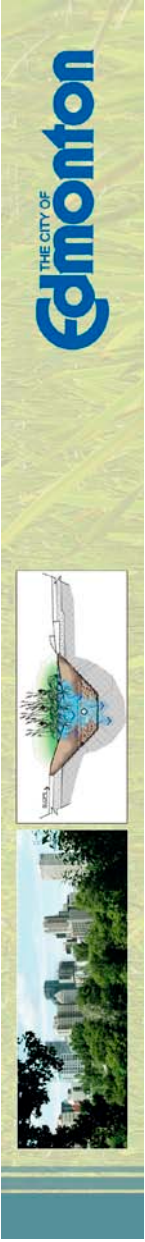


Figure 4.7 1960-1993 Seasonal Total Rainfall and Computed Runoff (Expressed as Total Depth over Development Area)

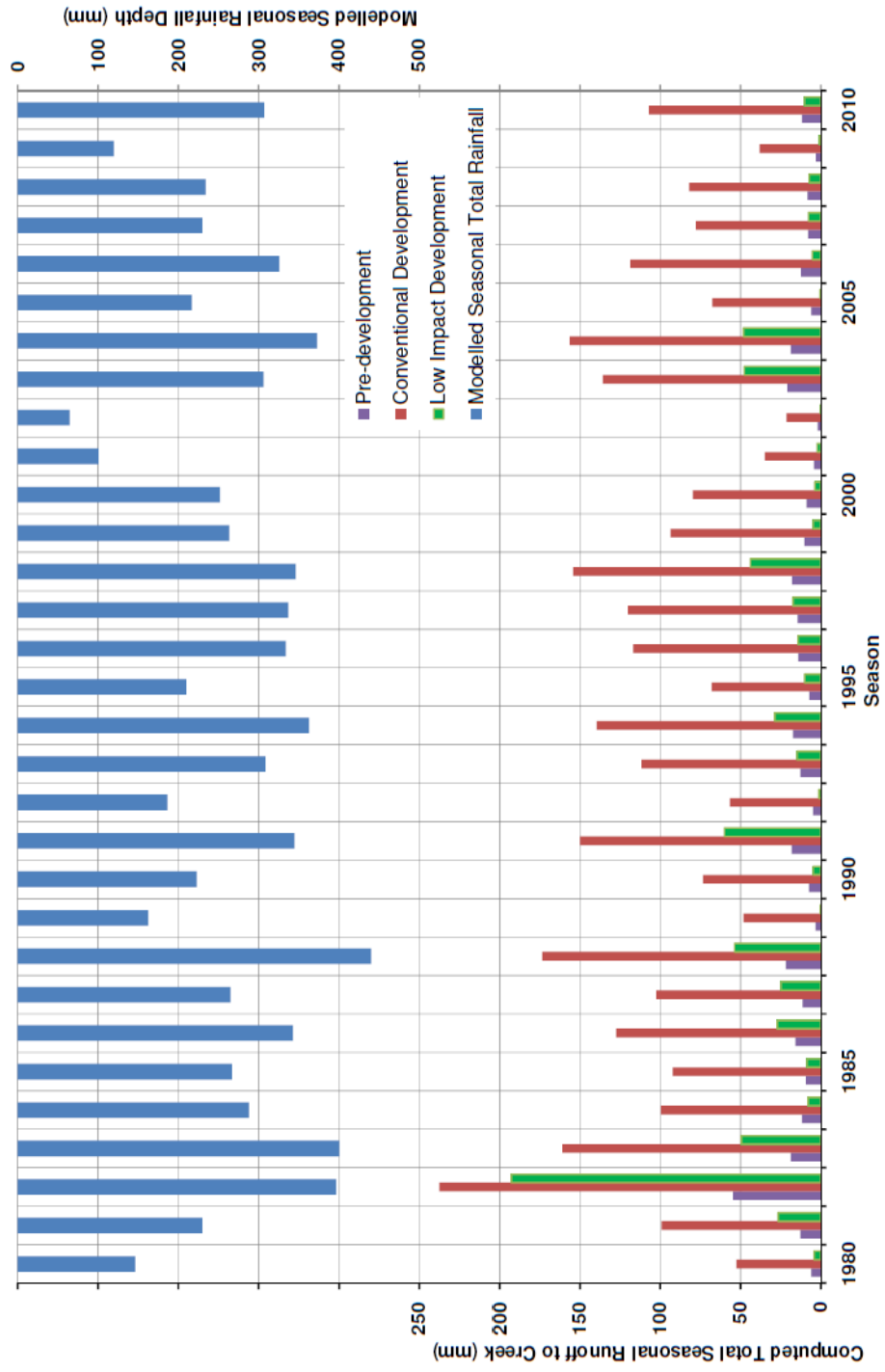
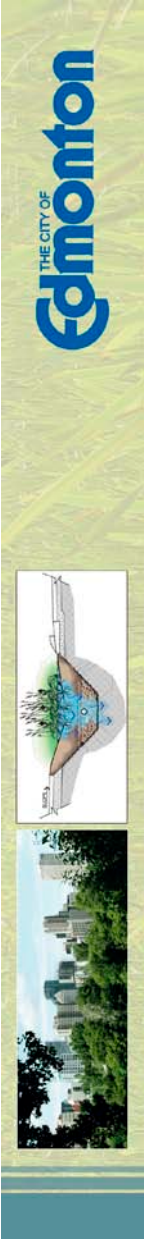
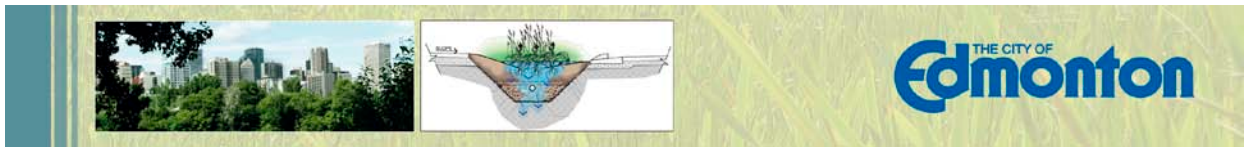


Figure 4. 1980-2010 Seasonal Total Rainfall and Computed Runoff (Expressed as Total Depth over Development Area)



4.3.3 Flow Durations (Potential Erosion Impacts)

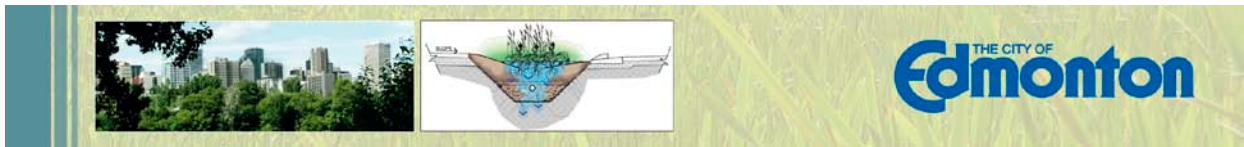
Annual flow durations were analyzed to provide an assessment on potential erosion impacts on the receiving stream. The analysis does not provide measures of actual erosion rates but does provide a means for comparing incremental impacts on erosion for the Conventional and LID-BMP stormwater management scenarios.

As a stream develops over an extended period of time it tends toward a stable regime where the channel is able to transport its natural sediment load without incurring any appreciable aggradation or degradation. While this channel may undergo lateral migration or undergo rapid local channel shifts (e.g., meander loop cut-offs), its reach-averaged hydraulic parameters tend to remain nearly constant.

Erosion of stream beds and banks are affected by the magnitude, frequency, and duration of stream flow discharges. Urbanization results in increased duration and frequency of higher energy flows that cause erosion of stream bed and bank materials. Stream erosion occurs naturally, but the rate at which erosion occurs can be accelerated as a result of urbanization. A natural stream is generally in a state of equilibrium between erosion and deposition within an engineering time scale, although it may be weighted slightly more towards erosion over a geological time scale.

The cumulative sediment transported by more frequent smaller magnitude events is greater over an intermediate to long term period of time than the infrequent large magnitude floods. Hence, the smaller more frequent events tend to form geometric dimensions of the channel. As a result, many jurisdictions consider the 1:2-year to 1:5-year runoff events to be the events responsible for forming and shaping the channel regime.

Erosion in stream channels actually occurs for a range of flows that exert forces on bed materials which exceed the critical forces necessary to initiate motion of those materials. Flows that occur at about mid-bankfull to bankfull level are responsible for forming and shaping stream channels. However, due to increases in runoff volumes caused by urbanization, the bankfull event often shifts to events smaller than the pre-development 1:2-year event. Smaller rainfall events that did not generate runoff under pre-development



conditions are now generating runoff, draining rapidly to ponds and discharging into receiving streams. Frequency of occurrence of mid-bankfull to bankfull events typically increases following urbanization.

The continuous model simulations provided a means for estimating potential impacts on stream erosion for the LID-BMP and Conventional development scenarios. The following steps were applied for the assessment:

1. estimate the channel forming discharge under pre-development conditions;
2. compute total duration of runoff at or exceeding the channel forming discharge for the pre-development, LID-BMP, and Conventional development conditions; and
3. compare total duration of flows exceeding the pre-development channel forming discharge.

A simple frequency analysis on the annual peak runoff rates for the pre-development condition provided an estimate for the 2-year discharge of $Q_{2-YR} = 0.05 \text{ m}^3/\text{s}$. This discharge was then adopted as the channel forming discharge for the total duration analysis.

The total duration (in hours) of runoff for pre- and post-development conditions was then calculated from long term continuous simulations. **Table 4.16** provides a summary of the results. The total duration of events exceeding the adopted channel forming discharge increases significantly for both the Conventional and LID-BMP scenarios. However, the analysis suggests that a 70-75% reduction in the total duration of channel forming discharges can be achieved through implementation of LID-BMP as compared to Conventional development.

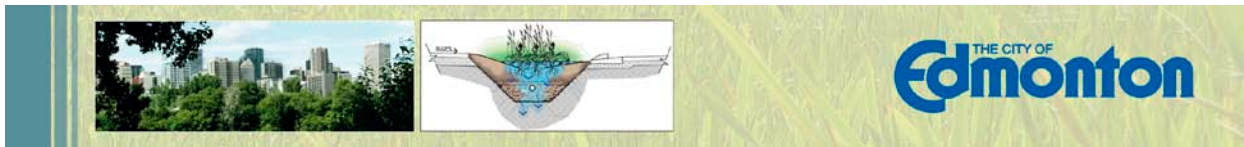


TABLE 4.16
Comparison of Computed Total Flow Durations (hrs) for
Channel Forming Discharge ($Q_{2-YR} = 0.05 \text{ m}^3/\text{s}$)

Simulation Period	Total Duration of Flows at or Above Q_{2-YR} (hrs)		
	Pre-Development	Conventional Development	Low Impact Development
1960-1993	172	4,533	1,193
1980-2010	128	3,445	1,013

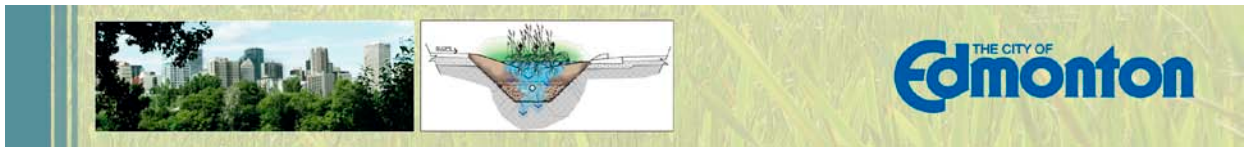
4.3.4 Treatment Efficiency of LID-BMP Scenario

The modelling results clearly suggest a significant improvement in water quality with the LID-BMP development compared with the Conventional development. This is demonstrated by the total reduction in runoff quantities reaching the downstream water course (recall **Tables 4.14** and **4.15**). The total reduction in runoff quantity provides a tangible representation of the improvement in water quality. However, an improved assessment on benefits offered by LID-BMPs can be achieved by quantifying the fate of total precipitation as it passes through various hydrologic processes. A rigorous accounting of the fate of all water for the long term continuous simulations was conducted to provide a more detailed assessment of the benefits received through implementation of LID-BMPs. Two pollutants were considered: total suspended solids (TSS); and total phosphorus (TP).

The analysis examined the relative treatment efficiency of the Conventional and LID-BMP scenarios under the following assumptions:

- an equal amount of pollutant loading is generated for both Conventional and LID-BMP scenarios since they have equivalent percentages of impervious area;
- conventional stormwater ponds and LID-BMP bioretention ponds provide a comparable level of treatment (this conservatively underestimates the treatment benefit of LID bioretention ponds); and
- total area serviced by LID-BMPs represents the incremental improvement (benefit) in treatment efficiency over the Conventional development scenario.

Table 4.17 presents a detailed accounting of the treatment



efficiency for TSS and TP, for stormwater passing through all simulated LID-BMP controls. It is reasonable to assume that the portion of runoff abstracted by evaporation and infiltration receives full treatment. Runoff that passes through the underdrain or overflows the LID-BMP during larger events receives partial treatment. The pollutant removal efficiency was estimated by applying removal rates for each treatment process. Removal efficiencies presented in the table are consistent with values reported in the Design Guide. Cumulative removal efficiency represents incremental improvement (or benefit) offered by the LID-BMP stormwater servicing concept.

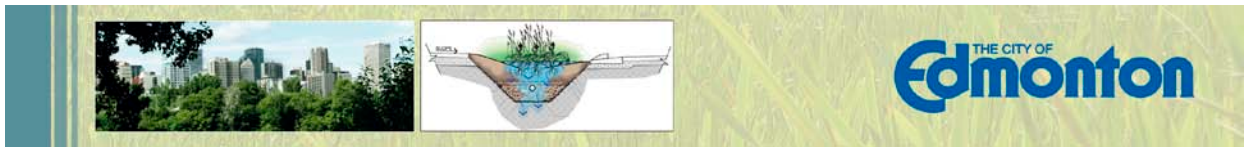
Through long term continuous simulations and a rigorous accounting of the fate of runoff through each LID-BMP control, the cumulative treatment efficiencies for TSS and TP were estimated to be 88% and 57%, respectively. These values represent an average of the two long term simulation periods (1960-1993 and 1980-2010).

TABLE 4.17
Treatment Efficiency on Flows Passing Through LID-BMP Controls

Treatment Process	Total Volume	Treatment Efficiency		Treated Volume	
		TSS	TP	TSS	TP
For Simulation Period 1960-1993					
Evaporation	192,205	100%	100%	192,205	192,205
Infiltration	1,130,296	100%	100%	1,130,296	1,130,296
Underdrain Flow*	220,446	60%	0%	132,267	-
Overflow/By-pass**	1,034,083	80%	20%	827,266	206,817
Total Cumulative	2,577,030	89%	59%	2,282,035	1,529,318
For Simulation Period 1980-2010					
Evaporation	161,947	100%	100%	161,947	161,947
Infiltration	790,718	100%	100%	790,718	790,718
Underdrain Flow*	168,508	60%	0%	101,105	-
Overflow/By-pass**	1,005,767	80%	20%	804,614	201,153
Total Cumulative	2,126,940	87%	54%	1,858,383	1,153,818

* flows passing through soils to drain and then to collection system

** flows overtopping LID-BMP controls when maximum ponding level is exceeded



5.0 LIFE CYCLE COST ANALYSIS

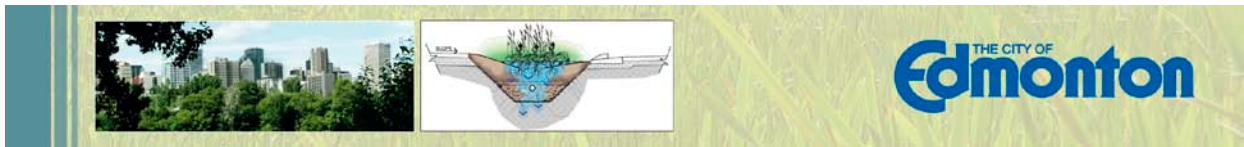
Life cycle cost (LCC) is the present worth of the total cost of a project or device over its life span. These include costs of design, construction, operation and maintenance (O & M) and closeout activities. Costs of constructing structural stormwater Best Management Practices (BMPs) depend on several factors including: time of year of construction; site conditions and topography; accessibility of equipment; economics of scale; and government regulations. Land cost is another major cost variable in the construction cost of structural BMPs, which will not be included in the analyses in this report. There are four basic methods of cost estimation:

- bottom-up method;
- analogy method;
- expert opinion method, and
- parametric method.

Two of the above cost estimation methods have been used in the costs analyses in this report: the bottom-up method and the parametric method. The bottom-up method relies on quantity take offs and compiled sources of unit cost data. It is used for estimating costs on an item by item basis and has been used where unit cost data are available. The parametric method relies on statistically-based or model-based relationships between cost and design parameters. This method has been used where direct cost data are not readily available.

A perpetual lifespan is assumed for public utility installations for the analyses in this report with routine annual maintenance and periodic major rehabilitation / replacement. To compare stormwater management for the Conventional development and the LID-BMP development, the capitalized cost method is used. The capitalized cost is the present worth of a project with infinite life.

Intangible and non-economic benefits have not been accounted for in this study as it is a life-cycle cost analysis rather than a cost-benefit analysis. The social and environmental benefits of stormwater LID-BMPs are extensive and have been documented



for each type of LID-BMP facility used in this study in the Design Guide.

5.1 Total Costs

5.1.1 Capital Costs

Capital costs include both construction and land costs. Construction costs of stormwater LID-BMPs include labour, material and equipment, excavation and grading, outlet control structures, erosion and sediment control, landscaping and appurtenances. The cost of professional/technical services necessary to support the design and construction of an LID-BMP facility are also included in the costs of construction. Actual construction costs and land costs are variable and depend largely on site conditions or the municipality.

Capital costs can typically be estimated using equations based on the size or volume of water to be treated. The general form of these equations is:

$$C = aP^b$$

Where, C is the estimated construction cost (\$), P is the determinant variable (area or volume) and a and b are statistical coefficients determined from regression analysis. The exponent b represents an economics of scale factor. If $b < 1$, the unit cost decreases as the size of the variable increases. **Table 5.1** lists cost estimating equations examined in this study for a range of values for various LID-BMPs.

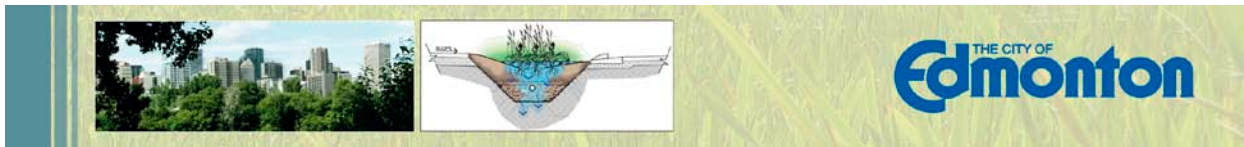


TABLE 5.1
Base Capital Costs (Without Land Costs) for Commonly Used LID-BMPs

LID-BMP Type	Base Capital Costs ¹ (\$)
Wet ponds/retention basins	$C=86.09V$; V in m^3
Vegetative swales	$C=(11 \text{ to } 35)A$; A in m^2
Naturalized drainage ways	$C=(25 \text{ to } 250)A$; A in m^2
Permeable pavement	$C=(340 \text{ to } 500)A$; A in m^2
Bioretention	$C=(30 \text{ to } 250)A$; A in m^2
Box planters	$C=(30 \text{ to } 350)A$; A in m^2
Green roofs (extensive)	$C=(230 \text{ to } 550)A$; A in m^2
Rainwater harvesting system	$C=(212 \text{ to } 1000)V$; V in m^3

Notes: V =BMP volume; A =BMP surface area

¹Median values used in cost table calculations where cost data are given as a range

5.1.2 Design, Permitting and Contingency Costs

Design and permitting costs include site investigation, surveying, planning and site and engineering design needed for regulatory approval prior to LID-BMP installation. Contingency costs are those unforeseen costs that occur during the development and construction of an LID-BMP facility. The costs in this category of the total cost are usually expressed as 25% of the base capital or construction costs (Wiegand *et. al.*, 1986; CWP, 1998; and US EPA, 1999).

5.1.3 Operation and Maintenance (O&M) Costs

O&M costs are post-construction costs needed to ensure continued performance of LID-BMPs at design capacity. These costs are usually estimated on an annual basis and include labour, material, energy and equipment costs required for smooth operation and functionality of an installation. Landscape, structural and infiltration maintenance as well as sediment, basin debris and litter removal are also included in the annual operating costs of maintaining a facility. Like design, permitting and contingency costs, O&M costs are often expressed as a percentage of the base capital costs. Annual O&M costs are dependent on the type of facility. A range of representative costs are presented in **Table 5.2**.

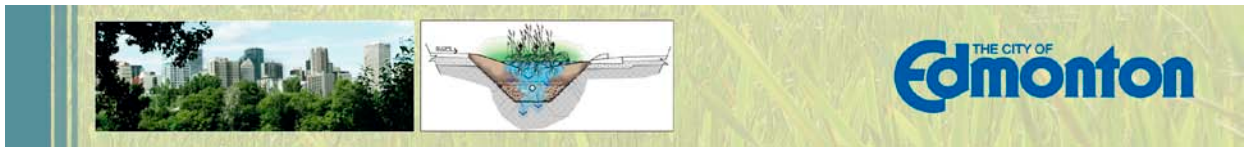


TABLE 5.2
Representative Annual O&M Costs of Different Types of Stormwater LID-BMPs

Item	Annual O&M Costs ¹
Wet ponds/retention basins	3 – 6 % of construction cost
Vegetative swales	\$(0.20-1.00)/m ²
Naturalized drainage ways	\$(<1.00-18.00)/m ²
Permeable pavement	\$(0.15-0.30)/m ²
Bioretention	\$(13.00-30.00)/m ²
Box planters	\$(13.00-30.00)/m ²
Green roofs (extensive)	\$(3.00-44.00)/m ²
Rainwater harvesting system	\$25.00/each

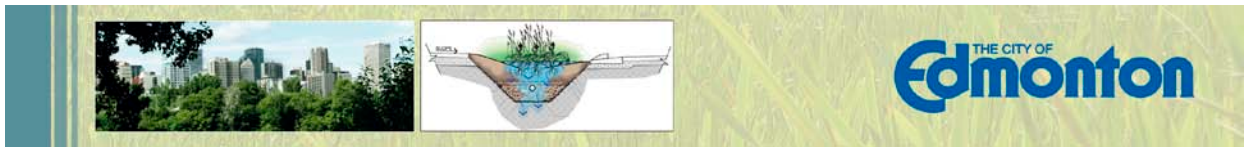
Notes: ¹Median values used in cost table calculations where cost data are given as a range

5.1.4 Land Costs

Land costs are a major component of the total cost of installation of a stormwater management facility. Land costs are site specific and highly variable depending on the region and adjacent land uses. Where applicable and permitted by local land use regulations, LID-BMPs can be installed in public spaces within a development, such as boulevards, curb bump-outs and parks, thereby reducing or eliminating the cost to be incurred in purchasing or dedicating land specifically for LID-BMP installation. Stormwater BMPs, especially LID-BMP techniques, may also be incorporated into reserve areas required in each development, thereby reducing extra land requirements for LID-BMPs. This analysis assumes that LID-BMP facilities are implemented in public and reserve land and do not have an identifiable associated land cost. In other situations, costs of land dedicated specifically for LID-BMP facilities, or where normal uses are precluded by the installation of LID-BMP facilities, must be incorporated into the cost analysis.

5.2 Inflation and Regional Cost Adjustments

The costs used in this report are obtained from literature and adjusted for inflation, regional differences and currency exchange. Construction cost indices are used to convert the data obtained from literature into current year dollars. The inflation adjusted cost



is further adjusted to account for regional cost variations. Regional cost differences account for variations in costs of living, labour and material costs in different jurisdictions. The final adjusted cost for inflation and regional differences is calculated with the following equation:

$$\text{Final cost (adjusted)} = \frac{\text{Capital cost (base year)} \times \text{Cost index (current year)}}{\text{Cost index (base year)}} \times R_f$$

Where R_f is the factor to adjust for regional differences.

5.3 Comparison of Alternatives

A comparison of the alternatives for stormwater management (Conventional and LID-BMP) is done using the capitalized cost method. The capitalized cost is the amount of money at $t = 0$ needed to perpetually support a project on the earned interest only. It is given by the following relationship:

$$\begin{aligned} \text{Capitalized cost} &= \text{initial cost} + \frac{\text{annual cost}}{i} \\ &= \text{initial cost} + \text{present worth of all expenses} \end{aligned}$$

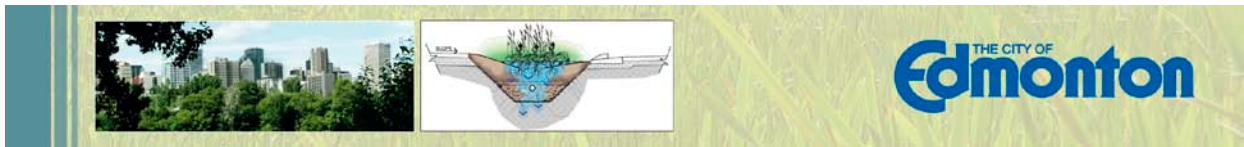
Where i is the discount or interest rate.

A summary of costs for the development being evaluated in this study is presented in **Table 5.3**. Detailed cost analyses and breakdown are included in **Appendix A**.

TABLE 5.3
Costs Summary

Item	Conventional	LID-BMP
Initial cost	\$12,043,538.38	\$16,594,015.78
Present Worth of:		
Annual O & M	\$ 4,840,800.89	\$ 9,812,859.60
Periodic maintenance	\$22,604.71	\$ 406,758.70
Capitalized Cost	\$16,906,943.97	\$26,813,634.07

The calculations in Table 5.3 are based on the following assumptions:



Cost Variables

Service lives	20, 25 and 75 years
Effective period	1 year
Effective annual interest rate	5%
Inflation rate	2.3%
Effective annual interest rate corrected for inflation	7.415

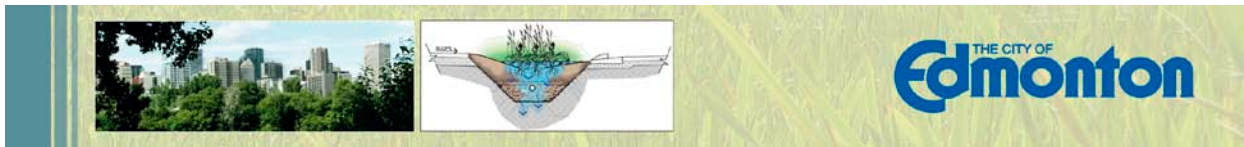
5.4 Discussion of Life Cycle Costs

Based on the LCC analysis, the LID-BMP option is the more costly alternative. LCC analysis provides an initial point of comparison between Conventional and LID-BMP alternatives; however, it does not provide a full accounting of potential benefits that are less tangible or difficult to quantify. For example it is difficult to quantify the benefits LID-BMPs offer in terms of total volume reduction and mitigation of erosion impacts on the receiving stream. Some potential benefits that consider water quality and stream health include:

- impact on potable water treatment costs;
- preservation of aquatic life or habitat;
- impact on costs of stream restoration; and
- preservation or enhancement of recreational uses of water.

The costs associated with water quality improvements and erosion control measures to downstream watercourses could be substantial.

In other words, when water quality control or improvement is the goal of stormwater management, LID-BMP technologies may prove to be a more feasible option when a more comprehensive cost benefit analysis is conducted. When the costs of managing the impacts of Conventional stormwater management practices are added to the costs of the Conventional development, it may well exceed the costs of an LID-BMP alternative.



6.0 CONCLUSIONS

The following sections summarize the key findings of this comparative modelling study.

6.1 Conceptual Models

The modelling exercise demonstrates that modelling a collection of LID-BMP facilities is feasible. Long term continuous simulation models were developed to provide a means of comparison between an LID-BMP stormwater management concept versus a Conventional stormwater management concept. These simulations provide a measure of the total seasonal volume reductions that can be achieved with an LID-BMP based stormwater system.

6.2 Seasonal Volume Reduction

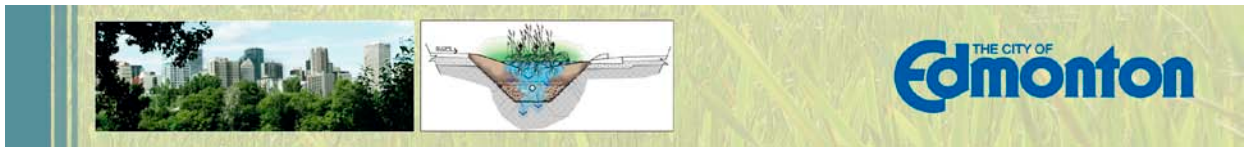
The modelling exercise clearly demonstrates that a significant reduction in total seasonal runoff volumes is achieved through implementation of LID-BMP systems. It is stormwater runoff that carries pollutant loads to the receiving stream. Therefore, a reduction in total runoff volume is a clear indicator of the relative reduction in total pollutant loading (particularly sediment loadings).

6.3 Detention Storage

For the concepts modelled in this exercise, it was found that a marginal decrease (~20%) in detention storage requirements can be achieved through implementation of LID-BMPs. While there may be a significant reduction in total seasonal runoff volumes, detention storage facilities are designed to accommodate very large storms. LID-BMP facilities (e.g., bioretention) can be incorporated into storage systems; however, they must still be sized to meet City performance standards for very large storms.

6.4 Flow Durations

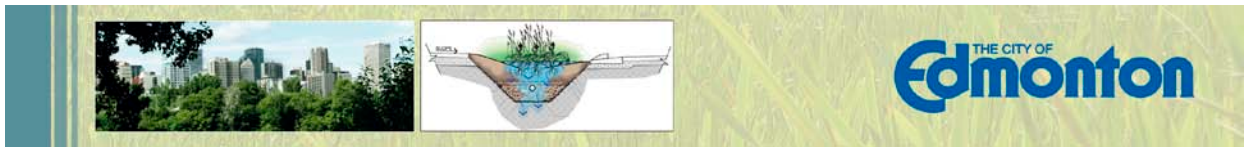
An assessment of flow durations demonstrates another very tangible benefit with implementation of LID-BMP systems: total duration of runoff events that could contribute to erosion can be significantly reduced.



The modelling exercise demonstrates an approach for assessing potential erosion impacts on the receiving stream. This assessment can only be achieved through examination of the population of runoff events from long term simulations.

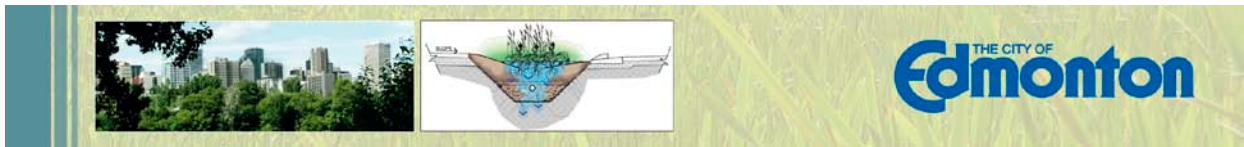
6.5 Treatment Efficiency

A rigorous accounting of flows passing through the simulated LID-BMP facilities for long term simulations provided a means for assessing the incremental treatment benefits of implementing LID-BMPs. The analysis suggests that stormwater serviced by LID-BMPs achieved removal efficiencies of 88% and 57% for removal of TSS and TP, respectively. The analysis considered the treatment of runoff through all source control LID-BMPs upstream of centralized bioretention ponds. Through distributed LID-BMPs, the net pollutant loading on centralized facilities is significantly reduced.



7.0 REFERENCES

- Center for Watershed Protection (CWP).** 1998. *Cost and Benefit of Stormwater BMPs*. Final Report 9/14/98. EPA Contract 68-C6-0001 WA2-15, Task 6 Parson Engineering Science.
- City of Edmonton (COE).** 2009. *Design and Construction Standards, Volume 3, Drainage*. January 2009. City of Edmonton, Alberta. <http://www.edmonton.ca/city_government/planning_development/city-design-construction-stand.aspx>. Accessed March 2010.
- Lindeburg, Michael R.** 2006. *Civil Engineering Reference Manual for the PE Exam*.
- Pitt, R.** 2005. *Module 3b: Small Storm Hydrology and Why it is Important for the Design of Stormwater Control Practices*. Department of Civil and Environmental Engineering. University of Alabama, Tuscaloosa, AL.
- United States Environmental Protection Agency (USEPA).** 2004. *Stormwater Best Management Practice Design Guide, Order No. 1C-R059-NTSX*. Office of Research and Development National Risk Management Research Laboratory – United States Environmental Protection Agency. Cincinnati, OH.
- United States Environmental Protection Agency (USEPA).** 2004. *The Use of Best Management Practices*.
- United States Environmental Protection Agency (USEPA).** 1999. *Preliminary Data Summary of Urban Stormwater Best Management Practices*. EPA-821-R-99-012. August. Office of Water, Washington, DC.
- Wiegand, C., T. Schueler, W. Chittenden, and D. Jellick.** 1986. *Cost of Urban Runoff Quality Controls*. Pp. 366-380. In: urban runoff quality. Engineering Foundation Conference. ASCE, Henniker, NH. June 23 – 27.



APPENDIX A

Detailed Life Cycle Cost Analyses Breakdown

CONVENTIONAL DEVELOPMENT INFRASTRUCTURE COST ANALYSES BREAKDOWN

Capital Costs

TABLE A1
Material and Construction Costs

Item	Description	Unit	Unit Price	Quantity	Amount
1	Catchbasins 900 mm	each	\$ 1,650.00	242	\$ 399,300.00
2	Manholes				
	Manholes 1200 mm	each	\$ 1,600.00	74	\$ 118,400.00
	Manholes 1500 mm	each	\$ 2,300.00	56	\$ 128,800.00
3	Concrete CB Leads 300 mm	m	\$ 85.00	2350	\$ 199,750.00
4	Storm pipes				
	375 mm 2-3 m deep	m	\$ 250.00	896	\$ 224,000.00
	450 mm 3-4 m deep	m	\$ 315.00	1790	\$ 563,850.00
	600 mm 4-5 m deep	m	\$ 430.00	1690	\$ 726,700.00
	750 mm 3-4 m deep	m	\$ 505.00	831	\$ 419,655.00
	900 mm 4-5 m deep	m	\$ 685.00	1557	\$ 1,066,545.00
5	SWM Ponds				
	POND_1	m³	\$ 86.09	23880	\$ 2,055,829.20
	POND_2	m³	\$ 86.09	21120	\$ 1,818,220.80
	POND_3	m³	\$ 86.09	22230	\$ 1,913,780.70
Total					\$ 9,634,830.70

Design, permitting and contingency costs (Estimated as 25% of the construction cost) \$ 2,408,707.68

Total Capital Cost \$12,043,538.38

TABLE A2
Detailed Annual O&M Costs

Item	Description	Maintenance Interval (times/year)	Unit	Estimated Cost/Unit	Quantity	Annual Cost	Adjusted Cost
1	Mechanical cleaning of catchbasins	1	each	\$ 30.00	242	\$ 7,260.00	\$ 7,260.00
2	Manholes						
	Manholes 1200 mm	0.5	each	\$ 30.00	74	\$ 1,110.00	\$ 1,110.00
	Manholes 1500 mm	0.5	each	\$ 30.00	56	\$ 840.00	\$ 840.00
3	Concrete CB Leads 300 mm	1	m	\$ 9.12	2350	\$ 21,432.00	\$ 23,021.18
4	Stormwater sewer mains cleaning & inspection						
	375 mm	1	m	\$ 9.12	896	\$ 8,171.52	\$ 8,777.44
	450 mm	1	m	\$ 9.12	1790	\$ 16,324.80	\$ 17,535.28
	600 mm	1	m	\$ 9.12	1690	\$ 15,412.80	\$ 16,555.66
	750 mm	1	m	\$ 9.12	831	\$ 7,578.72	\$ 8,140.68
	900 mm	1	m	\$ 9.12	1557	\$ 14,199.84	\$ 15,252.76
5	SWM Ponds						
	POND_1	1	visit	\$ 92,512.31	1	\$ 92,512.31	\$ 92,512.31
	POND_2	1	visit	\$ 81,819.94	1	\$ 81,819.94	\$ 81,819.94
	POND_3	1	visit	\$ 86,120.13	1	\$ 86,120.13	\$ 86,120.13

Total Annual O & M Cost

\$352,782.06 \$358,945.39

Notes: Costs of manhole inspection and cleaning assumed equal to that of a catchbasin
Costs of CCTV inspection estimated at \$0.32/m for clean sewers included in sewer mains cleaning and inspection
Tree root and grease control estimated at \$2.80/m included in sewer mains cleaning and inspection

TABLE A3
Summary of Annual O&M Costs

Description	Annual Cost
Storm sewer/catchbasin lead cleaning	\$ 85,031.43
Mechanical cleaning of catchbasins	\$ 7,260.00
Manhole inspection and cleaning	\$ 1,950.00
Ponds (4.5% of construction cost)	\$ 260,452.38
Total O & M Costs	\$ 354,693.81

Capital Costs

TABLE A4
Material and Construction Costs

Item	Description	Unit	Unit Price	Quantity	Amount	Adjusted Amount
1	LID-BMP Facilities					
	Bioretention	m ²	\$ 140.00	1965	\$ 275,043.23	\$ 295,437.69
	Box planter	m ²	\$ 190.00	1255	\$ 238,390.08	\$ 256,066.70
	Cistern	m ²	\$ 606.00	6	\$ 3,636.00	\$ 3,905.61
	Green Roof	m ²	\$ 390.00	11381	\$ 4,438,526.53	\$ 4,767,643.27
	NDW	m ²	\$ 137.50	4532	\$ 623,201.12	\$ 669,411.48
	Permeable Pavement	m ²	\$ 420.00	314	\$ 131,816.17	\$ 141,590.34
	Rain garden	m ²	\$ 190.00	291	\$ 55,195.00	\$ 59,287.71
	Vegetated Swale	m ²	\$ 23.00	42207	\$ 970,767.70	\$ 1,042,750.12
2	Culverts/Pipes					
	900 mm 3-4 m deep	m	\$ 660.00	1850	\$ 1,220,736.00	\$ 1,220,736.00
	1200 mm 4-5 m deep	m	\$1,065.00	84	\$ 89,460.00	\$ 89,460.00
3	SWM Ponds					
	POND_1	m ³	\$ 86.09	13650	\$ 1,175,128.50	\$ 1,175,128.50
	POND_2	m ³	\$ 86.09	11010	\$ 947,850.90	\$ 947,850.90
	POND_3	m ³	\$ 86.09	30270	\$ 2,605,944.30	\$ 2,605,944.30
Subtotal					\$12,775,695.52	\$13,275,212.62

Design, Permitting and Contingency Costs Estimated as 25% of the construction cost

\$ 3,318,803.16

Total Capital Cost

\$16,594,015.78

TABLE A5
Detailed Annual O&M Costs

Item	Description	Maintenance Interval (times/year)	Unit	Unit Price	Quantity	Amount	Adjusted Amount
1	LID-BMP Facilities						
	Bioretention	1	/m ²	\$ 21.50	1965	\$ 42,238.78	\$ 45,370.79
	Box Planter	1	/m ²	\$ 21.50	1255	\$ 26,982.50	\$ 28,983.25
	Cistern	1	/each	\$ 125.00	6	\$ 750.00	\$ 805.61
	Green Roof	1	/m ²	\$ 23.50	11381	\$ 267,449.68	\$ 287,281.07
	NDW	1	/m ²	\$ 9.50	4532	\$ 43,057.53	\$ 46,250.25
	Permeable Pavement	1	/m ²	\$ 0.23	314	\$ 72.19	\$ 77.54
	Rain Garden	1	/m ²	\$ 23.50	291	\$ 6,245.75	\$ 6,708.87
	Vegetated Swale	1	/m ²	\$ 0.60	42207	\$ 25,324.37	\$ 27,202.18
2	Culverts/Pipes						
	900 mm	1	/m	\$ 9.12	1850	\$ 16,868.35	\$ 18,119.14
	1200 mm	1	/m	\$ 9.12	84	\$ 766.08	\$ 822.88
3	SWM Ponds						
	POND_1	1	/visit	\$ 66,100.98	1	\$ 66,100.98	\$ 66,100.98
	POND_2	1	/visit	\$ 53,316.61	1	\$ 53,316.61	\$ 53,316.61
	POND_3	1	/visit	\$ 146,584.37	1	\$ 146,584.37	\$ 146,584.37

Total Annual Cost

\$720,018.43 \$751,884.78

TABLE A6
Summary of Annual O&M Costs

Description	Annual Cost
Culvert/pipes cleaning	\$ 18,942.03
LID-BMP Facilities	\$ 442,679.56
Ponds (4.5% of construction cost)	\$ 266,001.96
Total Annual O & M Costs	\$ 727,623.54

TABLE A7
Periodic Maintenance

Item	Description	Life Cycle (Years)	Unit	Unit Price	Quantity	Amount	Adjusted Amount	Present Worth Amount
1	LID-BMP Facilities							
	Bioretention	20	/m ²	\$ 87.00	1965	\$ 170,919.72	\$ 183,593.42	\$ 57,712.40
	Box Planter	25	/m ²	\$ 12.50	1255	\$ 15,687.50	\$ 16,850.73	\$ 3,384.41
	Cistern	25	/m ³	\$ 606.00	6	\$ 3,636.00	\$ 3,905.61	\$ 784.43
	Green Roof	25	/m ²	\$ 16.00	11381	\$ 182,093.40	\$ 195,595.62	\$ 39,284.69
	NDW	75	/m ²	\$ 137.50	4532	\$ 623,201.12	\$ 669,411.48	\$ 3,146.73
	Permeable Pavement	20	/m ²	\$ 420.00	314	\$ 131,816.17	\$ 141,590.34	\$ 44,508.78
	Rain Garden	20	/m ²	\$ 87.00	291	\$ 25,273.50	\$ 27,147.53	\$ 8,533.80
	Vegetative Swale	20	/m ²	\$ 17.50	42207	\$ 738,627.60	\$ 793,396.83	\$ 249,403.47
2	Culverts/Pipes							
	900 mm 3-4 m deep	75	m	\$ 660.00	1850	\$ 1,220,736.00	\$ 1,220,736.00	\$ 5,738.37
	1200 mm 4-5 m deep	75	m	\$ 1,065.00	84	\$ 89,460.00	\$ 89,460.00	\$ 420.53

Total Cost

\$ 406,758.70