Low Impact Development Guidelines

Stormwater Management Plan Update

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Prepared for:

Town of Stratford

Prepared by:

CBCL LIMITED

Consulting Engineers

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CHAPTER 1 INTRODUCTION

1.1 Background

The Town of Stratford is the fastest growing community in the province of Prince Edward Island. Areas traditionally used for agriculture are being converted into residential and light commercial developments. Such development typically changes the characteristics of stormwater runoff from the developing areas. For this reason, the Town of Stratford and Department of Transportation and Infrastructure Renewal (TIR) retained CBCL Limited to prepare an update of the Town's Stormwater Management Plan and develop Low Impact Development Guidelines.

The impact of greater runoff volumes and higher peak flows can be additional flooding. Natural storage systems may not be able to accommodate the larger volumes of runoff and drainage systems may not be able to handle the larger peak flows generated by urban drainage systems. This typically causes difficulties for property owners in the downstream portions of a watershed.

In 2003 the Town of Stratford and TIR retained CBCL Limited to prepare a stormwater management plan. A draft plan was submitted April 2004. Two concepts were considered in the development of the plan:

- Let the runoff volume and peak flow from a given area increase as development continues and provide stormwater drainage facilities to accommodate the increases in runoff.
- Maintain runoff volume and peak flows from a given area at the capacity of the drainage system as development continues.

The Town has embraced the concept of "sustainability" and the promotion of sustainable communities. At a meeting with the Town on October 29, 2009, the Town indicated that it had considered the alternatives available and expressed a desire to adopt a stormwater management plan consistent with a goal of sustainable development. To be sustainable and limit the risk of increased flooding, the plan would:

1. Address current flooding issues:
2. Provide guidelines for future development within the Town that would result in no additional increases in peak runoff flows in the drainage systems.

A plan consistent with these objectives was prepared and presented to the Town in May 2010. At that meeting the Town requested a subsequent study; to examine the potential impacts on the plan from increases in rainfall intensity resulting from global climate change. Additional assessments were completed to determine potential changes in rainfall intensity and the impacts of the changes on peak runoff flows in Stratford. The plan was modified to address the issues associated with these predicted changes.

This report summarizes the additional assessments and analysis completed in the development of a sustainable stormwater management plan for the Town of Stratford. Additional detail can be obtained from the draft stormwater management report prepared and submitted in 2003 and in a climate change assessment report dated October 27, 2011.

1.2 Stormwater Management Plan

1.2.1 Goals

The overall plan and guidelines prepared in this study must be consistent with Town goals that affect Stormwater Management. These goals are outlined in the Official Plan and include:

3.4.3 Economic – To maintain affordable tax rates and utility rates for all Stratford property owners.

3.4.5 Environmental – To protect the quality of the Town's surface and groundwater resources, and to protect and enhance significant natural areas in the Town.

To be consistent with the Town's goals, it was determined that the goals of this study and report would be as follows:

1. Update the 2003 assessments of the draft stormwater management plan study to reflect existing (2010) stormwater conditions in the Town. Then re-evaluate recommendations for stormwater management including upgrades to accommodate existing runoff;
2. Compile Stormwater Management Guidelines that are applicable for sustainable development in the Town of Stratford. The guidelines will limit runoff from future development to the capacity of upgraded drainage systems. Maintain peak runoff flows at current levels or as close as is reasonably possible to avoid changes in the morphology of existing waterways.

1.2.2 Objectives

Sustainable development within the Town is paramount. The Town's existing storm system has some capacity issues that should be addressed. If the existing drainage system is upgraded to accommodate the peak flows from existing development without causing unplanned flooding, then future development in the Town should be completed in such a manner that it will cause no additional flooding.

Applicable Town planning objectives include:

- Manage stormwater runoff in the most cost effective and environmentally appropriate manner.
- Protect the quantity and quality of the Town's vital groundwater resources.
- Protect and enhance the quality of surface water in the Town and the Town's natural features.
- Provide stormwater information for developments in the Town as they arise.

1.2.3 Applicable Town Policies

The Town's Stormwater Management Plan should be consistent with the Town's policies including:

- PS-4: Stormwater Management
- PE-1: Groundwater
- PE-2: Surface Water

Additional specific policies or modifications to existing policies are required to address specific issues. Some will be suggested in this study and others will be developed in the future as needs arise and requirements change. The Town's stormwater policies need to be flexible enough to allow modification and address changing regulations and the Town's needs. They also need to be practical enough that developers can easily understand what is required of them.

1.3 Scope of the Plan

This Stormwater Management Plan covers all lands within the Town Boundary as shown in Figure 1. Lands outside of the boundary are not controlled by the Town so development guidelines may not be imposable. To account for this, drainage system upgrades include allowance for development of these lands by traditional methods and the increases in peak flows that traditionally results.

1.4 Report Framework

To achieve the stated objectives, the study addressed the existing stormwater conditions, predicted future stormwater conditions recommends management practices, defines reasonable peak flow goals and recommends policies and design criteria for future development. The report discusses the following main tasks organized by chapter:

<u>Chapter 2 includes:</u>

- Updating the description of existing development and the major drainage systems for the Town to reflect conditions in 2010;
- Re-assessment of limitations in the major drainage systems for existing development as well as for the flows that are expected from future development; and
- Identify the opportunities to address these under-capacity sections.

<u>Chapter 3</u>

- Description of future development in the Town and a recommended stormwater management strategy.

<u>Chapter 4</u>

- Review of available Best Management Practices (BMPs) for Low Impact Development (LID)
- Identify which BMPs are most applicable for intended land-uses identified in the Town's Development Plan; and
- Define reasonable goals for increases in peak flow generation for each land-use using these BMPs in Stratford; and

<u>Chapter 5</u>

- Provide recommended policies and design criteria for implementation of the recommended plan.

TOWN OF STRATFORD

LEGEND:

- TOWN BOUNDARY
- MAJOR WATERSHED BOUNDARY
- ① MAJOR WATERSHED NAME
- MINOR WATERSHED BOUNDARY
- 1aA1 MINOR WATERSHED NAME

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TOWN OF STRATFORD
LOW IMPACT DEVELOPMENT
STORMWATER GUIDELINES

DEVELOPMENT 2010

GRAPHIC SCALE: 1:25,000 (m)
DATE: JUNE 29, 2010
PROJECT No. CBCL 092641

FIG. No. 1

CHAPTER 2 MAJOR DRAINAGE SYSTEM DEFICIENCIES

2.1 Previous Study

One of the major components of the 2003 Stormwater Management Study was a hydrologic and hydraulic assessment of watersheds within the Town of Stratford. Watersheds within the Town were delineated and hydrologic conditions that existed at the time were defined to estimate the peak runoff flows that could be generated from each. Included in these assessments were concept level models of the main drainage systems in each watershed.

The primary culverts and storm sewers that control the flows in the major drainage system in each watershed were identified and capacity assessments were completed. Culverts were considered to have capacity for runoff resulting from existing development if the maximum water level upstream of the culvert was at or below the top of the culvert. Culverts that lacked sufficient capacity were identified in a table and on drawings. Required upgrades to these deficient culverts to meet the specified capacity at each site were estimated.

2.2 Update of Assessment

Since the 2003 study, there has been changes made to the Town's storm drainage systems and significant development has occurred. As a result it was agreed to update the data used previously to define *existing conditions* as conditions in 2010 and repeat the assessment.

To accomplish this, the study team met with the Town and the Department of Transportation and Infrastructure Renewal (TIR) to identify and review recent developments in the Town as well as changes made to the drainage systems. Relevant data was collected for the newly developed areas and sections of the new or modified drainage systems. Information was based on record information provided and a limited topographic survey. The information was compiled on an updated plan of existing conditions, presented as Figure 1;

> Hydrologic characteristics of the new development areas, such as the amount impervious and amount of rain used to "wet the surface" were used to modify the hydrologic parameters for each watershed in the model. This was done based on measured areas of various land-uses in each watershed and typical hydrologic characteristics of each land-use to generate weighted hydrologic parameters for each watershed. Hydraulic characteristics of new culverts and major

storm sewer systems were added to the computer model of the drainage systems. Once the model was modified, a reassessment of existing peak flows and available capacity in the current drainage system was completed.

All information collected was compiled in a Master Culvert List that includes all of the major culverts in the Town as of 2010. These are shown on Figure 2.2 in Appendix A with an indication of the existing culvert's capacity compared to the estimated peak runoff flows. Limiting sections of the existing drainage systems generated by design rainfall events based on historical rainfall records are identified in the first columns of the tables in Appendix B. The generated rainfall events based on historic data are also provided in Appendix B.

2.3 Impacts of Climate Change

Before finalizing the 2010 update study, the Town requested additional assessments to determine the impact on the proposed stormwater management strategy of predicted changes in rainfall intensity resulting from global climate change. Traditional stormwater analysis uses historical rainfall data as opposed to future predicted rainfall events. Therefore, this additional work scope was undertaken with review and input from the Town, Environment Canada, and the provincial Departments of Transportation and Infrastructure Renewal (TIR) and Energy, Environment and Forestry. A separate report was submitted in October 2011 summarizing the draft findings and recommendations.

In summary, Global climate change models were downscaled for Charlottetown by Environment Canada and predicted changes in 24 hour precipitation for two models were provided to the study team. The Department of Energy, Environment and Forestry used several models to simulate precipitation records for Charlottetown and then compared the simulated records to historical record. They recommended one model as most suitable for this study (Model – HadCM3). The Town accepted the Department's recommendation and the study proceeded using the selected model.

Since design rainfall events based on **historical records** were generated in the original assessment, the predicted 24 hour precipitation records from the recommended model were used to generate design rainfall events for the Town of Stratford for **the next 100 years**. The design rainfall events based on both historical data and predicted increases in rainfall intensity are provided in Appendix B. These were used to assess peak runoff flows based on the updated hydrologic characteristics of existing (2010) development conditions for each watershed in the model. Limiting sections of the existing drainage systems generated by design rainfall events based on predicted increases in rainfall intensity are also provided in Table 2.2 in Appendix A.

CHAPTER 3 PLANS FOR FUTURE DEVELOPMENT

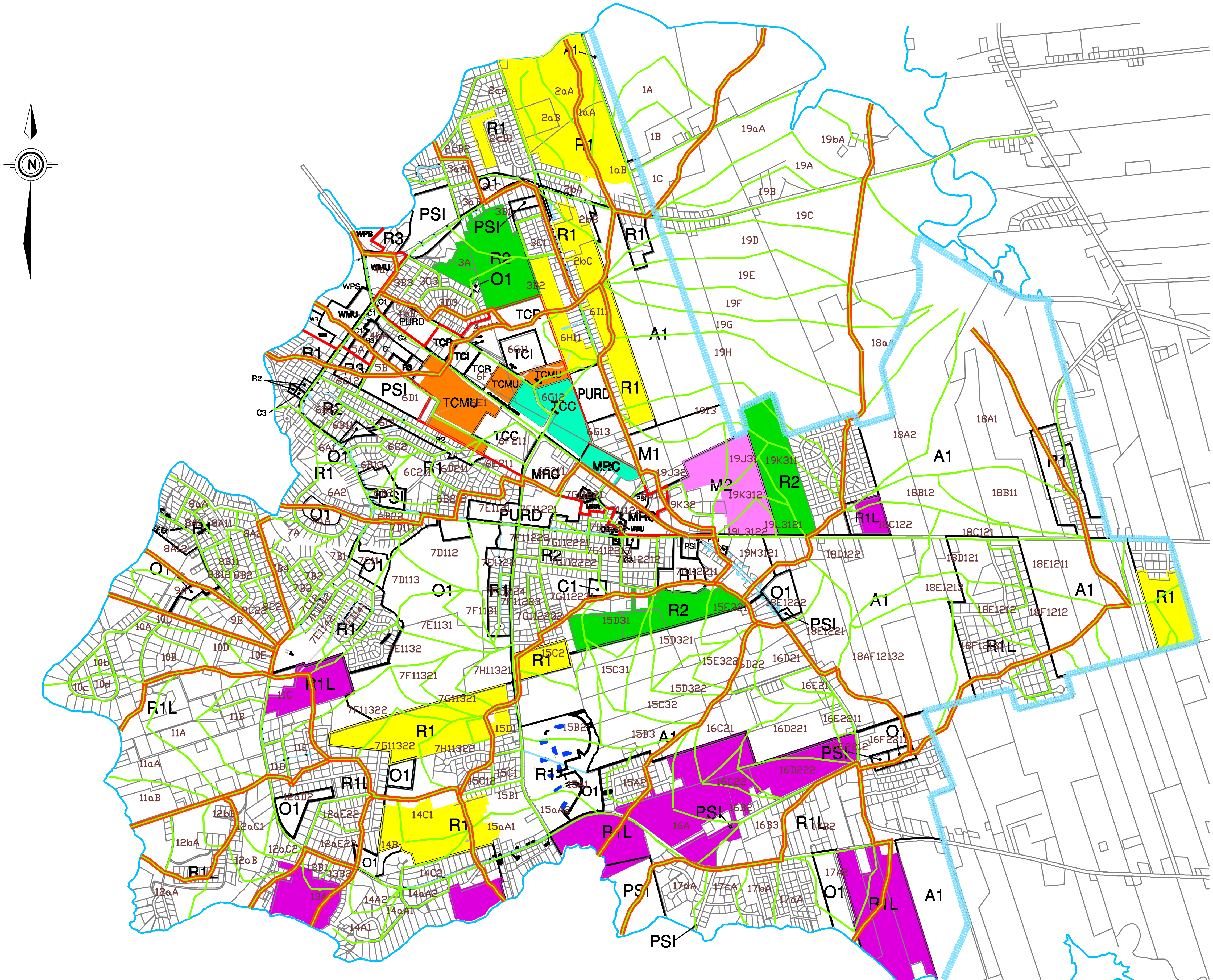
3.1 Areas for Future Development

At the initial meeting with the Town on January 6, 2010, future development in the Town was discussed. It was decided that the Town's existing zoning map would be used to define the types of expected development in the Town. Figure 3.1, page following shows the current zoning map over-laid on the watershed mapping. This was used to determine the amount and type of additional development expected in each watershed. Table 3.1 summarizes the various land-uses and the expected area to be developed by each land-use considered in each sub-watershed within the town.

Table 3.1 - Current Undeveloped Watershed Areas by Zone

Zone Label	Sub-Catchment Name	Zone Type	Watershed Area (ha)	Undeveloped Area (ha)	Percent Undeveloped
R1	SC-1aA	Single Family Residential	6.91	6.91	100.0
	SC-1aB	Single Family Residential	11.991	11.991	100.0
	SC-2aA	Single Family Residential	7.811	7.811	100.0
	SC-2aB	Single Family Residential	23.426	23.426	100.0
	SC-2bC	Single Family Residential	12.222	11.706	95.8
	SC-2bB	Single Family Residential	7.187	4.4676	62.2
	SC-14C1	Single Family Residential	11.731	11.731	100.0
	SC-7G11322	Single Family Residential	17.801	15.17	85.2
		R1 area sub-total	**99.079**	**93.2126**	**94.1**
R2	SC-3B2	Two Family Residential	21.041	20.739	98.6
	SC-3B1	Two Family Residential	15.721	14.5584	92.6
	SC-3A	Two Family Residential	12.179	10.7452	88.2
	SC-19L3121	Two Family Residential	3.447	3.213	93.2
	SC-19K311	Two Family Residential	10.559	10.559	100.0
		R2 area sub-total	**62.947**	**59.8146**	**95.0**
R1L	SC-18C122	Single Family Res. Large	10.98	6.621	60.3
	SC-17A2	Single Family Res. Large	14.711	11.3689	77.3
	SC-16D222	Single Family Res. Large	10.417	10.417	100.0
	SC-16C22	Single Family Res. Large	4.271	4.271	100.0
	SC-16B2	Single Family Res. Large	15.502	14.206	91.6
	SC-16A	Single Family Res. Large	19.901	16.764	84.2
	SC-13A	Single Family Res. Large	9.64	9.64	100.0
		R1L area sub-total	**85.422**	**73.2879**	**85.8**
MRC/TCC	SC-6G13	Commercial	26.076	19.6785	75.5
M2	SC-19J31, SC-19K312, SC-19L3122	Industrial	16.325	16.325	100.0
TCMU	SC-6E1, SC-6F1	Town Center Mixed Use	20.99	20.99	100.0
		Total	**558.287**	**509.6237**	**91.3**

TOWN OF STRATFORD



LEGEND:

- R1 – RESIDENTIAL
- R2 – RESIDENTIAL
- R1L – RESIDENTIAL (LARGE LOT)
- MRC/TCC – COMMERCIAL
- M2 – INDUSTRIAL
- TCMU – TOWN CENTER MIXED USE

A1: AGRICULTURAL RESERVE
C1: GENERAL COMMERCIAL
C2: HIGHWAY COMMERCIAL
C3: NEIGHBORHOOD COMMERCIAL
M1: LIGHT INDUSTRIAL
M2: INDUSTRIAL
MRC: MASON ROAD COMMERCIAL
MRMU: MASON ROAD MIXED USE
MRR: MASON ROAD RESIDENTIAL
O1: RECREATIONAL AND OPEN SPACE
O2: ENVIRONMENTAL RESERVE
PSI: PUBLIC SERVICE AND INSTITUTIONAL
PURD: PLANNED UNIT RESIDENTIAL DEVELOPMENT
R1: SINGLE FAMILY RESIDENTIAL
R2: TWO FAMILY RESIDENTIAL
R3: MULTIPLE FAMILY RESIDENTIAL
TCC: TOWN CENTRE COMMERCIAL
TCI: TOWN CENTRE INSTITUTIONAL
TCMU: TOWN CENTRE MIXED USE
TCOS: TOWN CENTRE OPEN SPACE
TCR: TOWN CENTRER RESIDENTIAL
WPS: WATERFRONT PUBLIC SPACE
WMU: WATERFRONT MIXED USE
WR: WATERFRONT RESIDENTIAL

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TOWN OF STRATFORD
LOW IMPACT DEVELOPMENT
STORMWATER GUIDELINES

CURRENT UNDEVELOPED
WATERSHED AREAS
BY ZONE

GRAPHIC SCALE: 1:25,000 (m)

DATE: JUNE 29, 2010

PROJECT No. CBCL 092641

FIG. No. 3.1

3.2 Overall Stormwater Management Approach

In the 2003 Study, several scenarios were presented to address potential flooding issues that existed at the time the study was completed and could potentially arise if development and stormwater generation in the Town continued as it had in the past.

At the meeting on October 29, 2009, the Town indicated that it wished future development to be sustainable. To achieve this goal it had decided that it would encourage development in the community that had minimal impacts on the surrounding environments, including existing natural drainage systems.

It was agreed at the meeting that the go forward plan for stormwater management would include two major components:

- Upgrade existing deficiencies in the major drainage systems in each watershed. Upgrading of the culverts identified in Table 2.2 (Appendix A) as deficient by replacing the existing culvert, or completing an equivalent measure, will produce a system able to convey the peak flows from existing development without causing unplanned flooding.
- All subsequent development of lands within the Town of Stratford should be completed as low impact development. This will minimize changes in runoff that typically result from urban development.

A master drainage plan for each watershed should be completed prior to completing any upgrades in a watershed to ensure that a culvert upgrade is the most appropriate upgrade at each site. After upgrades are completed, Best Management Practices that are considered suitable for use in the Town should be implemented. There are several presented in the Chapter 4. Every proposed development is to include these in their specific comprehensive stormwater management plan that addresses:

- Infiltration as part of runoff reduction;
- Systems to maintain post-development peak flows at pre-development rates; and
- Runoff and groundwater recharge quality.

3.3 Responsibilities

The Town will be responsible for implementation of a storm water management plan as it is responsible for planning and land development. As owners of the main drainage structures in the Town, the Department of Transportation and Infrastructure Renewal (TIR) will play a significant role in the first phase of a sustainable storm water management plan. If, through the development of master drainage plans, it is decided that the most appropriate measures are to upgrade culverts considered under capacity, then TIR will be involved in the replacements. .

To ensure long term success of a storm water management plan, it is recommended that the Town accept responsibility for:

1. Review of all comprehensive stormwater management plans submitted as part of the approval process for land development. These plans should:

- Be completed by a licensed engineer
- Include appropriate components listed in the following chapter as suitable for Stratford, or provide rational for alternatives.
- Identify pre and post development conditions such as watershed characteristics for all tributary areas and peak flows.
- Design runoff discharges to all watersheds impacted by the proposed development resulting from the 1in 5 year, 1in 10 year and 1 in 100 year design rainfall events as provided in this report (Appendix B). Calculations should be based on both historical rainfall records for the climate station at the Charlottetown Airport available in 2010 and maximum predicted rainfall intensities over the next 100 years provided in this report (Appendix B).

2. Operation of stormwater management facilities that are provided by developers to accommodate multiple properties including street rights of way and public lands;
3. Providing public education programs in the community. Owners of the individual properties will be responsible for operation of facilities provided by the developers for individual properties. To ensure that these systems function, all residents must understand:
   - That there is a stormwater management system in place in the community and how it works;
   - The consequences of actions that they take on their properties;
   - What they can do to ensure the plan is successful and make it work better.
4. Long term compliance monitoring of all facilities.

In addition, the Town and TIR will need to consider modifications to typical operations such as winter maintenance programs for the streets and roads. Salt and sand placed on the roads during winter degrades water quality in the drainage systems as well as in groundwater systems where groundwater recharge occurs naturally and where constructed infiltration systems are considered. It is recommended that traditional winter maintenance programs in the Town of Stratford be reviewed and adjustments made as necessary to minimize potential impacts on existing drainage and groundwater systems.

Developers will be responsible for design, and construction of the stormwater management facilities for all new development. These will include all of the items listed in Item a above and be submitted as part of the package required for approval.

CHAPTER 4 STORMWATER MANAGEMENT FOR FUTURE DEVELOPMENT

4.1 Stormwater Management Objectives for Future Development

Specific objectives for runoff from all future development include:

- Peak flows to all discharge points from the land to be developed shall be equal to or less than the peak flows currently (2010) discharged from the land;
- Increases in runoff volume from the developed land shall be minimized to the extent possible with technologies available at the approval stage of each proposed development;
- Pollutant concentrations in stormwater discharged from the proposed development shall be minimized through all stages of development including construction, maturation and long-term land use.

This chapter provides appropriate tools and information to help the Town guide development in achieving these objectives.

4.2 Low Impact Stormwater BMPs

Stormwater Best Management Practices (BMPs) are measures that can be used to change stormwater characteristics to achieve specified objectives. The Town's objectives for stormwater management require Low Impact Development (LID) for future development. This means the overall objective is minimal impacts on stormwater drainage systems, especially natural system. Typical LID plans attempt to maintain pre-development hydrology of the lands intended for development, including maintaining and enhancing existing storage, infiltration capacity and the generation of runoff.

4.2.1 Typical Impacts of Development on Hydrology

When precipitation falls on a piece of land it has several alternate paths that may be followed. Some infiltrates the ground surface and travels laterally subsurface or percolates to groundwater. Another portion evaporates either directly from the ground surface or storage pools or from other objects, or is taken up by plants and returned to the atmosphere by evapo-transpiration. The remainder becomes runoff.

Most development changes the balance between these components, typically reducing the rate of infiltration. Pavement or other hard surfaces reduce the amount of precipitation that infiltrates as well as the amount that is lost by evapo-transpiration. Instead, this portion becomes additional runoff.

In addition to increasing the volume of runoff, development typically increases the peak flow by increasing the efficiency of the drainage system. More runoff is generated and it accumulates and flows faster to the outlet (or discharge location) from a tributary area. Both factors contribute to increasing the peak runoff flow from a given area for a given rainfall intensity.

4.2.2 Typical Impacts of Development on Water Quality

In addition to impacting runoff quantity, development typically lowers runoff quality. Runoff water quality is affected by the materials it comes in contact with as it travels overland. The amount of pollutants available for contact with the runoff and the potential for contact is typically greater in developed areas than in most undeveloped areas. An exception is in agricultural areas where soil conservation is not practiced. Erodible fine soils, animal wastes, pesticides and fertilizers may be readily taken up by the runoff, deteriorating runoff quality. In this case, the change in water quality due to residential or commercial development can be less dramatic or an improvement.

Similar to the concepts available to mitigate the potential impacts on water quantity, impacts of development on water quality may be addressed by two concepts:

- By controlling the contact of runoff and pollutants at source to minimize increases in pollutant concentrations;
- By limiting exposure to heated surfaces and direct sunlight to minimize potential temperature increases;
- By treatment of the stormwater to remove pollutants that have been picked up by the runoff prior to entering a natural environment.

In practice it is not always possible to avoid runoff contact with pollutants so some runoff treatment may be required to improve runoff quality.

4.2.3 BMPs to Mitigate Typical Impacts of Development

Information on stormwater BMPs to maintain pre-development peak flows and existing water quality was compiled from various sources including the Stormwater Management Guidelines for the Provence of Alberta (1) and the United States Environmental Protection Agency USEPA (2). A range of BMP's from the USEPA's website are summarized under a number of categories that address the impacts on stormwater through all planning stages as well as through the life of the development, including:

1. Public Education - BMPs to inform individuals and households about ways to reduce stormwater pollution.
2. Public Involvement - BMPs to involve the public in the development, implementation, and review of a stormwater management program.

3. Illicit Discharge Detection & Elimination - BMPs for identifying and eliminating illicit discharges and spills to storm drain systems.
4. Construction - BMPs for construction site operators to address stormwater runoff from active construction sites.
5. Post-construction - BMPs for developers and property owners to address stormwater runoff after construction activities have been completed.
6. Pollution Prevention/Good Housekeeping - BMPs to address stormwater runoff from facilities and activities on an on-going basis.

(1) Stormwater Management Guidelines for the Province of Alberta, Municipal Program Development Branch, Environmental Sciences Division, Environmental Service, January 1999
(2) Stormwater BMPs: USEPA

4.3 BMPs Typically Considered for LID

BMP's listed in the sources identified were reviewed and those typically considered for management of runoff peak flows, runoff volume and runoff quality from low impact development (LID) include the following:

1. Grassed swales;
2. Wet ponds;
3. Dry ponds;
4. Constructed wetlands;
5. Parking Lot storage
6. Bioretention (rain gardens, green roof);
7. Vegetated filter strips;
8. Infiltration trenches and basins;
9. Porous asphalt pavement for single property applications where the risk of spills in lowest;
10. Oil – grit separators

Details of each of these BMP's are provided in the Facts Sheets compiled in Appendix C.

4.4 LID BMPs Most Applicable in Stratford

BMP's listed in the sources identified were reviewed and assessed for application in Stratford. Following are those considered the most applicable for the Town to achieve the goals of limiting increases in peak flows and not deteriorating the quality of the Town's surface water and groundwater resources.

4.4.1 Runoff Reduction

To maintain peak flows in drainage systems downstream of proposed development and alleviate potential flooding risks in flood prone areas requires measures to maintain existing infiltration capacity and promote additional capacity where feasible as well as storage to attenuate peak runoff flows generated on impervious areas such as rooftops and traditional paved parking lots.

Infiltration

Typical infiltration facilities attempt to maximize opportunities to allow infiltration to occur, to offset the opportunities lost during development by the creation of impervious surfaces. Soils in the study area were presented in Figure 2.2 of the 2003 Stormwater Management Report. Available soils information presented on the figure indicate that the surficial soils are predominantly coarse, loamy, imperfectly to well drained with permeability's of less than 5×10^{-5} m/s. Water travels relatively slowly through silty sand or till soils. Infiltration accounts for a smaller portion of total precipitation, resulting in higher portions of runoff for these soils. As a result, in areas with low permeability soils infiltration facilities to reduce runoff volumes need to be relatively large. Under these conditions, measures should be taken where it does not cause other problems to encourage infiltration to groundwater but infiltration may not play a significant role in stormwater management. It is however recommended that the feasibility of infiltration systems be investigated on a site by site basis prior to the design of a stormwater management plan for any proposed development. Otherwise, all of the remaining runoff must be accommodated by the other components of the stormwater management system.

To protect groundwater, waters with the least opportunities for contact with contaminants such as water from roof tops should be considered for direct infiltration. Other sources such as street runoff or runoff from parking lots should be preceded by systems to remove and collect materials such as sediment, oil and other hydro-carbons as well as metals.

Any of the infiltration based BMPs listed in section 4.3 are applicable in Stratford to the extent possible. Infiltration system will be most efficient when preceded by the BMPs to remove any pollutants to the greatest extent possible as well as storage for attenuation of peak flows.

Storage

Storage facilities are designed to accept runoff flows as they are generated and release them to the downstream system at a controlled rate. This will typically be the peak flow rate that comes from the same area under existing (2010) conditions, prior to development. Included in the assessment of existing peak flows is existing storage, mostly in the form of low lying lands on the upstream side of the existing culverts. This storage must remain available during the development process in all situations. The total volume of addition storage required to offset the effects of overall decreases in permeability and reduced infiltration capacity depends on:

- Tributary area and the volume of additional runoff generated by the proposed changes in land-use;
- Efficiency of the proposed stormwater drainage systems in the proposed development;
- The maximum flow rate that can be released to the downstream system, identified by the existing (2010) pre-development peak flows from the same area;
- Time to release the stored volume, based on typical occurrence frequencies of rainfall events in Stratford.

Estimated minimum additional storage required for each hectare of land developed to achieve the objective of maintaining pre-development peak flows are summarized in Table 4.4.1, page following. These are guideline values for preliminary assessment only, detailed assessment to establish actual values are required on a site by site basis. To be most effective and limit flow increases in all components of the major drainage systems as well as the downstream drainage systems, storage should be distributed throughout the developments and the watersheds.

Storage may be generated in many forms as described in the list of BMPs in section 4.3. There are advantages and disadvantages of each type. Selection of the most suitable type for a given development will depend on criteria such as:

- Construction cost, typically ponds are the least costly type;
- Availability and cost of land;
- Need to minimize temperature increases, underground facilities address this issue better than surface storage;
- Maintenance, the level required depends on upstream BMPs.

4.4.2 Treatment Based BMPs

It is recommended that treatment based systems be included to preserve water quality prior to discharging the stormwater to receiving environments. This is important to maintain surface water as well as groundwater quality.

Selection of the most appropriate BMPs depends on the materials of concern, those that need to be removed, as well as the downstream system. Typically pollutants that may be removed include:

- Grit, sediment, salt as well as metals that may be attached;
- Heat;
- Nutrients through plant uptake and adsorption to soils;
- Oil and other hydrocarbons from parking lots.

4.5 Applicable BMPs

Recommended BMPs for various land-uses are listed in Table 4.5. These are based on the assessment of BMP's available at the time this study was completed. As new systems to manage stormwater are developed, these should be evaluated and included where appropriate.

Table 4.5 Applicable Stormwater BMP's by Land-use

Land Use	Applicable BMPs (see list in section 4.3)
Residential Zone - R1	Single property:1, 6, 9 Multiple properties:1, 2 ,3, 4, 5, 6, 7, 8, 9, 10
Residential Zone - R2	1, 2 ,3, 4, 5, 6, 7, 8, 9, 10
Residential Zone - R1L	1, 2 ,3, 4, 5, 6, 7, 8, 9, 10
Commercial	1, 2 ,3, 4, 5, 6, 7, 8, 9, 10
Industrial	1, 2 ,3, 4, 5, 6, 7, 8, 9, 10

Note: See the Summary of Fact Sheets in Appendix C for detailed description of BMPs

4.5.1 Multiple Property Systems

Systems designed to accommodate runoff from multiple properties including multiple residences in sub-divisions and commercial and industrial lot developments, should include vegetated swales, appropriate grading, wet ponds, and regulated discharges. Systems constructed in street rights of way to accommodate runoff are desirable to facilitate management as well as operation and maintenance of these systems.

Vegetated Swales

Vegetated swales are for collection of runoff and site storage. These should be incorporated in the street cross sections and discharges between reaches of the swale should be regulated with inlet controls on cross culverts and driveway culverts. Where soil conditions allow, infiltration trenches should be incorporated to maximize infiltration capacity. Where natural soils allow only slow infiltration, underdrains should be provided to minimize the risk of standing water between events.

Proper Site Grading

It is important that buildings are located above the maximum flood elevation in the proposed collection systems and the properties are graded so that the swales provide adequate drainage for each property to ensure that extraneous flows are not delivered to the wastewater collection and treatment system. Where this is not possible, a deep storm sewer with capacity to convey foundation drainage from every property connected should be included.

Wet Ponds & Constructed Wetlands

Wet ponds or constructed wetland treatment should be on public land, the lowest lands in the proposed development, and integrated with the swales. Where additional land is required to provide additional detention storage, the land may be retained in its natural state where this is desired or may be co-use common land such as parkland or recreation fields.

Regulated Discharge Locations

Regulated discharges to local drainage systems are required. The flows discharged from the developed site should be equal to or less than the flow discharged from the same site under current (2010) conditions.

4.5.2 Systems to Service Individual Properties

Where infill development necessitates construction of stormwater management facilities, the following measures are recommended for residential and commercial development categories. Detailed descriptions of these BMPs are provided in a Summary Table of Fact Sheets from the USEPA for each BMP in Appendix C.

Residential

Swales

Similar to the concept discussed for public areas, swales can be constructed between properties to provide a place for roof leader discharges as well as interception of surface flows. These would be constructed to encourage detention of flows during wet weather events but free draining so that they dry up shortly after each event. The swales would eventually drain to the existing storm drainage systems, but control devices would limit discharge rates. The bottoms of the swales would be constructed to encourage infiltration to groundwater to the extent possible with surrounding soils.

Once constructed the swales would be owned and maintained by individual property owners. Local resident associations would play an important role in making sure that swales common to a number of properties were not filled in or obstructed by monitoring activities in the neighbourhood.

Rain Gardens
Rain gardens are similar to the swale concept in that they provide detention storage but infiltration plays a larger role. There is typically a depth of porous soils that receives runoff and detains it prior to infiltration. Local water tolerant plants are used to enhance the treatment the runoff receives as it makes its way through the soils. Once the infiltration capacity of the surrounding soils is reached, the soils become saturated and eventually ponding can occur at the surface. Additional runoff flows past the rain garden at this point.

These can be implemented on a property-by-property basis in which case each property owner takes responsibility for his or her garden. They could also be implemented for a group of properties, in a location such ason the side property line where neighbours agreed or along the back property line where a number of owners were agreeable.

Rain Barrels
Rain barrels collect water from downspouts during rainfall events. This water is completely removed from the flow to the drainage system during the peak of the rainfall event, provided there are enough barrels for the roof area. The barrels typically used have a valve controlled outlet that is opened by the homeowner when the collected water is need for irrigation, between runoff events. They are typically only used in the spring, summer and fall and are replaced by a section of pipe that discharges to a grassed area in the winter when freezing occurs.

Institutional, Commercial and Industrial
Surface Ponding
Large paved parking areas such as retail parking lots offer potential for surface storage to reduce peak flows generated from predominantly impervious properties consisting of building rooftops and parking lots themselves. This may be perceived as a hazard to the users of the lots but this could be offset with signs and procedures during extreme rainfall events.

Constructed Underground Storage Facilities
An alternative is to construct storage under parking lots. This is significantly more costly but alleviates the safety concerns. Some alternatives also provide opportunity to retain infiltration capacity on the site, although care must be taken to ensure that only clean water, not water from the parking area itself is allowed to infiltrate to groundwater. Alternatives for construction of such facilities include:

- Concrete tanks – most accessible for maintenance but most costly;

- Plastic compartmentalized tanks – large storage volume per square metre of available space (same as concrete tank) but less accessible;
- Large diameter pipes – less efficient use of available space;
- Gravel beds – least effective storage but good opportunity for infiltration.

Pretreatment

Combinations of the BMPs to remove appropriate pollutants are recommended and may include:

- Depressed boulevards and traffic islands in combination with filter strips;
- Oil and grit separators.

4.5.3 Other BMPs

Other BMPs that should be considered and included in a stormwater management plan were mentioned in section 4.2.3. These include education of existing residents in the community and those that move into the new developments, to minimize the risk of accidental contamination of natural systems and stewardship programs to involve citizens in the upkeep and care of natural drainage systems in their community. Citizens can also assist with monitoring and education programs both formal and informal.

CHAPTER 5 RECOMMENDED POLICIES AND DESIGN CRITERIA

5.1 Summary of Expected Changes in Stormwater

There are two main factors affecting the flows that enter the existing natural and constructed drainage systems in the Town of Stratford:

- Changes in the amount of runoff that is generated by tributary lands brought about by changes in land-use or development or redevelopment of the land; and
- Changes in rainfall intensities (currently increasing but expected to later decrease) resulting from global climate change.

Both of these changes have resulted in increases in peak flows in the drainage system and this has resulted in flooding and deteriorating water quality in these systems. It is expected that without a stormwater management plan that addresses both factors, these trends will continue.

5.2 Policies

5.2.1 Major Drainage System Upgrades

Typically drainage systems are design to provide capacity for peak flows generated by:

- A design rainfall event with a 1 in 100 year return period for the major drainage systems (culverts on natural and constructed drainage systems); and
- A design rainfall event with a 1 in 5 to a 1 in 10 year return period for the minor drainage systems (storm sewers).

The Town and the Department of Transportation and Infrastructure Renewal should complete master drainage plans for each watershed in the town prior to upgrading any of the infrastructure identified in Table 2.2 as being under capacity. This is a plan showing all of the system components selected to convey flows from the watershed when all planned development is complete. It should also show the extents of planned flooding under this condition.

A policy is required with respect to the level of service to be provided by the major drainage systems. It may be different in each watershed depending on the amount of flooding that can be accepted. All stakeholders, including property owners at risk of flooding, should have input to a process to establish an appropriate level of service in each watershed. Lands that will be allowed to flood during extreme rainfall events should be agreed with property owners and then designated as flood prone areas on the Towns Zoning Map; see Figure 3.1, page following, for the current version.

Once the allowable flooding areas are established, the flows that must be conveyed by the major drainage system can be defined and these may be used to size structures and assess erosion potential along the channels. The results of these assessments should be used to decide on the appropriate measures to address upgrades in each watershed.

5.2.2 Future Development
Increases in runoff volume and peak flows resulting from land development can be minimized or reversed by implementing a policy requiring that all future development in the Town follow the principals of low impact development and require that post-development peak flows discharged from the development are equal to or less than the peak flows from the same area prior to development.

The approval process for any new development or redevelopment of existing development should be modified to include a stormwater management plan with the items listed in section 3.3. It should include the most suitable of the BMPs listed in Chapter 4.

When lands are conveyed for public use, the Town should try to obtain low lands that could be used to:

- Generate additional detention storage for attenuation of peak flows;
- Create retention storage or constructed wetlands for runoff treatment;
- Maintain floodplains along natural drainage systems.

Co use with parks or recreational areas should be considered as well as maintaining some land as natural areas.

5.3 Design Criteria

5.3.1 Design Rainfall Events
Design Rainfall Events to be used in the development of stormwater management plans are presented in Appendix B. All assessments of exiting (2010) conditions (pre-development) are to be completed using the design events based on historical rainfall records. Assessments of post-development conditions are to use the design rainfall events based on predicted rainfall intensities resulting from global climate change models.

5.3.2 BMPs
Design criteria for recommended BMPs require the use of site specific measurements. General guidelines for design are presented in the Summary of Fact Sheets in Appendix C. These may be used for conceptual design purposes.

CHAPTER 6 IMPLEMENTATION

6.1 Timeline for Implementation

Rainfall intensities are predicted to increase over the next few years by the model suggest by the Department of Energy, Environment and Forestry as most applicable for Stratford. By this model they are predicted to reach a maximum in the period 2040 to 2069. They are predicted to decline again following the peak. Any capacity upgrades must be implemented prior to the maximum rainfall intensities, otherwise capacity will not be available when it is required.

This means that the upgrades of the major drainage systems must be decided and completed within the next 30 years in order to be ready for the predicted maximum. Until the measures are completed, the capacity of the existing systems will be exceeded on an increasing frequency. Given the uncertainty with these assessments, it is in the best interest of the Town, the Department of Transportation and Infrastructure Renewal and the landowners with risk of flooding to have this work done sooner than later.

All new sub-divisions should be designed as low impact development and meet the guidelines outline in this report. This should begin as soon as possible.

6.2 Implementation Priority

Figure 1 shows the main culverts in each watershed in the Town. In the capacity assessment described in Chapter 2, the capacities of the identified existing culverts were compared to the estimate peak runoff flows and the culverts were grouped as follows:
Group 1 - Peak runoff flow is less than the existing capacity: No upgrades are required;
Group 2 - Peak runoff flow is 1 to 2.5 times the existing capacity;
Group 3 - Peak runoff flow is 2.5 to 5 times the existing capacity;
Group 4 - Peak runoff flow is more than 5 times the existing capacity.

Any culvert that has capacity less than the expected peak runoff flow poses a flood risk. Group 4 culverts pose the greatest risks of causing flooding.

In addition to culvert capacity, the Town must also consider the consequences of failure of any of these systems resulting in potential flooding upstream of undersized culverts as well as flooding of downstream areas if the culvert washes out. Upon completion of a master drainage plan, the cost of implementing the decided measures should be compared to the total cost of repairs should failure occur without the improvements. Water sheds with the greatest cost of failure should be considered the greatest priority.

The upgrades should be completed as a package (the package should be developed in a master drainage planning program) on a watershed by watershed basis. Once the issues are considered with input from the Department of Transportation and Infrastructure Renewal as well as stakeholders from each watershed, the Town will be in a better position to set priorities for watershed drainage system upgrades.

6.3 Leadership

Ownership of facilities is usually a subject of debate in the development of an overall stormwater management plan. Current ownership of the storm sewers and major culverts in the road rights of way resides with the Department of Transportation and Infrastructure Renewal. Drainage channels cross over private lands, including some parkland owned by the Town. To be effective, all components need to work as a system and this requires all parties to work towards common goals. This requires co-operation and co-ordination between the parties and success depends on a strong leader such as the Town. Stormwater management should not be left to individual property owners or developers.

The Town is encouraged to take a leadership role in stormwater management in the community. All property owned by the Town should include the recommended BMPs including retrofitting of BMPs on those properties already developed. Not only does it show developers that the Town is committed to LID development, it is an opportunity to demonstrate the BMPs and how they work.

APPENDIX A

Significant Culverts in the Town of Stratford

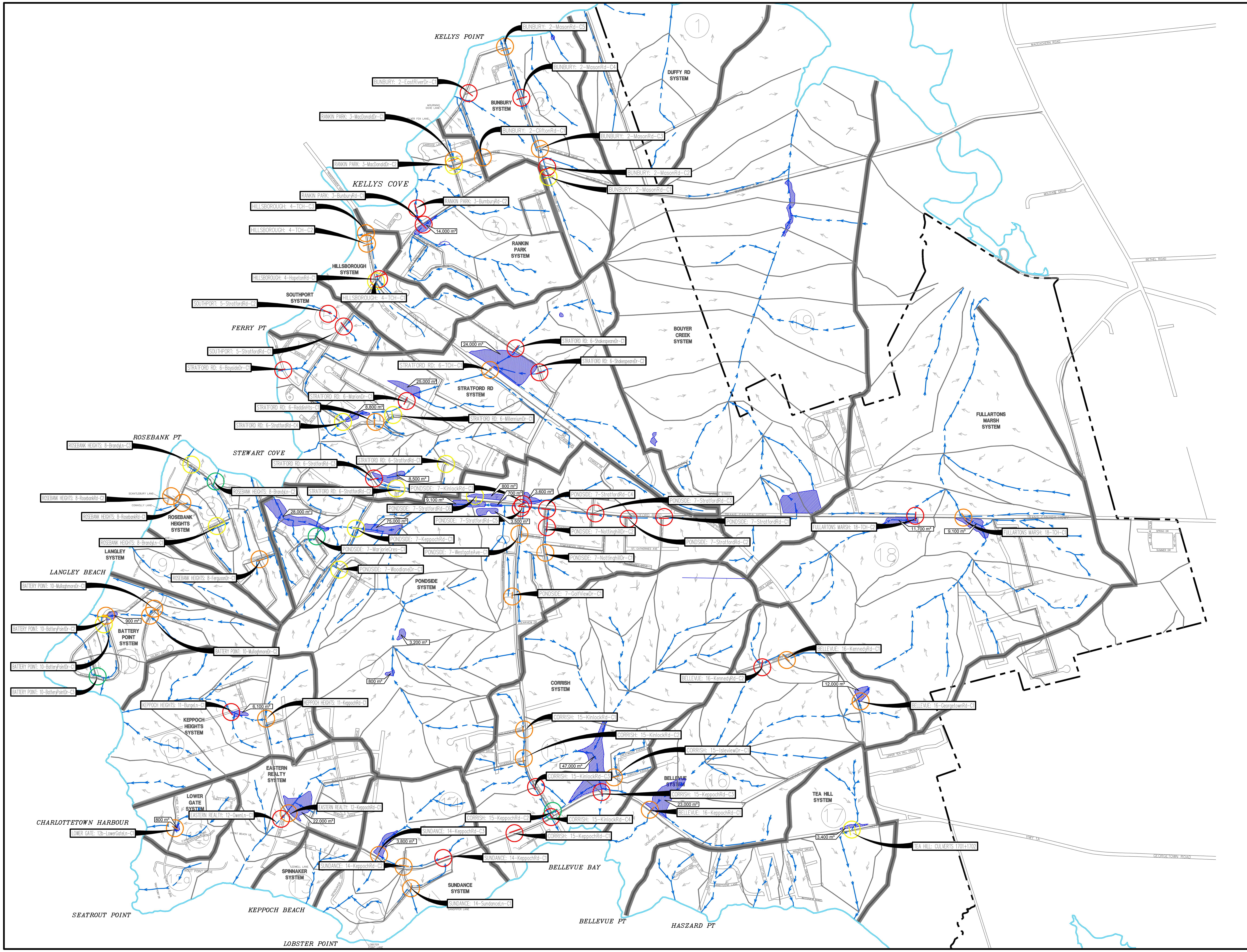
(Table 2.2 and Figure 2.2)

Table 2.2 Master Culvert Sheet

Properties of Existing Conduits								Required Conduits to Accommodate Peak Flows Generated By Design Rainfall Events Based on Historical Rainfall Records									Required Conduits to Accommodate Peak Flows Generated By Design Rainfall Events Based on Climate Change Model HadCM3 for Year 2050											
								1 in 5 Year Return Period			1 in 10 Year Return Period			1 in 100 Year Return Period			1 in 5 Year Return Period				1 in 10 Year Return Period				1 in 100 Year Return Period			
Conduit Name (see Figure 2.2 for location)	Conduit Shape	Existing Material	Size	Equivalent Pipe Diameter	Length	Slope	Current Capacity*	Maximum Flow	Equivalent Pipe Diameter	Upgrade Cost**	Maximum Flow	Equivalent Pipe Diameter	Upgrade Cost**	Maximum Flow	Equivalent Pipe Diameter	Upgrade Cost**	Maximum Flow	Flow Increase	Equivalent Pipe Diameter	Upgrade Cost**	Maximum Flow	Flow Increase	Equivalent Pipe Diameter	Upgrade Cost**	Maximum Flow	Flow Increase	Equivalent Pipe Diameter	Upgrade Cost**
			(mm)	(mm)	(m)	(%)	(m^3/s)	(m^3/s)	(mm)	$	(m^3/s)	(mm)	$	(m^3/s)	(mm)	$	(m^3/s)		(mm)	$	(m^3/s)		(mm)	$	(m^3/s)		(mm)	$
2-CliftonRd-C1	Circular	CSP	450	450	25	2.00	0.170	0.171	600	$ 48,000	0.212	600	$ 48,000	0.354	750	$ 49,000	0.249	146%	600	$ 48,000	0.300	142%	600	$ 48,000	0.513	145%	750	$ 62,000
2-MasonRd-C1	Circular	PVC	750	750	190	0.53	0.610	0.471	750	$ -	0.587	750	$ -	0.993	1050	$ 497,000	0.699	148%	900	$ 480,000	0.845	144%	900	$ 480,000	1.459	147%	1200	$ 681,000
2-MasonRd-C2	Circular	CSP	900	900	75	1.37	0.980	0.772	900	$ -	0.925	900	$ -	1.829	1200	$ 274,000	1.129	146%	1050	$ 238,000	1.324	143%	1050	$ 238,000	2.599	142%	1350	$ 330,000
2-MasonRd-C3	Circular	CSP	900	900	30	1.59	0.980	1.015	1050	$ 107,000	1.227	1050	$ 107,000	2.350	1350	$ 146,000	1.789	176%	1200	$ 133,000	1.889	154%	1200	$ 133,000	3.126	133%	1500	$ 168,000
2-MasonRd-C4	Circular	-	300	300	10	10.00	0.040	0.979	1050	$ 49,000	1.242	1050	$ 49,000	2.090	1350	$ 66,000	1.521	155%	1200	$ 64,000	1.855	149%	1200	$ 64,000	3.072	147%	1500	$ 76,000
2-MasonRd-C5	Circular	CSP	600	600	30	1.01	0.330	0.436	750	$ 72,000	0.541	750	$ 72,000	0.909	900	$ 84,000	0.643	147%	900	$ 93,000	0.775	143%	900	$ 93,000	1.328	146%	1050	$ 107,000
2-EastRiverDr-C1	Circular	CSP	450	450	30	1.00	0.120	0.569	750	$ 72,000	0.709	900	$ 93,000	1.191	1050	$ 102,000	0.838	147%	900	$ 93,000	1.009	142%	1050	$ 107,000	1.733	146%	1200	$ 133,000
3-BunburyRd-C1	Circular	CSP	1000	1000	31	0.97	1.235	3.185	1500	$ 173,000	3.954	1800	$ 235,000	6.551	2100	$ 263,000	4.817	151%	1800	$ 235,000	6.750	171%	2100	$ 283,000	10.852	166%	2400	$ 336,000
3-BurnburyRd-C2	Rectangular	Timber	2 - 700x900	1267	30	3.33	0.755	2.680	1500	$ 168,000	3.242	1500	$ 168,000	4.573	1800	$ 197,000	3.871	144%	1800	$ 229,000	4.395	136%	1800	$ 229,000	6.038	132%	2100	$ 276,000
3-MacDonaldDr-C1	Circular	CSP	450	450	30	0.67	0.180	0.251	600	$ 56,000	0.311	600	$ 56,000	0.513	750	$ 65,000	0.359	143%	750	$ 72,000	0.431	139%	750	$ 72,000	0.726	142%	900	$ 93,000
3-MacDonaldDr-C2	Circular	CSP	450	450	30	1.46	0.175	0.100	450	$ -	0.125	450	$ -	0.213	600	$ 49,000	0.149	149%	450	$ -	0.180	144%	600	$ 56,000	0.311	146%	600	$ 56,000
4-TCH-C1	Circular	-	900	900	50	2.00	0.970	0.770	900	$ -	0.956	1050	$ 165,000	1.595	1200	$ 178,000	1.114	145%	1050	$ 165,000	1.344	141%	1050	$ 165,000	2.283	143%	1350	$ 230,000
4-TCH-C2	Circular	Concrete	900	900	360	1.39	0.965	1.261	1050	$ 1,064,000	1.656	1200	$ 1,264,000	2.736	1500	$ 1,534,000	1.934	153%	1200	$ 1,264,000	2.294	139%	1350	$ 1,469,000	4.247	155%	1800	$ 2,203,000
4-TCH-C3	Circular	Concrete	1200	1200	20	5.00	2.025	1.530	1200	$ -	2.043	1350	$ 110,000	3.698	1800	$ 129,000	2.300	150%	1350	$ 110,000	3.415	167%	1500	$ 122,000	4.734	128%	1800	$ 170,000
4-HopetonRd-C1	Circular	-	450	450	40	3.28	0.170	0.643	900	$ 117,000	0.800	900	$ 117,000	1.348	1050	$ 136,000	0.979	152%	1050	$ 136,000	1.183	148%	1050	$ 136,000	2.032	151%	1350	$ 190,000
5-StratfordRd-C1	Circular	-	450	450	35	4.29	0.175	0.501	750	$ 81,000	0.622	900	$ 105,000	1.041	1050	$ 110,000	0.726	145%	900	$ 105,000	0.877	141%	900	$ 105,000	1.493	143%	1200	$ 150,000
5-StratfordRd-C2	Circular	HDPE	450	450	223	1.00	0.170	0.869	900	$ 560,000	1.092	1050	$ 668,000	1.753	1200	$ 758,000	1.257	145%	1050	$ 668,000	1.531	140%	1200	$ 795,000	2.574	147%	1350	$ 922,000
6-BaysideDr-C1	Circular	CSP	450	450	6	1.00	0.175	0.354	750	$ 24,000	0.438	750	$ 24,000	0.725	900	$ 25,000	0.509	144%	750	$ 24,000	0.613	140%	900	$ 35,000	1.035	143%	1050	$ 37,000
6-ReddinHts-C1	Circular	CSP	600	600	10	2.90	0.406	0.477	750	$ 32,000	0.589	750	$ 32,000	0.972	1050	$ 45,000	0.684	143%	900	$ 44,000	0.822	140%	900	$ 44,000	1.389	143%	1050	$ 49,000
6-StratfordRd-C1	Circular	CSP	450	450	457	1.25	0.175	0.132	450	$ -	0.163	450	$ -	0.272	600	$ -	0.192	145%	600	$ -	0.231	142%	600	$ -	0.395	145%	750	$ -
6-StratfordRd-C2	Circular	CSP	450	450	25	3.03	0.178	0.085	450	$ -	0.106	450	$ -	0.180	600	$ 40,000	0.125	147%	450	$ -	0.152	143%	450	$ -	0.260	144%	600	$ 48,000
6-StratfordRd-C3	Circular	CSP	900	900	40	0.55	0.975	1.491	1200	$ 167,000	1.848	1200	$ 167,000	3.121	1500	$ 210,000	2.273	152%	1350	$ 190,000	2.717	147%	1500	$ 215,000	4.675	150%	1800	$ 289,000
6-StratfordRd-C4	Arch	CSP	1050x1800	1551	35	0.29	2.505	2.160	1350	$ -	2.574	1350	$ -	4.647	1800	$ 224,000	3.195	148%	1500	$ -	3.803	148%	1800	$ 257,000	6.553	141%	2100	$ 310,000
6-MillenniumDr-C1	Circular	CSP	600	600	50	6.15	0.408	0.191	600	$ -	0.235	600	$ -	0.386	750	$ 92,000	0.270	141%	600	$ -	0.325	138%	600	$ -	0.544	141%	750	$ 111,000
6-ShakespeareDr-C1	Circular	Concrete	750	750	25	2.77	0.615	1.217	1050	$ 93,000	1.514	1200	$ 116,000	2.540	1350	$ 130,000	1.793	147%	1200	$ 116,000	2.164	143%	1350	$ 130,000	3.705	146%	1800	$ 200,000
6-ShakespeareDr-C2	Circular	Concrete	750	750	25	7.36	0.395	0.407	750	$ -	0.506	750	$ -	0.851	900	$ 71,000	0.618	152%	900	$ 81,000	0.746	147%	900	$ 81,000	1.335	157%	1050	$ 93,000
6-TCH-C1	Rectangular	Concrete	1200x2400	1915	39	0.83	4.455	3.452	1800	$ -	4.242	1800	$ -	7.141	2100	$ 330,000	5.207	151%	1800	$ -	6.291	148%	2100	$ 341,000	10.766	151%	2400	$ 407,000
6-MarionDr-C1	Circular	CSP	450	450	161	0.39	0.170	2.240	1350	$ 674,000	2.721	1500	$ 773,000	4.150	1800	$ 878,000	3.365	150%	1500	$ 773,000	3.880	143%	1800	$ 1,013,000	5.825	140%	2100	$ 1,262,000
7-GolfViewDr-C1	Circular	Concrete	450	450	124	3.55	0.175	0.197	600	$ 205,000	0.225	600	$ 205,000	0.371	750	$ 214,000	0.242	123%	600	$ 205,000	0.370	164%	750	$ 258,000	0.522	141%	750	$ 258,000
7-KinlockRd-C1	Circular	CSP	800	800	45	2.89	0.645	1.398	1050	$ 151,000	1.735	1200	$ 184,000	2.905	1500	$ 224,000	2.095	150%	1350	$ 210,000	2.521	145%	1350	$ 210,000	4.289	148%	1800	$ 319,000
7-StratfordRd-C1	Circular	-	600	600	226	1.61	0.350	0.886	900	$ 567,000	1.096	1050	$ 675,000	1.813	1200	$ 780,000	1.271	143%	1050	$ 675,000	1.529	140%	1200	$ 804,000	2.581	142%	1350	$ 933,000
7-StratfordRd-C2	Circular	-	600	600	219	1.17	0.350	1.274	1050	$ 654,000	1.914	1200	$ 779,000	2.711	1500	$ 939,000	2.014	158%	1350	$ 904,000	2.539	133%	1350	$ 904,000	3.706	137%	1800	$ 1,357,000
7-StratfordRd-C3	Circular	-	750	750	309	2.52	0.615	1.813	1200	$ 1,088,000	2.254	1350	$ 1,264,000	3.218	1500	$ 1,439,000	2.484	137%	1350	$ 1,264,000	2.806	124%	1500	$ 1,454,000	4.675	145%	1800	$ 1,896,000
7-StratfordRd-C4	Circular	-	900	900	159	2.38	0.975	2.798	1500	$ 763,000	3.210	1500	$ 763,000	5.312	1800	$ 1,015,000	3.862	138%	1800	$ 1,000,000	4.570	142%	1800	$ 1,000,000	7.695	145%	2100	$ 1,245,000
7-StratfordRd-C5	Circular	-	900	900	15	1.55	0.965	3.103	1500	$ 99,000	4.090	1800	$ 140,000	6.673	2100	$ 154,000	4.970	160%	1800	$ 140,000	5.812	142%	2100	$ 163,000	10.005	150%	2400	$ 189,000
7-StratfordRd-C6	Circular	CSP	700	700	18	3.67	0.465	0.295	600	$ -	0.367	750	$ 48,000	0.619	900	$ 49,000	0.435	147%	750	$ 48,000	0.526	143%	750	$ 48,000	0.902	146%	900	$ 64,000
7-WestgateAve-C1	Circular	CSP	650	650	20	2.65	0.445	0.725	900	$ 68,000	0.899	900	$ 68,000	1.495	1200	$ 81,000	1.048	145%	1050	$ 78,000	1.263	140%	1050	$ 78,000	2.148	144%	1350	$ 110,000
7-NottinghillDr-C1	Circular	CSP	600	600	20	4.86	0.365	0.596	750	$ 52,000	0.741	900	$ 68,000	1.246	1050	$ 76,000	0.873	146%	900	$ 68,000	1.056	143%	1050	$ 78,000	1.819	146%	1200	$ 99,000
7-NottinghillDr-C2	Circular	HDPE	450	450	20	2.50	0.175	0.875	900	$ 68,000	1.089	1050	$ 78,000	1.831	1200	$ 88,000	1.263	144%	1050	$ 78,000	1.518	139%	1200	$ 99,000	2.673	146%	1500	$ 122,000
7-KeppochRd-C1	Arch	CSP	1500x1800	1854	65	3.08	10.880	10.278	2400	$ 651,000	12.601	2700	$ 775,000	21.128	3300	$ 989,000	15.508	151%	3000	$ 911,000	18.616	148%	3000	$ 911,000	31.145	147%	4000	$ 1,448,000
7-WoodlaneDr-C1	Circular	CSP	750	750	20	3.88	0.635	0.354	750	$ -	0.438	750	$ -	0.723	900	$ 56,000	0.508	144%	750	$ -	0.611	139%	900	$ 68,000	1.032	143%	1050	$ 78,000
7-MarjorieCres-C1	Circular	CSP	600	600	94	11.22	0.380	0.095	450	$ -	0.118	450	$ -	0.195	600	$ -	0.137	144%	450	$ -	0.165	140%	450	$ -	0.278	143%	600	$ -
8-BrandyLn-C1	Circular	Concrete	600	600	110	0.02	0.345	0.176	600	$ -	0.218	600	$ -	0.362	750	$ 189,000	0.254	144%	600	$ -	0.306	140%	600	$ -	0.519	143%	750	$ 230,000
8-BrandyLn-C2	Circular	Concrete	750	750	70	1.74	0.650	0.410	750	$ -	0.510	750	$ -	0.854	900	$ 176,000	0.608	148%	750	$ -	0.732	144%	900	$ 189,000	1.251	146%	1050	$ 223,000
8-BrandyLn-C3	Circular	Concrete	600	600	65	0.11	0.375	0.143	450	$ -	0.177	600	$ -	0.361	750	$ 115,000	0.254	178%	600	$ -	0.309	175%	600	$ -	0.604	167%	750	$ 141,000
8-RosebankRd-C1	Circular	HDPE	450	450	10	1.68	0.175	0.217	600	$ 23,000	0.269	600	$ 23,000	0.448	750	$ 25,000	0.315	145%	600	$ 23,000	0.379	141%	750	$ 31,000	0.642	143%	900	$ 43,000
8-RosebankRd-C2	Circular	HDPE	450	450	51	1.01	0.170	0.214	600	$ 89,000	0.263	600	$ 89,000	0.440	750	$ 98,000	0.311	145%	600	$ 89,000	0.374	142%	750	$ 113,000	0.628	143%	900	$ 143,000
8-FergusonDr-C1	Circular	CSP	450	450	20	0.04	0.175	0.206	600	$ 40,000	0.255	600	$ 40,000	0.424	750	$ 43,000	0.298	145%	600	$ 40,000	0.359	141%	750	$ 52,000	0.608	143%	750	$ 52,000
10-BatteryPointDr-C1	Arch	CSP	300x600	479	60	1.72	0.145	0.065	450	$ -	0.082	450	$ -	0.141	450	$ -	0.099	152%	450	$ -	0.120	146%	450	$ -	0.209	148%	600	$ 104,000
10-BatteryPointRd-C2	Circular	CSP	2 - 750	1061	16	0.81	1.250	1.150	1050	$ -	1.390	1050	$ -	2.382	1350	$ 93,000	1.738	151%	1200	$ 86,000	2.089	150%	1350	$ 95,000	3.638	153%	1800	$ 147,000
10-BatteryPointRd-C3	Circular	CSP	600	600	72	0.68	0.360	0.043	300	$ -	0.054	300	$ -	0.094	450	$ -	0.065	151%	450	$ -	0.080	148%	450	$ -	0.139	148%	450	$ -
10-MullaghmoreDr-C1	Circular	Concrete	750	750	20	1.10	0.605	0.562	750	$ -	0.697	900	$ 67,000	1.175	1050	$ 73,000	0.853	152%	900	$ 67,000	1.031	148%	1050	$ 77,000	1.773	151%	1200	$ 97,000
10-MullaghmoreDr-C2	Circular	Concrete	600	600	15	3.33	0.355	0.444	750	$ 42,000	0.551	750	$ 42,000	0.923	900	$ 56,000	0.649	146%	900	$ 56,000	0.783	142%	900	$ 56,000	1.343	146%	1050	$ 64,000
11-BurgeLn-C1	Circular	CSP	450	450	15	3.33	0.175	1.059	1050	$ 64,000	1.322	1050	$ 64,000	2.196	1350	$ 86,000	1.576	149%	1200	$ 81,000	1.895	143%	1200	$ 81,000	3.107	141%	1500	$ 99,000
11-KeppochRd-C1	Circular	CSP	2 - 700	990	13	1.25	0.910	1.102	1050	$ 57,000	1.371	1050	$ 57,000	2.298	1350	$ 79,000	1.627	148%	1200	$ 74,000	1.960	143%	1200	$ 74,000	3.991	174%	1800	$ 127,000
12-KeppochRd-C1	Circular	CSP	900	900	37	0.81	0.950	1.921	1200	$ 157,000	2.387	1350	$ 179,000	3.989	1800	$ 222,000	2.792	145%	1500	$ 202,000	3.368	141%	1500	$ 202,000	5.724	143%	2100	$ 330,000
12-OwenLn-C1	Circular	CSP	750	750	25	2.78	0.635	0.935	900	$ 81,000	0.969	1050	$ 93,000	1.205	1050	$ 89,000	1.046	112%	1050	$ 93,000	1.152	119%	1050	$ 93,000	1.533	127%	1200	$ 116,000
12b-LowerGateLn-C1	Circular	CSP	450	450	13	1.09	0.170	0.192	600	$ 28,000	0.240	600	$ 28,000	0.407	750	$ 29,000	0.295	154%	600	$ 28,000	0.357	149%	750	$ 37,000	0.617	152%	900	$ 50,000
14-KeppochRd-C1	Circular	HDPE	600	600	63	0.74	0.360	0.300	600	$ -	0.374	750	$ 138,000	0.626	900	$ 142,000	0.440	147%	750	$ 138,000	0.531	142%	750	$ 138,000	0.905	145%	900	$ 173,000
14-KeppochRd-C2	Circular	CSP	600	600	16	0.89	0.360	0.341	600	$ -	0.366	750	$ 43,000	0.611	900	$ 44,000	0.430	126%	750	$ 43,000	0.525	143%	750	$ 43,000	0.886	145%	900	$ 58,000
14-KeppochRd-C3	Circular	CSP	900	900	60	1.55	0.865	1.641	1200	$ 236,000	2.084	1350	$ 270,000	3.522	1800	$ 318,000	2.489	152%	1350	$ 270,000	3.005	144%	1500	$ 307,000	5.180	147%	1800	$ 409,000
14-SundanceLn-C1	Circular	CSP	450	450	57	1.75	0.175	0.262	600	$ 99,000	0.323	600	$ 99,000	0.536	750	$ 117,000	0.375	143%	750	$ 125,000	0.452	140%	750	$ 125,000	0.766	143%	900	$ 158,000
15-KinlockRd-C1	Circular	CSP	600	600	197	6.14	0.370	0.498	750	$ 403,000	0.616	900	$ 497,000	1.021	1050	$ 522,000	0.715	144%	900	$ 497,000	0.861	140%	900	$ 497,000	1.460	143%	1200	$ 706,000
15-KinlockRd-C2	Circular	PVC	750	750	189	2.31	0.625	0.869	900	$ 477,000	0.987	1050	$ 568,000	1.680	1200	$ 632,000	1.279	147%	1050	$ 568,000	1.398	142%	1050	$ 568,000	2.529	151%	1350	$ 786,000
15-KinlockRd-C3	Circular	PVC	750	750	235	7.22	0.505	1.379	1050	$ 701,000	1.611	1200	$ 834,000	3.096	1500	$ 1,079,000	2.243	163%	1350	$ 968,000	2.843	176%	1500	$ 1,113,000	4.207	136%	1800	$ 1,454,000
15-KinlockRd-C4	Circular	PVC	750	750	29	0.50	0.625	2.064	1350	$ 145,000	2.843	1500	$ 162,000	4.408	1800	$ 186,000	3.385	164%	1500	$ 162,000	3.762	132%	1800	$ 222,000	6.462	147%	2100	$ 266,000
15-KeppochRd-C1	Circular	HDPE	525	525	82	7.41	0.265	0.861	900	$ 218,000	1.063	1050	$ 257,000	1.757	1200	$ 291,000	1.233	143%	1050	$ 257,000	1.483	140%	1200	$ 310,000	2.505	143%	1350	$ 357,000
15-KeppochRd-C2	Circular	CSP	600	600	40	8.63	0.375	0.439	750	$ 91,000	0.543	750	$ 91,000	0.900	900	$ 108,000	0.632	144%	900	$ 117,000	0.761	140%	900	$ 117,000	1.288	143%	1050	$ 136,000
15-KeppochRd-C3	Rectangular	Timber	2400x1500	2141	45	0.09	7.855	6.543	2100	$ -	8.043	2400	$ 469,000	13.588	2700	$ 541,000	9.952	152%	2400	$ 469,000	11.952	149%	2700	$ 556,000	20.350	150%	3300	$ 753,000
15-IsleviewDr-C1	Circular	-	600	600	13	2.00	0.350	0.553	750	$ 38,000	0.686	900	$ 51,000	1.140	1050	$ 55,000	0.797	144%	900	$ 51,000	0.960	140%	1050	$ 58,000	1.625	143%	1200	$ 75,000
16-KennedyRd-C1	Circular	HDPE	450	450	12	3.44	0.175	0.206	600	$ 27,000	0.257	600	$ 27,000	0.436	750	$ 29,000	0.307	149%	600	$ 27,000	0.370	144%	750	$ 36,000	0.643	147%	900	$ 49,000
16-KennedyRd-C2	Circular	CSP	600	600	11	3.67	0.365	1.005	1050	$ 52,000	1.250	1050	$ 52,000	2.105	1350	$ 70,000	1.485	148%	1200	$ 68,000	1.800	144%	1200	$ 68,000	3.098	147%	1500	$ 81,000
16-GeorgetownRd-C1	Circular	CSP	600	600	12	2.62	0.360	0.577	750	$ 36,000	0.718	900	$ 50,000	1.206	1050	$ 54,000	0.849	147%	900	$ 50,000	1.024	143%	1050	$ 55,000	1.754	145%	1200	$ 72,000
16-KeppochRd-C1	Rectangular	Timber	1800x1200	1658	31	0.33	4.085	5.213	1800	$ 232,000	6.423	2100	$ 280,000	10.688	2400	$ 334,000	7.854	151%	2100	$ 280,000	9.420	147%	2400	$ 332,000	15.954	149%	3000	$ 454,000
17-KeppochRd-C1	Circular	CSP	2 - 750	1061	20	2.77	1.090	1.855	1200	$ 97,000	2.304	1350	$ 108,000	3.868	1800	$ 129,000	2.702	146%	1500	$ 120,000	3.267	142%	1500	$ 120,000	5.615	145%	2100	$ 197,000
18-TCH-C1	Circular	CSP	1200	1200	31	0.74	2.005	3.988	1800	$ 237,000	4.820	1800	$ 237,000	7.444	2100	$ 282,000	5.771	145%	2100	$ 285,000	6.724	140%	2100	$ 285,000	10.405	140%	2400	$ 339,000
18-TCH-C2	Circular	-	750	750	31	0.70	0.605	2.322	1350	$ 155,000	2.876	1500	$ 174,000	4.822	1800	$ 209,000	3.517	151%	1800	$ 237,000	4.239	147%	1800	$ 237,000	7.256	150%	2100	$ 285,000
Total Cost										$ 11,748,000			$ 14,505,000			$ 19,301,000				$ 16,513,000				$ 19,073,000				$ 25,881,000
Cost Premium to Accommodate Predicted Changes in Rainfall Intensities										-			-			-				141%				131%				134%
Number of Conduits to be Upgraded										53			60			73				64				69				74

*Current capacity is estimated based on inlet capacity with a depth to diameter ratio of 1

**Upgrade cost esimates are only shown for pipes that require an upgrade



LEGEND:

- MAJOR WATERSHED NAME
- MAJOR WATERSHED BOUNDARY
- MINOR WATERSHED BOUNDARY
- OVERLAND FLOW DIRECTION
- MAJOR FLOW PATH
- TOWN BOUNDARY
- CULVERT NAME
- EXISTING STORAGE VOLUME*

CULVERT CAPACITY FOR 1 IN 100 YEAR STORM**:

- UNDER CAPACITY
- 100% to 250% EXCEEDED
- 251% to 500% EXCEEDED
- OVER 500% EXCEEDED

*FLOODED AREAS ARE SCHEMATIC REPRESENTATION OF EXISTING STORAGE VOLUME UTILIZED

**1 IN 100 YEAR STORM PROJECTIONS BASED ON THE CLIMATE CHANGE MODEL HADCM3 FOR YEAR 2050 – MODEL 1

TOWN OF STRATFORD STORMWATER MANAGEMENT PLAN

RESULTS OF CULVERT CAPACITY ASSESSMENT

CBCL LIMITED
Consulting Engineers
ISO 9001 CERTIFIED

Scale 1:10 000	Date Feb 2012	Drawn JM
Designed AW	Checked AM	Approved EMD
Contract No 092641		Revision
FIGURE 2.2		

DATE: Mar 01, 2012 – 3:53pm CAD OPERATOR: jeffmarvin
DRAWING FILENAME: L:\092641 – Stratford SWMP\092641_FINAL REPORT Culvert_Capacities.dwg LAYOUT NAME: DWG1
LIST OF XREFS:]

APPENDIX B

Design Rainfall Events

CBCL LIMITED
Consulting Engineers

Design Storms for SWMM - Stormnet Assessments - Charlottetown CDA

Historical

1 in 100 year Design Rainfall Event		1 in 10 year Design Rainfall Event		1 in 5 year Design Rainfall Event	
Time (hr:min)	Intensity (mm/hr)	Time (hr:min)	Intensity (mm/hr)	Time (hr:min)	Intensity (mm/hr)
0:00	2.3	0:00	1.7	0:00	1.5
0:05	2.3	0:05	1.7	0:05	1.5
0:10	2.3	0:10	1.7	0:10	1.5
0:15	2.3	0:15	1.7	0:15	1.5
0:20	2.3	0:20	1.7	0:20	1.5
0:25	2.3	0:25	1.7	0:25	1.5
0:30	2.3	0:30	1.7	0:30	1.5
0:35	2.3	0:35	1.7	0:35	1.5
0:40	2.3	0:40	1.7	0:40	1.5
0:45	2.3	0:45	1.7	0:45	1.5
0:50	2.3	0:50	1.7	0:50	1.5
0:55	2.3	0:55	1.7	0:55	1.5
1:00	2.4	1:00	1.7	1:00	1.5
1:05	2.4	1:05	1.7	1:05	1.5
1:10	2.4	1:10	1.7	1:10	1.5
1:15	2.4	1:15	1.7	1:15	1.5
1:20	2.4	1:20	1.7	1:20	1.5
1:25	2.4	1:25	1.7	1:25	1.5
1:30	2.5	1:30	1.8	1:30	1.6
1:35	2.5	1:35	1.8	1:35	1.6
1:40	2.5	1:40	1.8	1:40	1.6
1:45	2.5	1:45	1.8	1:45	1.6
1:50	2.5	1:50	1.8	1:50	1.6
1:55	2.5	1:55	1.8	1:55	1.6
2:00	2.5	2:00	1.8	2:00	1.6
2:05	2.5	2:05	1.8	2:05	1.6
2:10	2.5	2:10	1.8	2:10	1.6
2:15	2.5	2:15	1.8	2:15	1.6
2:20	2.5	2:20	1.8	2:20	1.6
2:25	2.5	2:25	1.8	2:25	1.6
2:30	2.6	2:30	1.9	2:30	1.7
2:35	2.6	2:35	1.9	2:35	1.7
2:40	2.6	2:40	1.9	2:40	1.7
2:45	2.6	2:45	1.9	2:45	1.7

Design Storms Based on HadCM3 - 2050 - Method 1

1 in 100 year Design Rainfall Event		1 in 10 year Design Rainfall Event		1 in 5 year Design Rainfall Event	
Time (hr:min)	Intensity (mm/hr)	Time (hr:min)	Intensity (mm/hr)	Time (hr:min)	Intensity (mm/hr)
0:00	2.9	0:00	2.1	0:00	1.9
0:05	2.9	0:05	2.1	0:05	1.9
0:10	2.9	0:10	2.1	0:10	1.9
0:15	2.9	0:15	2.1	0:15	1.9
0:20	2.9	0:20	2.1	0:20	1.9
0:25	2.9	0:25	2.1	0:25	1.9
0:30	3.0	0:30	2.1	0:30	1.9
0:35	3.0	0:35	2.1	0:35	1.9
0:40	3.0	0:40	2.1	0:40	1.9
0:45	3.0	0:45	2.1	0:45	1.9
0:50	3.0	0:50	2.1	0:50	1.9
0:55	3.0	0:55	2.1	0:55	1.9
1:00	3.1	1:00	2.2	1:00	2.0
1:05	3.1	1:05	2.2	1:05	2.0
1:10	3.1	1:10	2.2	1:10	2.0
1:15	3.1	1:15	2.2	1:15	2.0
1:20	3.1	1:20	2.2	1:20	2.0
1:25	3.1	1:25	2.2	1:25	2.0
1:30	3.2	1:30	2.3	1:30	2.1
1:35	3.2	1:35	2.3	1:35	2.1
1:40	3.2	1:40	2.3	1:40	2.1
1:45	3.2	1:45	2.3	1:45	2.1
1:50	3.2	1:50	2.3	1:50	2.1
1:55	3.2	1:55	2.3	1:55	2.1
2:00	3.3	2:00	2.3	2:00	2.1
2:05	3.3	2:05	2.3	2:05	2.1
2:10	3.3	2:10	2.3	2:10	2.1
2:15	3.3	2:15	2.3	2:15	2.1
2:20	3.3	2:20	2.3	2:20	2.1
2:25	3.3	2:25	2.3	2:25	2.1
2:30	3.4	2:30	2.4	2:30	2.2
2:35	3.4	2:35	2.4	2:35	2.2
2:40	3.4	2:40	2.4	2:40	2.2
2:45	3.4	2:45	2.4	2:45	2.2

Historical

1 in 100 year Design Rainfall Event		1 in 10 year Design Rainfall Event		1 in 5 year Design Rainfall Event	
Time (hr:min)	Intensity (mm/hr)	Time (hr:min)	Intensity (mm/hr)	Time (hr:min)	Intensity (mm/hr)
2:50	2.6	2:50	1.9	2:50	1.7
2:55	2.6	2:55	1.9	2:55	1.7
3:00	2.7	3:00	2.0	3:00	1.7
3:05	2.7	3:05	2.0	3:05	1.7
3:10	2.7	3:10	2.0	3:10	1.7
3:15	2.7	3:15	2.0	3:15	1.7
3:20	2.7	3:20	2.0	3:20	1.7
3:25	2.7	3:25	2.0	3:25	1.7
3:30	2.8	3:30	2.0	3:30	1.8
3:35	2.8	3:35	2.0	3:35	1.8
3:40	2.8	3:40	2.0	3:40	1.8
3:45	2.8	3:45	2.0	3:45	1.8
3:50	2.8	3:50	2.0	3:50	1.8
3:55	2.8	3:55	2.0	3:55	1.8
4:00	2.9	4:00	2.1	4:00	1.9
4:05	2.9	4:05	2.1	4:05	1.9
4:10	2.9	4:10	2.1	4:10	1.9
4:15	2.9	4:15	2.1	4:15	1.9
4:20	2.9	4:20	2.1	4:20	1.9
4:25	2.9	4:25	2.1	4:25	1.9
4:30	3.0	4:30	2.2	4:30	1.9
4:35	3.0	4:35	2.2	4:35	1.9
4:40	3.0	4:40	2.2	4:40	1.9
4:45	3.0	4:45	2.2	4:45	1.9
4:50	3.0	4:50	2.2	4:50	1.9
4:55	3.0	4:55	2.2	4:55	1.9
5:00	3.2	5:00	2.3	5:00	2.0
5:05	3.2	5:05	2.3	5:05	2.0
5:10	3.2	5:10	2.3	5:10	2.0
5:15	3.2	5:15	2.3	5:15	2.0
5:20	3.2	5:20	2.3	5:20	2.0
5:25	3.2	5:25	2.3	5:25	2.0
5:30	3.3	5:30	2.4	5:30	2.1
5:35	3.3	5:35	2.4	5:35	2.1
5:40	3.3	5:40	2.4	5:40	2.1
5:45	3.3	5:45	2.4	5:45	2.1
5:50	3.3	5:50	2.4	5:50	2.1
5:55	3.3	5:55	2.4	5:55	2.1
6:00	3.5	6:00	2.5	6:00	2.2
6:05	3.5	6:05	2.5	6:05	2.2

Design Storms Based on HadCM3 - 2050 - Method 1

1 in 100 year Design Rainfall Event		1 in 10 year Design Rainfall Event		1 in 5 year Design Rainfall Event	
Time (hr:min)	Intensity (mm/hr)	Time (hr:min)	Intensity (mm/hr)	Time (hr:min)	Intensity (mm/hr)
2:50	3.4	2:50	2.4	2:50	2.2
2:55	3.4	2:55	2.4	2:55	2.2
3:00	3.5	3:00	2.5	3:00	2.3
3:05	3.5	3:05	2.5	3:05	2.3
3:10	3.5	3:10	2.5	3:10	2.3
3:15	3.5	3:15	2.5	3:15	2.3
3:20	3.5	3:20	2.5	3:20	2.3
3:25	3.5	3:25	2.5	3:25	2.3
3:30	3.6	3:30	2.6	3:30	2.3
3:35	3.6	3:35	2.6	3:35	2.3
3:40	3.6	3:40	2.6	3:40	2.3
3:45	3.6	3:45	2.6	3:45	2.3
3:50	3.6	3:50	2.6	3:50	2.3
3:55	3.6	3:55	2.6	3:55	2.3
4:00	3.8	4:00	2.7	4:00	2.4
4:05	3.8	4:05	2.7	4:05	2.4
4:10	3.8	4:10	2.7	4:10	2.4
4:15	3.8	4:15	2.7	4:15	2.4
4:20	3.8	4:20	2.7	4:20	2.4
4:25	3.8	4:25	2.7	4:25	2.4
4:30	3.9	4:30	2.8	4:30	2.5
4:35	3.9	4:35	2.8	4:35	2.5
4:40	3.9	4:40	2.8	4:40	2.5
4:45	3.9	4:45	2.8	4:45	2.5
4:50	3.9	4:50	2.8	4:50	2.5
4:55	3.9	4:55	2.8	4:55	2.5
5:00	4.1	5:00	2.9	5:00	2.6
5:05	4.1	5:05	2.9	5:05	2.6
5:10	4.1	5:10	2.9	5:10	2.6
5:15	4.1	5:15	2.9	5:15	2.6
5:20	4.1	5:20	2.9	5:20	2.6
5:25	4.1	5:25	2.9	5:25	2.6
5:30	4.3	5:30	3.0	5:30	2.7
5:35	4.3	5:35	3.0	5:35	2.7
5:40	4.3	5:40	3.0	5:40	2.7
5:45	4.3	5:45	3.0	5:45	2.7
5:50	4.3	5:50	3.0	5:50	2.7
5:55	4.3	5:55	3.0	5:55	2.7
6:00	4.5	6:00	3.2	6:00	2.9
6:05	4.5	6:05	3.2	6:05	2.9

Historical

1 in 100 year Design Rainfall Event		1 in 10 year Design Rainfall Event		1 in 5 year Design Rainfall Event	
Time (hr:min)	Intensity (mm/hr)	Time (hr:min)	Intensity (mm/hr)	Time (hr:min)	Intensity (mm/hr)
6:10	3.5	6:10	2.5	6:10	2.2
6:15	3.5	6:15	2.5	6:15	2.2
6:20	3.5	6:20	2.5	6:20	2.2
6:25	3.5	6:25	2.5	6:25	2.2
6:30	3.7	6:30	2.7	6:30	2.4
6:35	3.7	6:35	2.7	6:35	2.4
6:40	3.7	6:40	2.7	6:40	2.4
6:45	3.7	6:45	2.7	6:45	2.4
6:50	3.7	6:50	2.7	6:50	2.4
6:55	3.7	6:55	2.7	6:55	2.4
7:00	3.9	7:00	2.8	7:00	2.5
7:05	3.9	7:05	2.8	7:05	2.5
7:10	3.9	7:10	2.8	7:10	2.5
7:15	3.9	7:15	2.8	7:15	2.5
7:20	3.9	7:20	2.8	7:20	2.5
7:25	3.9	7:25	2.8	7:25	2.5
7:30	4.2	7:30	3.0	7:30	2.7
7:35	4.2	7:35	3.0	7:35	2.7
7:40	4.2	7:40	3.0	7:40	2.7
7:45	4.2	7:45	3.0	7:45	2.7
7:50	4.2	7:50	3.0	7:50	2.7
7:55	4.2	7:55	3.0	7:55	2.7
8:00	4.5	8:00	3.3	8:00	2.9
8:05	4.5	8:05	3.3	8:05	2.9
8:10	4.5	8:10	3.3	8:10	2.9
8:15	4.5	8:15	3.3	8:15	2.9
8:20	4.5	8:20	3.3	8:20	2.9
8:25	4.5	8:25	3.3	8:25	2.9
8:30	4.9	8:30	3.6	8:30	3.1
8:35	4.9	8:35	3.6	8:35	3.1
8:40	4.9	8:40	3.6	8:40	3.1
8:45	4.9	8:45	3.6	8:45	3.1
8:50	4.9	8:50	3.6	8:50	3.1
8:55	4.9	8:55	3.6	8:55	3.1
9:00	5.5	9:00	3.9	9:00	3.5
9:05	5.5	9:05	3.9	9:05	3.5
9:10	5.5	9:10	3.9	9:10	3.5
9:15	5.5	9:15	3.9	9:15	3.5
9:20	5.5	9:20	3.9	9:20	3.5
9:25	5.5	9:25	3.9	9:25	3.5

Design Storms Based on HadCM3 - 2050 - Method 1

1 in 100 year Design Rainfall Event		1 in 10 year Design Rainfall Event		1 in 5 year Design Rainfall Event	
Time (hr:min)	Intensity (mm/hr)	Time (hr:min)	Intensity (mm/hr)	Time (hr:min)	Intensity (mm/hr)
6:10	4.5	6:10	3.2	6:10	2.9
6:15	4.5	6:15	3.2	6:15	2.9
6:20	4.5	6:20	3.2	6:20	2.9
6:25	4.5	6:25	3.2	6:25	2.9
6:30	4.8	6:30	3.4	6:30	3.0
6:35	4.8	6:35	3.4	6:35	3.0
6:40	4.8	6:40	3.4	6:40	3.0
6:45	4.8	6:45	3.4	6:45	3.0
6:50	4.8	6:50	3.4	6:50	3.0
6:55	4.8	6:55	3.4	6:55	3.0
7:00	5.1	7:00	3.6	7:00	3.2
7:05	5.1	7:05	3.6	7:05	3.2
7:10	5.1	7:10	3.6	7:10	3.2
7:15	5.1	7:15	3.6	7:15	3.2
7:20	5.1	7:20	3.6	7:20	3.2
7:25	5.1	7:25	3.6	7:25	3.2
7:30	5.4	7:30	3.8	7:30	3.5
7:35	5.4	7:35	3.8	7:35	3.5
7:40	5.4	7:40	3.8	7:40	3.5
7:45	5.4	7:45	3.8	7:45	3.5
7:50	5.4	7:50	3.8	7:50	3.5
7:55	5.4	7:55	3.8	7:55	3.5
8:00	5.8	8:00	4.1	8:00	3.7
8:05	5.8	8:05	4.1	8:05	3.7
8:10	5.8	8:10	4.1	8:10	3.7
8:15	5.8	8:15	4.1	8:15	3.7
8:20	5.8	8:20	4.1	8:20	3.7
8:25	5.8	8:25	4.1	8:25	3.7
8:30	6.4	8:30	4.5	8:30	4.0
8:35	6.4	8:35	4.5	8:35	4.0
8:40	6.4	8:40	4.5	8:40	4.0
8:45	6.4	8:45	4.5	8:45	4.0
8:50	6.4	8:50	4.5	8:50	4.0
8:55	6.4	8:55	4.5	8:55	4.0
9:00	7.1	9:00	5.0	9:00	4.5
9:05	7.1	9:05	5.0	9:05	4.5
9:10	7.1	9:10	5.0	9:10	4.5
9:15	7.1	9:15	5.0	9:15	4.5
9:20	7.1	9:20	5.0	9:20	4.5
9:25	7.1	9:25	5.0	9:25	4.5

Historical

1 in 100 year Design Rainfall Event		1 in 10 year Design Rainfall Event		1 in 5 year Design Rainfall Event	
Time (hr:min)	Intensity (mm/hr)	Time (hr:min)	Intensity (mm/hr)	Time (hr:min)	Intensity (mm/hr)
9:30	6.2	9:30	4.4	9:30	3.9
9:35	6.2	9:35	4.4	9:35	3.9
9:40	6.2	9:40	4.4	9:40	3.9
9:45	6.2	9:45	4.4	9:45	3.9
9:50	6.2	9:50	4.4	9:50	3.9
9:55	6.2	9:55	4.4	9:55	3.9
10:00	7.2	10:00	5.1	10:00	4.5
10:05	7.2	10:05	5.1	10:05	4.5
10:10	7.2	10:10	5.1	10:10	4.5
10:15	7.2	10:15	5.1	10:15	4.5
10:20	7.2	10:20	5.1	10:20	4.5
10:25	7.2	10:25	5.1	10:25	4.5
10:30	8.9	10:30	6.3	10:30	5.5
10:35	8.9	10:35	6.3	10:35	5.5
10:40	8.9	10:40	6.3	10:40	5.5
10:45	8.9	10:45	6.3	10:45	5.5
10:50	8.9	10:50	6.3	10:50	5.5
10:55	8.9	10:55	6.3	10:55	5.5
11:00	12.2	11:00	8.7	11:00	7.5
11:05	12.2	11:05	8.7	11:05	7.5
11:10	12.2	11:10	8.7	11:10	7.5
11:15	12.2	11:15	8.7	11:15	7.5
11:20	12.2	11:20	8.7	11:20	7.5
11:25	12.2	11:25	8.7	11:25	7.5
11:30	15.8	11:30	11.1	11:30	9.6
11:35	17.7	11:35	12.4	11:35	10.8
11:40	20.5	11:40	14.3	11:40	12.4
11:45	24.7	11:45	17.2	11:45	14.9
11:50	32.6	11:50	22.6	11:50	19.4
11:55	55.3	11:55	38.0	11:55	32.5
12:00	176.7	12:00	117.1	12:00	98.3
12:05	55.3	12:05	38.0	12:05	32.5
12:10	32.6	12:10	22.6	12:10	19.4
12:15	24.7	12:15	17.2	12:15	14.9
12:20	20.5	12:20	14.3	12:20	12.4
12:25	17.7	12:25	12.4	12:25	10.8
12:30	15.8	12:30	11.1	12:30	9.6
12:35	15.8	12:35	11.1	12:35	9.6
12:40	15.8	12:40	11.1	12:40	9.6
12:45	15.8	12:45	11.1	12:45	9.6

Design Storms Based on HadCM3 - 2050 - Method 1

1 in 100 year Design Rainfall Event		1 in 10 year Design Rainfall Event		1 in 5 year Design Rainfall Event	
Time (hr:min)	Intensity (mm/hr)	Time (hr:min)	Intensity (mm/hr)	Time (hr:min)	Intensity (mm/hr)
9:30	8.0	9:30	5.6	9:30	5.0
9:35	8.0	9:35	5.6	9:35	5.0
9:40	8.0	9:40	5.6	9:40	5.0
9:45	8.0	9:45	5.6	9:45	5.0
9:50	8.0	9:50	5.6	9:50	5.0
9:55	8.0	9:55	5.6	9:55	5.0
10:00	9.3	10:00	6.5	10:00	5.8
10:05	9.3	10:05	6.5	10:05	5.8
10:10	9.3	10:10	6.5	10:10	5.8
10:15	9.3	10:15	6.5	10:15	5.8
10:20	9.3	10:20	6.5	10:20	5.8
10:25	9.3	10:25	6.5	10:25	5.8
10:30	11.5	10:30	8.0	10:30	7.1
10:35	11.5	10:35	8.0	10:35	7.1
10:40	11.5	10:40	8.0	10:40	7.1
10:45	11.5	10:45	8.0	10:45	7.1
10:50	11.5	10:50	8.0	10:50	7.1
10:55	11.5	10:55	8.0	10:55	7.1
11:00	15.8	11:00	11.0	11:00	9.7
11:05	15.8	11:05	11.0	11:05	9.7
11:10	15.8	11:10	11.0	11:10	9.7
11:15	15.8	11:15	11.0	11:15	9.7
11:20	15.8	11:20	11.0	11:20	9.7
11:25	15.8	11:25	11.0	11:25	9.7
11:30	20.4	11:30	14.0	11:30	12.4
11:35	22.9	11:35	15.7	11:35	13.9
11:40	26.4	11:40	18.1	11:40	16.0
11:45	31.9	11:45	21.8	11:45	19.2
11:50	42.1	11:50	28.6	11:50	25.1
11:55	71.5	11:55	48.1	11:55	42.0
12:00	228.3	12:00	148.3	12:00	127.0
12:05	71.5	12:05	48.1	12:05	42.0
12:10	42.1	12:10	28.6	12:10	25.1
12:15	31.9	12:15	21.8	12:15	19.2
12:20	26.4	12:20	18.1	12:20	16.0
12:25	22.9	12:25	15.7	12:25	13.9
12:30	20.4	12:30	14.0	12:30	12.4
12:35	20.4	12:35	14.0	12:35	12.4
12:40	20.4	12:40	14.0	12:40	12.4
12:45	20.4	12:45	14.0	12:45	12.4

Historical

1 in 100 year Design Rainfall Event		1 in 10 year Design Rainfall Event		1 in 5 year Design Rainfall Event	
Time (hr:min)	Intensity (mm/hr)	Time (hr:min)	Intensity (mm/hr)	Time (hr:min)	Intensity (mm/hr)
12:50	15.8	12:50	11.1	12:50	9.6
12:55	15.8	12:55	11.1	12:55	9.6
13:00	12.2	13:00	8.7	13:00	7.5
13:05	12.2	13:05	8.7	13:05	7.5
13:10	12.2	13:10	8.7	13:10	7.5
13:15	12.2	13:15	8.7	13:15	7.5
13:20	12.2	13:20	8.7	13:20	7.5
13:25	12.2	13:25	8.7	13:25	7.5
13:30	8.9	13:30	6.3	13:30	5.5
13:35	8.9	13:35	6.3	13:35	5.5
13:40	8.9	13:40	6.3	13:40	5.5
13:45	8.9	13:45	6.3	13:45	5.5
13:50	8.9	13:50	6.3	13:50	5.5
13:55	8.9	13:55	6.3	13:55	5.5
14:00	7.2	14:00	5.1	14:00	4.5
14:05	7.2	14:05	5.1	14:05	4.5
14:10	7.2	14:10	5.1	14:10	4.5
14:15	7.2	14:15	5.1	14:15	4.5
14:20	7.2	14:20	5.1	14:20	4.5
14:25	7.2	14:25	5.1	14:25	4.5
14:30	6.2	14:30	4.4	14:30	3.9
14:35	6.2	14:35	4.4	14:35	3.9
14:40	6.2	14:40	4.4	14:40	3.9
14:45	6.2	14:45	4.4	14:45	3.9
14:50	6.2	14:50	4.4	14:50	3.9
14:55	6.2	14:55	4.4	14:55	3.9
15:00	5.5	15:00	3.9	15:00	3.5
15:05	5.5	15:05	3.9	15:05	3.5
15:10	5.5	15:10	3.9	15:10	3.5
15:15	5.5	15:15	3.9	15:15	3.5
15:20	5.5	15:20	3.9	15:20	3.5
15:25	5.5	15:25	3.9	15:25	3.5
15:30	4.9	15:30	3.6	15:30	3.1
15:35	4.9	15:35	3.6	15:35	3.1
15:40	4.9	15:40	3.6	15:40	3.1
15:45	4.9	15:45	3.6	15:45	3.1
15:50	4.9	15:50	3.6	15:50	3.1
15:55	4.9	15:55	3.6	15:55	3.1
16:00	4.5	16:00	3.3	16:00	2.9
16:05	4.5	16:05	3.3	16:05	2.9

Design Storms Based on HadCM3 - 2050 - Method 1

1 in 100 year Design Rainfall Event		1 in 10 year Design Rainfall Event		1 in 5 year Design Rainfall Event	
Time (hr:min)	Intensity (mm/hr)	Time (hr:min)	Intensity (mm/hr)	Time (hr:min)	Intensity (mm/hr)
12:50	20.4	12:50	14.0	12:50	12.4
12:55	20.4	12:55	14.0	12:55	12.4
13:00	15.8	13:00	11.0	13:00	9.7
13:05	15.8	13:05	11.0	13:05	9.7
13:10	15.8	13:10	11.0	13:10	9.7
13:15	15.8	13:15	11.0	13:15	9.7
13:20	15.8	13:20	11.0	13:20	9.7
13:25	15.8	13:25	11.0	13:25	9.7
13:30	11.5	13:30	8.0	13:30	7.1
13:35	11.5	13:35	8.0	13:35	7.1
13:40	11.5	13:40	8.0	13:40	7.1
13:45	11.5	13:45	8.0	13:45	7.1
13:50	11.5	13:50	8.0	13:50	7.1
13:55	11.5	13:55	8.0	13:55	7.1
14:00	9.3	14:00	6.5	14:00	5.8
14:05	9.3	14:05	6.5	14:05	5.8
14:10	9.3	14:10	6.5	14:10	5.8
14:15	9.3	14:15	6.5	14:15	5.8
14:20	9.3	14:20	6.5	14:20	5.8
14:25	9.3	14:25	6.5	14:25	5.8
14:30	8.0	14:30	5.6	14:30	5.0
14:35	8.0	14:35	5.6	14:35	5.0
14:40	8.0	14:40	5.6	14:40	5.0
14:45	8.0	14:45	5.6	14:45	5.0
14:50	8.0	14:50	5.6	14:50	5.0
14:55	8.0	14:55	5.6	14:55	5.0
15:00	7.1	15:00	5.0	15:00	4.5
15:05	7.1	15:05	5.0	15:05	4.5
15:10	7.1	15:10	5.0	15:10	4.5
15:15	7.1	15:15	5.0	15:15	4.5
15:20	7.1	15:20	5.0	15:20	4.5
15:25	7.1	15:25	5.0	15:25	4.5
15:30	6.4	15:30	4.5	15:30	4.0
15:35	6.4	15:35	4.5	15:35	4.0
15:40	6.4	15:40	4.5	15:40	4.0
15:45	6.4	15:45	4.5	15:45	4.0
15:50	6.4	15:50	4.5	15:50	4.0
15:55	6.4	15:55	4.5	15:55	4.0
16:00	5.8	16:00	4.1	16:00	3.7
16:05	5.8	16:05	4.1	16:05	3.7

Historical

1 in 100 year Design Rainfall Event		1 in 10 year Design Rainfall Event		1 in 5 year Design Rainfall Event	
Time (hr:min)	Intensity (mm/hr)	Time (hr:min)	Intensity (mm/hr)	Time (hr:min)	Intensity (mm/hr)
16:10	4.5	16:10	3.3	16:10	2.9
16:15	4.5	16:15	3.3	16:15	2.9
16:20	4.5	16:20	3.3	16:20	2.9
16:25	4.5	16:25	3.3	16:25	2.9
16:30	4.2	16:30	3.0	16:30	2.7
16:35	4.2	16:35	3.0	16:35	2.7
16:40	4.2	16:40	3.0	16:40	2.7
16:45	4.2	16:45	3.0	16:45	2.7
16:50	4.2	16:50	3.0	16:50	2.7
16:55	4.2	16:55	3.0	16:55	2.7
17:00	3.9	17:00	2.8	17:00	2.5
17:05	3.9	17:05	2.8	17:05	2.5
17:10	3.9	17:10	2.8	17:10	2.5
17:15	3.9	17:15	2.8	17:15	2.5
17:20	3.9	17:20	2.8	17:20	2.5
17:25	3.9	17:25	2.8	17:25	2.5
17:30	3.7	17:30	2.7	17:30	2.4
17:35	3.7	17:35	2.7	17:35	2.4
17:40	3.7	17:40	2.7	17:40	2.4
17:45	3.7	17:45	2.7	17:45	2.4
17:50	3.7	17:50	2.7	17:50	2.4
17:55	3.7	17:55	2.7	17:55	2.4
18:00	3.5	18:00	2.5	18:00	2.2
18:05	3.5	18:05	2.5	18:05	2.2
18:10	3.5	18:10	2.5	18:10	2.2
18:15	3.5	18:15	2.5	18:15	2.2
18:20	3.5	18:20	2.5	18:20	2.2
18:25	3.5	18:25	2.5	18:25	2.2
18:30	3.3	18:30	2.4	18:30	2.1
18:35	3.3	18:35	2.4	18:35	2.1
18:40	3.3	18:40	2.4	18:40	2.1
18:45	3.3	18:45	2.4	18:45	2.1
18:50	3.3	18:50	2.4	18:50	2.1
18:55	3.3	18:55	2.4	18:55	2.1
19:00	3.2	19:00	2.3	19:00	2.0
19:05	3.2	19:05	2.3	19:05	2.0
19:10	3.2	19:10	2.3	19:10	2.0
19:15	3.2	19:15	2.3	19:15	2.0
19:20	3.2	19:20	2.3	19:20	2.0
19:25	3.2	19:25	2.3	19:25	2.0

Design Storms Based on HadCM3 - 2050 - Method 1

1 in 100 year Design Rainfall Event		1 in 10 year Design Rainfall Event		1 in 5 year Design Rainfall Event	
Time (hr:min)	Intensity (mm/hr)	Time (hr:min)	Intensity (mm/hr)	Time (hr:min)	Intensity (mm/hr)
16:10	5.8	16:10	4.1	16:10	3.7
16:15	5.8	16:15	4.1	16:15	3.7
16:20	5.8	16:20	4.1	16:20	3.7
16:25	5.8	16:25	4.1	16:25	3.7
16:30	5.4	16:30	3.8	16:30	3.5
16:35	5.4	16:35	3.8	16:35	3.5
16:40	5.4	16:40	3.8	16:40	3.5
16:45	5.4	16:45	3.8	16:45	3.5
16:50	5.4	16:50	3.8	16:50	3.5
16:55	5.4	16:55	3.8	16:55	3.5
17:00	5.1	17:00	3.6	17:00	3.2
17:05	5.1	17:05	3.6	17:05	3.2
17:10	5.1	17:10	3.6	17:10	3.2
17:15	5.1	17:15	3.6	17:15	3.2
17:20	5.1	17:20	3.6	17:20	3.2
17:25	5.1	17:25	3.6	17:25	3.2
17:30	4.8	17:30	3.4	17:30	3.0
17:35	4.8	17:35	3.4	17:35	3.0
17:40	4.8	17:40	3.4	17:40	3.0
17:45	4.8	17:45	3.4	17:45	3.0
17:50	4.8	17:50	3.4	17:50	3.0
17:55	4.8	17:55	3.4	17:55	3.0
18:00	4.5	18:00	3.2	18:00	2.9
18:05	4.5	18:05	3.2	18:05	2.9
18:10	4.5	18:10	3.2	18:10	2.9
18:15	4.5	18:15	3.2	18:15	2.9
18:20	4.5	18:20	3.2	18:20	2.9
18:25	4.5	18:25	3.2	18:25	2.9
18:30	4.3	18:30	3.0	18:30	2.7
18:35	4.3	18:35	3.0	18:35	2.7
18:40	4.3	18:40	3.0	18:40	2.7
18:45	4.3	18:45	3.0	18:45	2.7
18:50	4.3	18:50	3.0	18:50	2.7
18:55	4.3	18:55	3.0	18:55	2.7
19:00	4.1	19:00	2.9	19:00	2.6
19:05	4.1	19:05	2.9	19:05	2.6
19:10	4.1	19:10	2.9	19:10	2.6
19:15	4.1	19:15	2.9	19:15	2.6
19:20	4.1	19:20	2.9	19:20	2.6
19:25	4.1	19:25	2.9	19:25	2.6

Historical

1 in 100 year Design Rainfall Event		1 in 10 year Design Rainfall Event		1 in 5 year Design Rainfall Event	
Time (hr:min)	Intensity (mm/hr)	Time (hr:min)	Intensity (mm/hr)	Time (hr:min)	Intensity (mm/hr)
19:30	3.0	19:30	2.2	19:30	1.9
19:35	3.0	19:35	2.2	19:35	1.9
19:40	3.0	19:40	2.2	19:40	1.9
19:45	3.0	19:45	2.2	19:45	1.9
19:50	3.0	19:50	2.2	19:50	1.9
19:55	3.0	19:55	2.2	19:55	1.9
20:00	2.9	20:00	2.1	20:00	1.9
20:05	2.9	20:05	2.1	20:05	1.9
20:10	2.9	20:10	2.1	20:10	1.9
20:15	2.9	20:15	2.1	20:15	1.9
20:20	2.9	20:20	2.1	20:20	1.9
20:25	2.9	20:25	2.1	20:25	1.9
20:30	2.8	20:30	2.0	20:30	1.8
20:35	2.8	20:35	2.0	20:35	1.8
20:40	2.8	20:40	2.0	20:40	1.8
20:45	2.8	20:45	2.0	20:45	1.8
20:50	2.8	20:50	2.0	20:50	1.8
20:55	2.8	20:55	2.0	20:55	1.8
21:00	2.7	21:00	2.0	21:00	1.7
21:05	2.7	21:05	2.0	21:05	1.7
21:10	2.7	21:10	2.0	21:10	1.7
21:15	2.7	21:15	2.0	21:15	1.7
21:20	2.7	21:20	2.0	21:20	1.7
21:25	2.7	21:25	2.0	21:25	1.7
21:30	2.6	21:30	1.9	21:30	1.7
21:35	2.6	21:35	1.9	21:35	1.7
21:40	2.6	21:40	1.9	21:40	1.7
21:45	2.6	21:45	1.9	21:45	1.7
21:50	2.6	21:50	1.9	21:50	1.7
21:55	2.6	21:55	1.9	21:55	1.7
22:00	2.5	22:00	1.8	22:00	1.6
22:05	2.5	22:05	1.8	22:05	1.6
22:10	2.5	22:10	1.8	22:10	1.6
22:15	2.5	22:15	1.8	22:15	1.6
22:20	2.5	22:20	1.8	22:20	1.6
22:25	2.5	22:25	1.8	22:25	1.6
22:30	2.5	22:30	1.8	22:30	1.6
22:35	2.5	22:35	1.8	22:35	1.6
22:40	2.5	22:40	1.8	22:40	1.6
22:45	2.5	22:45	1.8	22:45	1.6

Design Storms Based on HadCM3 - 2050 - Method 1

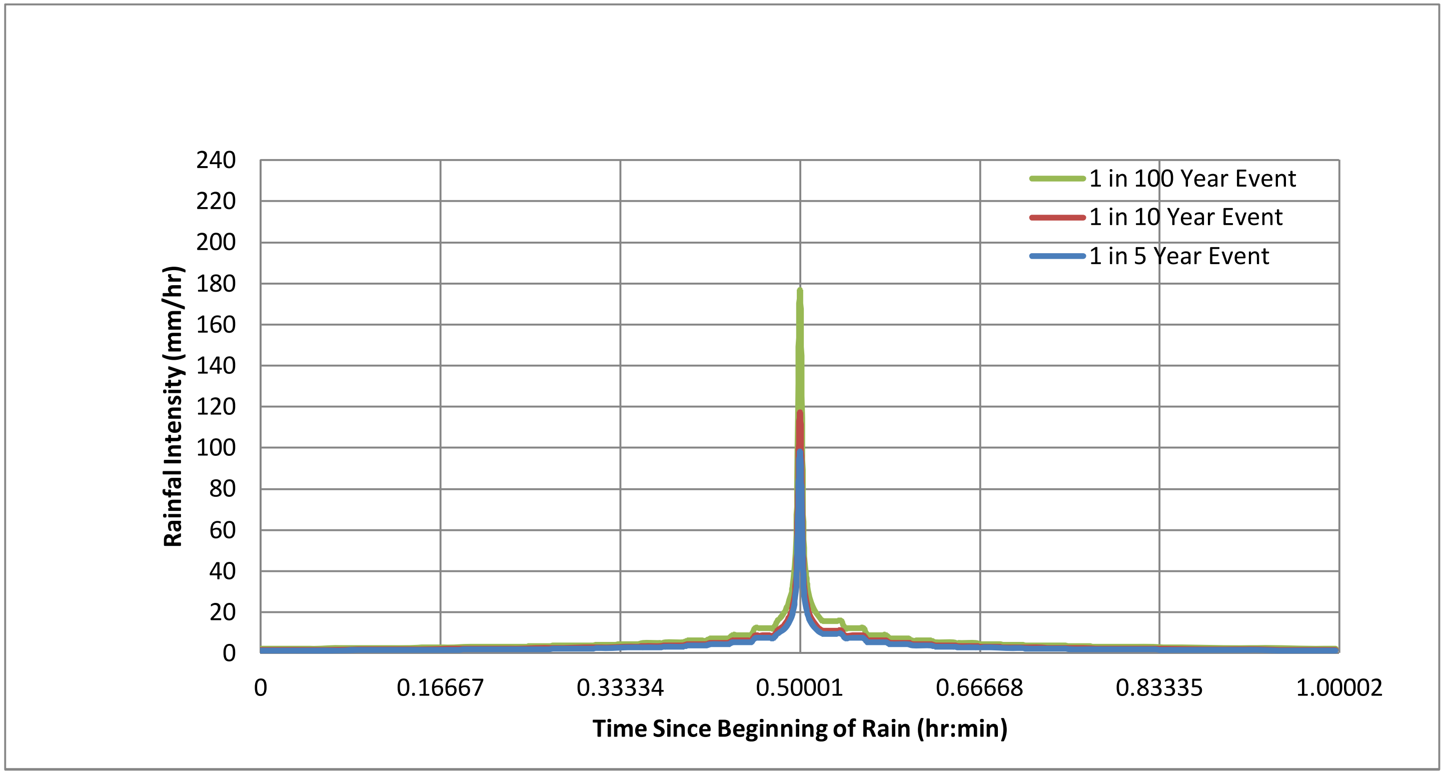
1 in 100 year Design Rainfall Event		1 in 10 year Design Rainfall Event		1 in 5 year Design Rainfall Event	
Time (hr:min)	Intensity (mm/hr)	Time (hr:min)	Intensity (mm/hr)	Time (hr:min)	Intensity (mm/hr)
19:30	3.9	19:30	2.8	19:30	2.5
19:35	3.9	19:35	2.8	19:35	2.5
19:40	3.9	19:40	2.8	19:40	2.5
19:45	3.9	19:45	2.8	19:45	2.5
19:50	3.9	19:50	2.8	19:50	2.5
19:55	3.9	19:55	2.8	19:55	2.5
20:00	3.8	20:00	2.7	20:00	2.4
20:05	3.8	20:05	2.7	20:05	2.4
20:10	3.8	20:10	2.7	20:10	2.4
20:15	3.8	20:15	2.7	20:15	2.4
20:20	3.8	20:20	2.7	20:20	2.4
20:25	3.8	20:25	2.7	20:25	2.4
20:30	3.6	20:30	2.6	20:30	2.3
20:35	3.6	20:35	2.6	20:35	2.3
20:40	3.6	20:40	2.6	20:40	2.3
20:45	3.6	20:45	2.6	20:45	2.3
20:50	3.6	20:50	2.6	20:50	2.3
20:55	3.6	20:55	2.6	20:55	2.3
21:00	3.5	21:00	2.5	21:00	2.3
21:05	3.5	21:05	2.5	21:05	2.3
21:10	3.5	21:10	2.5	21:10	2.3
21:15	3.5	21:15	2.5	21:15	2.3
21:20	3.5	21:20	2.5	21:20	2.3
21:25	3.5	21:25	2.5	21:25	2.3
21:30	3.4	21:30	2.4	21:30	2.2
21:35	3.4	21:35	2.4	21:35	2.2
21:40	3.4	21:40	2.4	21:40	2.2
21:45	3.4	21:45	2.4	21:45	2.2
21:50	3.4	21:50	2.4	21:50	2.2
21:55	3.4	21:55	2.4	21:55	2.2
22:00	3.3	22:00	2.3	22:00	2.1
22:05	3.3	22:05	2.3	22:05	2.1
22:10	3.3	22:10	2.3	22:10	2.1
22:15	3.3	22:15	2.3	22:15	2.1
22:20	3.3	22:20	2.3	22:20	2.1
22:25	3.3	22:25	2.3	22:25	2.1
22:30	3.2	22:30	2.3	22:30	2.1
22:35	3.2	22:35	2.3	22:35	2.1
22:40	3.2	22:40	2.3	22:40	2.1
22:45	3.2	22:45	2.3	22:45	2.1

Historical

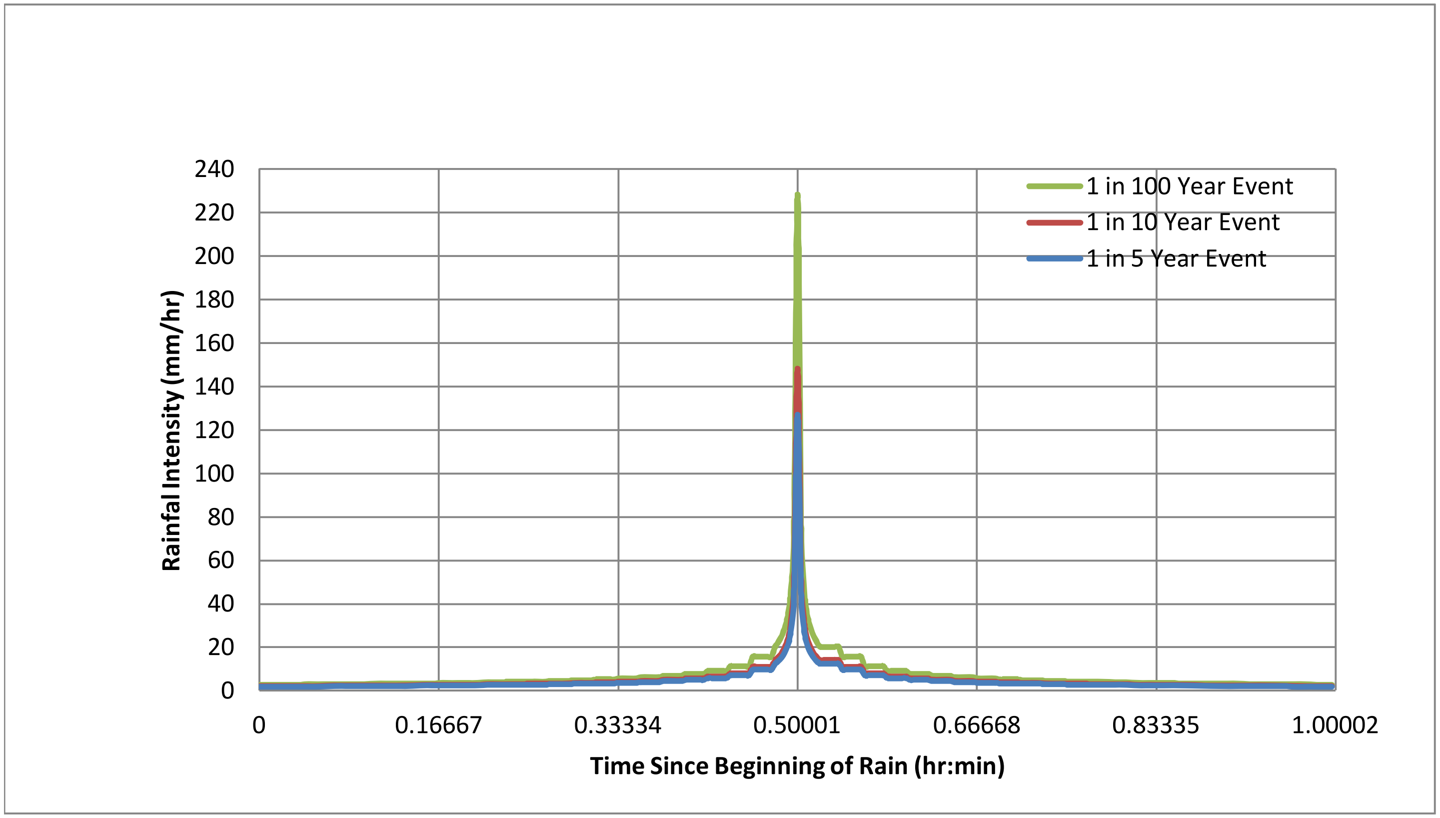
1 in 100 year Design Rainfall Event		1 in 10 year Design Rainfall Event		1 in 5 year Design Rainfall Event	
Time (hr:min)	Intensity (mm/hr)	Time (hr:min)	Intensity (mm/hr)	Time (hr:min)	Intensity (mm/hr)
22:50	2.5	22:50	1.8	22:50	1.6
22:55	2.5	22:55	1.8	22:55	1.6
23:00	2.4	23:00	1.7	23:00	1.5
23:05	2.4	23:05	1.7	23:05	1.5
23:10	2.4	23:10	1.7	23:10	1.5
23:15	2.4	23:15	1.7	23:15	1.5
23:20	2.4	23:20	1.7	23:20	1.5
23:25	2.4	23:25	1.7	23:25	1.5
23:30	2.3	23:30	1.7	23:30	1.5
23:35	2.3	23:35	1.7	23:35	1.5
23:40	2.3	23:40	1.7	23:40	1.5
23:45	2.3	23:45	1.7	23:45	1.5
23:50	2.3	23:50	1.7	23:50	1.5
23:55	2.3	23:55	1.7	23:55	1.5

Design Storms Based on HadCM3 - 2050 - Method 1

1 in 100 year Design Rainfall Event		1 in 10 year Design Rainfall Event		1 in 5 year Design Rainfall Event	
Time (hr:min)	Intensity (mm/hr)	Time (hr:min)	Intensity (mm/hr)	Time (hr:min)	Intensity (mm/hr)
22:50	3.2	22:50	2.3	22:50	2.1
22:55	3.2	22:55	2.3	22:55	2.1
23:00	3.1	23:00	2.2	23:00	2.0
23:05	3.1	23:05	2.2	23:05	2.0
23:10	3.1	23:10	2.2	23:10	2.0
23:15	3.1	23:15	2.2	23:15	2.0
23:20	3.1	23:20	2.2	23:20	2.0
23:25	3.1	23:25	2.2	23:25	2.0
23:30	3.0	23:30	2.1	23:30	1.9
23:35	3.0	23:35	2.1	23:35	1.9
23:40	3.0	23:40	2.1	23:40	1.9
23:45	3.0	23:45	2.1	23:45	1.9
23:50	3.0	23:50	2.1	23:50	1.9
23:55	3.0	23:55	2.1	23:55	1.9



Design Rainfall Events Based on Historical Rainfall Records for Charlottetown CDA 24 Year Record



Design Rainfall Events Based on HadCM3 Model Predicted Rainfall for Year 2050 - Method 1: Ratio of Sub-daily Rainfall Intensities to 24 Hour Intensity to Match Ratios Derived from Historical Records

APPENDIX C

Summary Fact Sheets for Stormwater BMPs in Stratford

CBCL LIMITED
Consulting Engineers

Appendix C Summary Fact Sheets for Stormwater BMPs in Stratford

No.	BMP	Description	Applicability	Design Guidelines
1	Swales	A vegetated, open-channel designed to convey and attenuate stormwater runoff as well as promote infiltration where applicable. As stormwater runoff flows along these channels, it is treated through vegetation slowing the water to allow sedimentation, filtering through a subsoil matrix, and infiltration into the underlying soils. When the longitudinal slope is low, water may be retained in areas where infiltration is minimal, a perforated pipe and sand underdrain is required in these conditions.	Grassed swales are well suited for treating highway, residential road and parking lot runoff or as a drainage system between properties. Swales that promote infiltration are not recommended on the upslope side of roadways without underdrains. Swales are also useful as one of a series of stormwater BMPs such as conveying water to a detention pond and receiving water from filter strips.	Maximum depth: 0.6 metres Minimum bottom width: 0.6 metres Maximum side slope: 4 Horizontal: 1 Vertical Grass lined, c/w underdrain where slope is less than 0.2%
2	Wet Ponds	Wet ponds are constructed basins that have a permanent pool of water throughout the year (or at least throughout the wet season). Ponds treat incoming stormwater runoff by allowing particles to settle and algae to take up nutrients. The primary removal mechanism is settling as stormwater runoff resides in this pool, and pollutant uptake, particularly of nutrients, also occurs through biological activity in the pond.	Wet ponds are widely applicable where space is available.	Maximum water depth: permanent pool 1 metre, detention storage: 1.5 metres Water surface area of permanent pool shall be 1% of drainage area. Side slopes: inside minimum 4:1, outside 3:1; Minimum length : width ratio = 1.5:1 Two water quality outlets: 1) Reverse slope pipe (no orifice less than 100 mm) 2) Weir outlet with trash rack See Table 4.4.1 for recommended detention volume in each watershed. Sediment forbay required, 10% of overall volume
3	Dry Detention Ponds	Dry detention ponds are basins with outlets designed to detain stormwater runoff to provide flood control. Co-use with other land uses such as playing fields are encouraged with proper warnings to users, including signage.	Dry detention ponds require a large amount of space to build them. In many instances, smaller-sized best management practices are more appropriate alternatives (see Grassed Swales, Infiltration Basin, Infiltration Trench, Porous Pavement, and Bioretention (Rain Gardens), Alternative Pavers, or Green Roofs.	Side slopes: inside maximum 4:1, outside maximum 3:1; requires supporting geotechnical report. Sediment forbay required, 10% of overall volume Maximum water depth: 1.5 metres, 0.5 metres for 1 in 100 year event in co-use applications Two outlets are required: 1) Reverse slope pipe (no orifice less than 100 mm), 2) Weir outlet with trash rack

No.	BMP	Description	Applicability	Design Guidelines
				Two outlets are required: 1) Reverse slope pipe (no orifice less than 100 mm), 2) Weir outlet with trash rack
				See Table 4.1.1 for recommended detention volume in each watershed.
4	Constructed Wetland	Constructed stormwater wetlands are similar to wet ponds that incorporate wetland plants into the design. As stormwater runoff flows through the wetland, pollutant removal is achieved through settling and biological uptake. Wetlands are among the most effective stormwater practices in terms of pollutant removal and they also offer aesthetic and habitat value. Although natural wetlands can sometimes be used to treat stormwater runoff that has been properly pretreated, stormwater wetlands are fundamentally different from natural wetland systems. Stormwater wetlands are designed specifically for the purpose of treating stormwater runoff. Wetlands should include zones of both very shallow (<150 millimetres) and moderately shallow (<450 millimetres) water, using underwater earth berms to create the zones.	Constructed wetlands are widely applicable stormwater management practices. Space restrictions must be considered as well as potential nuisances such as mosquitoes.	Water surface area of wetland shall be 1% of drainage area.
			A distinction should be made between using a constructed wetland for stormwater management and diverting stormwater into a natural wetland. The latter practice is not recommended because altering the hydrology of the existing wetland with additional stormwater can degrade the resource and result in plant die-off and the destruction of wildlife habitat. In all circumstances, natural wetlands should be protected from the adverse effects of development, including impacts from increased stormwater runoff. This is especially important because natural wetlands provide stormwater and flood control benefits on a regional scale.	Maximum normal water depth in wet pond: 1.0 metres. Maximum water depth during wet weather: 1.5 metres
				Elevation drop from the inlet to the outlet should be 1 to 1.5 metres.
				Shall be designed with multiple cells, with a berm or weir separating each cell
				Two water quality outlets are required per cell: 1) Reverse slope pipe (no orifice less than 100 mm) 2) Weir outlet with trash rack
5	Parking Lot Storage	Underground storm water retention/detention systems capture and store runoff in large pipes or other subsurface structures. Storm water enters the system through a riser pipe connected to a catch basin or curb inlet and flows into a series of chambers or compartments for storage. Captured runoff is retained throughout the storm event, and then released back to the storm drainage system through an outlet pipe. Outlet pipes are sized to release stored runoff at pre- development flow rates.	Underground retention/detention systems are primarily used where land cost and/or availability are major concerns. Most systems are built under parking lots or other paved surfaces in commercial, industrial, and residential areas. Some pretreatment such as sediment traps or filter strips as well as oil -water separators are recommended to reduce sediment accumulation in the underground chambers.	Structural design must consider potential loads
				Access to each section should be provided for maintenance.

No.	BMP	Description	Applicability	Design Guidelines
		Parking lots may be graded to allow surface storage in a parking lot. The selected area drains to a single catch basin with an outlet control device to regulate the discharge. Signage, alerting drivers to avoid the low areas during rainfall events is recommended.	Remote areas of a parking lot or in a parking overflow area.	Access to each section should be provided for maintenance.
6	Bioretention (rain gardens, green roof)	Bioretention areas, or rain gardens, are landscaping features adapted to provide on-site treatment of stormwater runoff. They are commonly located in parking lot islands or within small pockets of residential land uses. Surface runoff is directed into shallow, landscaped depressions. These depressions are designed to incorporate many of the pollutant removal mechanisms that operate in forested ecosystems. During storms, runoff ponds above the mulch and soil in the system. Runoff from larger storms is generally diverted past the facility to the storm drain system. The remaining runoff filters through the mulch and prepared soil mix. The filtered runoff is then collected in a perforated underdrain and returned to the storm drain system or may infiltrate to groundwater where soil conditions allow (see infiltration basins and trenches).	Bioretention systems are generally applied to small sites (2 hectares or less) and in a highly urbanized setting.	Should usually be used on small sites (i.e., 2 hectares or less) with slopes less than 5%, size should be 10% of impervious area. Bottom must be a minimum of 0.6 metres above groundwater table, requires geotechnical report to establish groundwater table to be considered as treatment of runoff. The bioretention area should be planted with salt-tolerant, non-woody plant species.
7	Vegetated filter strips	Vegetated filter strips are vegetated surfaces that are designed to treat sheet flow from adjacent surfaces. Filter strips function by slowing runoff velocities and filtering out sediment and other pollutants, and by providing some infiltration into underlying soils. Filter strips were originally used as an agricultural treatment practice, and have more recently evolved into an urban practice. With proper design and maintenance, filter strips can provide relatively high pollutant removal. One challenge associated with filter strips, however, is that it is difficult to maintain sheet flow, so the practice may be "short circuited" by concentrated flows, receiving little or no treatment.	Filter strips are best suited to treating runoff from roads and highways, roof downspouts, very small parking lots, and pervious surfaces. They are also ideal components of the "outer zone" of a stream buffer, or as pretreatment to other practices.	One hectare of impervious surface requires a minimum of 440 metres of filter strip for treatment of runoff. Cross slopes between 2 and 6 percent, a pea gravel diaphragm should be used at the top of the slope, a pervious berm of sand and gravel at the toe of the slope. At least 6 metres from top of slope to bottom of slope to provide water quality treatment. Vegetation in the filter strip should be salt-tolerant.

No.	BMP	Description	Applicability	Design Guidelines
8	Infiltration Basins and Trenches	An infiltration basin is a shallow impoundment which is designed to infiltrate stormwater into the soil. This practice is believed to have a high pollutant removal efficiency and can also help recharge the ground water, thus increasing baseflow to stream systems. Infiltration basins can be challenging to apply on many sites, however, because of soils requirements. In addition, some studies have shown relatively high failure rates compared with other management practices.	Infiltration basins and trenches are to be selectively used with "clean runoff", from roof drainage etc. and from relatively small sites such as single family residences, tributary areas less than 2 hectares. They are not applicable within 20 metres of road rights of way.	The bottom of infiltration basins need to be completely flat and located a minimum of 06. metres above the seasonal high groundwater table elevation, requires a geotechnical report to establish this elevation.
		An infiltration trench is a rock-filled trench with no outlet that receives stormwater runoff. Stormwater runoff passes through some combination of pretreatment measures, such as a swale and detention basin, and into the trench. There, runoff is stored in the void space between the stones and infiltrates through the bottom and into the soil matrix. The primary pollutant removal mechanism of this practice is filtering through the soil.	Soil infiltration rates should be 12 to 75 millimetres per hour. Soils should have less than 20 percent clay content, and less than 40 percent silt/clay content.	Minimum infiltration trench width: 1 metre Systems must be capable of draining in 24 hours.
9	Permeable pavements	Porous asphalt, also known as pervious, permeable, "popcorn," or open-graded asphalt, is standard hot-mix asphalt with reduced sand or fines and allows water to drain through it. Porous asphalt is place over a crushed stone aggregate bedding layer and base that supports the asphalt while providing storage and runoff treatment.	Porous asphalt can be used for municipal applications as well as for private development applications. Pervious pavements can replace traditional impervious pavement for most pedestrian and vehicular applications. It performs well in pedestrian walkways, sidewalks, driveways, parking lots, and low-volume roadways.	Minimum air voids: 16% Do not use sand for snow or ice treatment. Use salt in moderation. Subsurface components: top layer, base layer and sub-base all over an uncompacted subgrade. Requires geotechnical design to provide structural support as well as storage in the voids of the aggregate.
		Permeable interlocking concrete pavement (PICP) consists of manufactured concrete units in place of the porous asphalt The impervious units are designed with small openings between permeable joints. The openings typically comprise 5% to 15% of the paver surface area and are filled with highly permeable, small-sized aggregates. The joints allow stormwater to enter the crushed stone aggregate bedding layer and base that supports the pavers while providing storage and runoff treatment. PICPs	PICP can replace traditional impervious pavement for most pedestrian and vehicular applications except high-volume/high-speed roadways. In addition to providing stormwater volume and quality management, light colored pavers are cooler than conventional asphalt and help to reduce urban temperatures and improve air quality. The textured surface of PICP also provides traffic calming and provides an aesthetic amenity.	The concrete pavers with permeable joint material comprise the surface layer.

No.	BMP	Description	Applicability	Design Guidelines
		are highly attractive, durable, easily repaired, require low maintenance, and can withstand heavy vehicle loads.		
			PICP should not be confused with concrete grid pavements (i.e., concrete units with cells that typically contain topsoil and grass). These paving units can infiltrate water, but at rates lower than PICP. Unlike PICP, concrete grid pavements are generally not designed with an open graded, crushed stone base for water storage. Moreover, grids are for intermittently trafficked areas such as overflow parking areas and emergency fire lanes.	Pavers are typically 80 mm (3 1/8 in.) thick for vehicular areas.
10	Oil – grit separators	Water quality inlets (WQIs), also commonly called oil/grit separators or oil/water separators, consist of a series of chambers that promote sedimentation of coarse materials and separation of free oil (as opposed to emulsified or dissolved oil) from storm water. Most WQIs also contain screens to help retain larger or floating debris, and many of the newer designs also include a coalescing unit that helps to promote oil/water separation. WQIs typically capture only the first portion of runoff for treatment and are generally used for pretreatment before discharging to other best management practices (BMPs). The addition of a coalescing unit to the WQI can dramatically increase its effectiveness in oil/water separation while also greatly reducing the size of the required unit. Coalescing units are made from oil-attracting materials, such as polypropylene or other materials. These units attract small oil droplets, which begin to concentrate until they are large enough to float to the surface and separate from the storm water. Without these units, the oil and grease particles must concentrate and separate naturally. This requires a much larger surface area; and therefore, units that do not use the coalescing process must be larger than units utilizing a coalescing unit.	WQIs are often used where land requirements and cost prohibit the use of larger BMP devices, such as ponds or wetlands. Because of their ability to remove hydrocarbons, WQIs are typically located at sites with automotive related contamination or at other sites that generate high hydrocarbon concentrations. For example, small, highly impervious areas, such as gas stations, loading areas, or parking areas. Many WQIs, particularly those installed at industrial sites, serve the dual purpose of treating storm water runoff from contaminated areas, and serving as collection and treatment units for washdown processes or petroleum spills. Higher residual hydrocarbon concentrations in trapped sediments cause maintenance and residual disposal costs associated with WQIs to be higher than those of other BMPs. Therefore, planners should carefully evaluate maintenance and residual disposal issues for the site before selecting a WQI. Possible alternatives to the WQI include sand filters, oil absorbent materials, and other innovative BMPs.	Drainage area of less than 0.5 hectares. Any construction activities within the drainage area should be completed before installation of the WQI, and the drainage area should be revegetated so that the sediment loading to the WQI is minimized. WQIs are designed to handle the first 12 millimetres of runoff from the drainage areas. Each chamber requires a separate manhole to provide access for cleaning and inspection The combined volume of the first and second chambers should be determined based on 1.1 cubic meters (40 cubic feet) per 0.04 hectares (0.10 acres) draining to the WQI. The first and second chambers require permanent pools with depths of 1.2 metres. These chambers are connected by an opening covered by a trash rack, a PVC pipe, or other suitable material pipe. The second and third chambers are connected by an inverted elbow that should extend a minimum of 1 metre into the second chamber's permanent pool.

Note: For a complete description of each of the listed BMPs, and others, see the references listed in section 4.2.3.