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City of Cambridge
Stormwater Management Master Plan

Final

August 2011

CITY OF CAMBRIDGE

STORMWATER MANAGEMENT MASTER PLAN

FINAL

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Cambridge, Ontario

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EXECUTIVE SUMMARY

Introduction

In recent years, the City of Cambridge, as well as many other southern Ontario urban centres, have been impacted by extreme storm events, leading to considerable flood and erosion damage. City of Cambridge Council and Senior Management have recognized the need for an integrated process to develop and implement capital programs to address the City's important drainage infrastructure needs in a co-ordinated and effective manner. It has been recognized that in the absence of an integrated and balanced plan, City staff would struggle to meet the important drainage needs of residents and businesses.

The City of Cambridge initiated the preparation of a City-wide Stormwater Management Master Plan, to evaluate existing infrastructure and policies, identify drainage system deficiencies, and develop an implementation plan, including capital planning estimates and potential funding mechanisms for a long-term sustainable program, including policy to manage stormwater in Cambridge. Specific components of this study have consisted of the following:

- Analysis of trunk storm sewers and associated major (overland) flow paths to identify deficiencies, infrastructure needs, and cost estimates including prioritization for remediation.
- Development of Maintenance Program for drainage infrastructure.
- Stormwater quality management program for future infill and redevelopment areas as related to the City's Growth Management Strategy.
- Assessment of City-owned bridges and culverts to identify capacity deficiencies and establish priorities for remediation.

Project Process

The Stormwater Management Master Plan has been prepared in accordance with the Municipal Engineers Association Class Environmental Assessment (Class EA) procedures. The Master Plan has adopted Approach #1 in the 2007 MEA Documentation, which addresses Phase 1 (identify the problem or opportunity) and Phase 2 (identify alternative solutions and establish the preferred solution) of the Class EA process. The Class EA process states that subsequent projects (which are identified as Schedule B) when advanced in accordance with the recommendations provided in this Master Plan, may proceed directly to the *Notice of Completion* and then the detailed design and implementation stages.

The development of this Master Plan has been directed and reviewed by a Project Team, which has been comprised of representatives from various City of Cambridge departments, the Region of Waterloo, and the Grand River Conservation Authority. Numerous meetings have been convened with this Project Team during the course of this multi-year study for the review and comment of the analyses completed for this study, as well as the updates to the stormwater management policies. The analyses completed in support of this Master Plan have applied the best available information which has been furnished by the City of Cambridge and the Grand River Conservation Authority.

Analysis of Storm Sewers and Roadways (Minor/Major System)

Hydrologic (flows) and hydraulic (capacity) analyses have been conducted using a numerical model (XP-SWMM methodology) for all of the City trunk sewers for the sewershed networks as defined by this study. The results have indicated that, in general, the existing minor system (storm sewers) within the City either provides sufficient capacity to convey the 5 year storm event, or else would be susceptible to incidences of local surcharge (water levels above pipe but below road surface); incidences of surface flooding are relatively uncommon for a 5 year storm event standard.

The assessment has also indicated that 100 year storms would generally be anticipated to overtop the depth of roadway curbs, and thus extend toward private property in the majority of the City. The risk of flooding of private structures under this condition is essentially contingent upon the standards of the day (i.e. historic centres versus newer areas applying more contemporary design standards).

A long list of alternatives has been considered in this study in order to mitigate the surcharge and flooding conditions for the minor system for a 5 year storm event. It has been determined that the prevailing solution has been to increase storm sewer sizes in order to satisfactorily accommodate the 5 year storm event without surcharge, due to the over-riding limitation of a lack of readily available land for reducing peak flows through the use of quantity control storage.

Cost estimates for infrastructure improvements have been developed based upon the associated analysis. The total replacement cost includes the pipe and also accounts for installation, replacement appurtenances (i.e. catchbasins and manholes), and resurfacing of the roads. (ref. Table 1).

Table 1: Preliminary Cost Estimates For Sewer Upgrades To 5 Year Capacity

City Area	Total Length To Be Replaced (m)	Estimated Total Cost ($)
Blair	100	$36,000
Freeport	293	$335,000
Galt	7,437	$11,054,000
Hespeler	2,855	$3,707,000
Preston	2,140	$2,393,000
Entire City	**12,825**	**$17,525,000**

The analyses completed for the trunk sewers within the Groff Mill Creek Watershed have indicated that the surcharge condition during the 5 year event is attributable to the tailwater conditions at the outlet to the Groff Mill Creek. Consequently, the condition cannot be successfully mitigated by the replacement of the storm sewers, but could require alternative strategies in order to fully mitigate those conditions (i.e. implement off-line storage areas within public spaces, implement super-pipe to provide on-line stormwater quantity control, regrade watermain to reduce tailwater elevations, or combinations of the above). The evaluation of these alternatives would necessarily require a more detailed assessment of the constraints within the subject area, which is beyond the scope of this Master Plan. It is therefore recommended that the above alternatives and additional alternatives be evaluated in conjunction with the Capital Projects within the City.

A prioritization of the storm sewer upgrade program has been established based on various factors including the flood risks associated with the deficiencies, past record of flooding, as well as the age of the infrastructure (ref. Table 2).

Table 2: Storm Sewer Upgrade Prioritization Summary

City Area	Network Number	Overall Ranking
Blair	55	Low
	68	Low
	69	Low
	70	Low
	67	No Action Required
Freeport	Freeport	Moderately High
Galt	4	High
	5	High
	6/7	High
	11	High
	14	High
	18/19	High
	20	High
	25	High
	57/65	High
	61	High
	27	Moderately High
	28	Moderately High
	52	Moderately High
	13	Moderate
	56	Moderate
	3	Low
	32	Low
	33	Low
	37	Low
	47	Low
	48/49/50/51/59	Low
	53/54	Low
	58	Low
	63	Low
Groff	Groff	Low
Hespeler	2	High
	1	Moderately High
	8	Moderately High
	38	Moderately High
	9/10/39	Moderate
	41	Low
Preston	15	High
	16	High
	45	High
	23	High
	24	Moderately High
	26	Moderately High
	17	Low
	44	Low

Opportunities to integrate the above priorities with other capital projects (i.e. road reconstruction, watermain and sanitary sewer replacements, etc.) should be explored as part of the City's overall capital asset management program.

In an effort to develop an initial understanding of the potential cost implications associated with modifying the minor system in order to mitigate the risk of flooding to private property during the 100 year storm event, additional analyses have been completed for selected networks in order to determine the potential increase in sewer size which would be required to reduce the depth of major system flooding during the 100 year storm event to the gutter depth of the road (i.e. 0.15 m);cost estimates for the major flow works have been prepared accordingly. The results of this assessment have indicated that the cost for upgrading the minor systems in order to mitigate flooding issues for the 100 year storm event would be greater than 3 times the cost for upgrading the minor system in order to mitigate incidences of surcharge and flooding alone; consequently, opportunities to mitigate deficiencies related to the 100 year storm event through upgrades to the City's minor system are considered overly cost-prohibitive to be practically implemented. Alternative strategies to mitigate the impacts of flooding of private property during the 100 year storm event include:

- Implement off-line storage areas within available public spaces.
- Implement super pipes to provide on-line stormwater quantity control.
- Modify grading on private property to mitigate flooding.
- Modify grading within road right of way to mitigate flooding.
- Combinations.

The evaluation of each of the above alternatives would necessarily require a more detailed assessment of the local constraints within each identified area (i.e. grading within and adjacent to right-of-way, utilities, sewer connections, outfall conditions and obstructions, etc.), which are beyond the scope of this Master Plan. It is therefore recommended that the above alternatives and additional alternatives be evaluated wherever and whenever opportunities unfold to address these issues in conjunction with other Capital Projects within the City. The plans produced as part of the hydrologic and hydraulic assessment can be used to identify the critical areas on an overall priority basis.

Stormwater Management Maintenance Program for Drainage Infrastructure

Culverts

Current standards for inspection of culverts require visual inspections be completed every two years in order to confirm the structural condition of the culverts. The cost for the visual inspection depends upon the size and type of structure, but generally ranges from $500 to $2000 per structure. For the purpose of establishing a budget for the City of Cambridge, an allowance of $1000 per structure every two years has been applied for visual inspections. Repairs or replacements of structures are contingent upon the results of the visual inspections, as well as any supplemental analyses which may be completed (i.e. hydraulic analyses). The annual budget for conducting visual inspections of culverts is thus $21,000.

The cost associated with repairing or replacing the culvert depends upon the results of the inspection, as well as the size and type of structure. It is recommended that City staff incorporate this cost into the capital plan as appropriate, based upon the past trends for culvert replacements. For the purpose of providing a preliminary budget item, an annual allowance of $250,000 has been advanced as part of this Master Plan for the purpose of completing structural minor repairs.

Stormwater Management Facilities

An inventory of the City-managed stormwater management facilities has been completed as part of this study through a review of available background information (reports and drawings), field reconnaissance, and meetings with City staff. Through this process, each of the City-managed stormwater management facilities has been classified according to the type of facility (i.e. constructed wet pond or constructed wetland, sediment basin, infiltration basin, natural pond or wetland, natural depression, etc.), the facility function (i.e. stormwater quality control, erosion control, flood control, infiltration), and construction year. The results of this inventory have been compiled into a Microsoft Access™ database, along with additional details where available for the facilities (i.e. storage-discharge relationship, Certificate of Approval Number). In addition, Bathymetric surveys (below water topography) have been completed at select City-managed stormwater management facilities in order to obtain the surface geometry of the accumulated sediment within the stormwater management facilities, which, when compared to the original design drawings, provides an indication of the need for cleanout. This information has been used to define the current maintenance requirements of the City-managed stormwater management facilities, as well as to develop a long-term maintenance management program for implementation by City staff.

Based upon the field inspection, maintenance requirements have been identified for 2011, which are in addition to the routine annual maintenance activities. These range from completing minor repairs (in addition to routine annual maintenance), to dredging the facility to remove sediment, to removal of overgrowth within the facilities. The cost estimates for these activities is summarized in Table 3.

Table 3: Cost Estimates for 2011 Stormwater Management Facility Maintenance (2010 $)

Type of Maintenance Required	Cost
Routine Annual Maintenance/Minor Repairs	$102,000
Sediment Removal	$1,202,000
Removal of Overgrowth	$1,171,000

Cost estimates for maintenance of stormwater management facilities have been developed for key maintenance activities over the design life of the city-managed stormwater management facilities. These have been categorized into routine annual maintenance costs (which would be incurred annually), sediment removal (which would be incurred approximately every 8 years), and facility reconstruction (which would incurred approximately every 20 years). The results of this assessment are summarized in Table 4.

Table 4: Cost Estimates for Stormwater Management Facility Maintenance Over Facility Design Life (2010 $)

Type of Maintenance Required	Cost
Routine Annual Maintenance	$66,000/year
Sediment Removal	$1,300,000/8 years
Facility Reconstruction	$1,940,000/20 years

Storm Sewer System

The current budget for maintaining the City's storm sewer system should necessarily be increased in order to provide for the completion of video inspections, catchbasin cleanout of sediment, and flushing of storm sewers. In order to allow for these activities, an allowance of $506,000.00 per annum is recommended to be incorporated into the City's current storm infrastructure budget. The complete video survey and catchbasin cleanout of the City's storm sewer system should be completed over the course of a 5 year period, with priority given to the older infrastructure. Sewer flushing should be completed on an as-needed basis, based upon the results of the video survey.

Watercourses

Visual inspections of the watercourses within the City of Cambridge should be conducted every two to five years and after significant storm events in order to identify any erosion which may have occurred in the areas. These inspections should include obtaining a photo inventory of the watercourse, and the preparation of a monitoring report.

For budgeting purposes, an annual allowance of $5,000 per watercourse has been advanced for the completion of the visual inspections, at an average annual cost of $45,000 for the completion of visual inspections of the City's watercourses.

The specific maintenance activities along the watercourses would depend upon the results of the visual inspections. For the purpose of preparing a budget for the City, an allowance of $150,000 is recommended in order to accommodate small local repairs/rehabilitation to the watercourses in the vicinity of the culverts. Should more extensive repairs be warranted (i.e. realignments/reconstructions), more extensive study and design would necessarily be required.

Other Best Management Practices

The City of Cambridge is required to maintain the six municipally-owned oil/grit separators. An annual allowance of $10,000 per structure, for a total annual cost of $60,000, is recommended for the inspection, cleanout and disposal of accumulated material within the City-owned oil/grit separators.

Stormwater Quality Management Program for Future Infill and Intensification Development

Stormwater quality control is required for all urban development, including future infill and redevelopment areas, in accordance with Provincial Standards. Conventional practice prescribes the need for stormwater quality control facilities for each individual development site. Since the City of Cambridge Growth Management Strategy has established a considerable number of infill and redevelopment sites within the City of Cambridge, this would propagate a considerable number of stormwater management facilities on high coverage lots which would lead to potentially onerous design and operation and maintenance requirements, as well as overall functional concerns. Consequently, an alternate approach toward providing stormwater quality control for future infill and intensification zones has been advanced for consideration, which consists of consolidated and centralized retrofits to existing storm outfalls and existing dry pond facilities, in order to reduce overall operations and maintenance requirements and improve functionality by providing treatment to those areas most in need; such a program would be financed as a *cash-in-lieu of on-site stormwater management program* in accordance with current Provincial standards. From a Municipal perspective, the latter approach of providing centralized stormwater management is considered preferable due to the lower operations and maintenance requirements, and the long-term reliability which would be achieved through the implementation of publicly managed stormwater management facilities, as opposed to privately owned facilities which are typically associated with individual stormwater management facilities for each individual development. During the course of this Stormwater Management Master Plan, GRCA staff has expressed concern with respect to the implementation of centralized stormwater management facilities, primarily due to a preference to providing treatment at-source or as a minimum treating stormwater runoff by way of a treatment train approach (i.e. source, conveyance, and end-of-pipe). Other potential issues cited by GRCA as related to the implementation of retrofits includes conflicts and encroachments into natural features, particularly Provincially Significant Wetlands. As such, the potential exists for a hybrid approach of both source and centralized retrofits with the determinants/factors in selection founded on such considerations as the sensitivity of the receiver, size of drainage area, type of development, and many others. The final selection and detailed design for any centralized stormwater management retrofits would necessarily need to proceed under a Class EA Schedule B process, as a subsequent study to this Stormwater Management Master Plan, and the final siting and selection of the retrofit sites would be established accordingly. City staff will continue to consult with GRCA staff in an effort to establish a mutually acceptable blend of at-source stormwater management with off-site retrofits for future infill and redevelopment areas.

Candidate locations for the construction of stormwater management retrofits in order to provide the requisite stormwater quality control for the future infill and redevelopment areas, have been advanced based upon the size of the contributing drainage area, the available space for construction of facility (i.e. on Public lands), and accessibility for construction and maintenance of the facility. Based upon this assessment, six (6) candidate sites for construction of stormwater quality retrofit facilities have been advanced. The final siting of these retrofit facilities would be subject to refinement at the detailed design stage, based upon additional environmental constraints. In addition to the six priority sites located on public lands, as redevelopment occurs within the City of Cambridge, additional opportunities for siting retrofit facilities may be advanced, whereby the City may have the opportunity to acquire privately-held land for the purpose of constructing stormwater quality retrofit facilities. Furthermore, significant opportunities to provide stormwater quality control within the Dumfries Conservation Area (DCA) have been previously identified within the Groff Mill Creek Watershed Flooding Assessment Class Environmental Assessment (Philips Engineering Ltd., 2007). These opportunities have not been advanced at the present time due to past opposition from the general public, however the City may nevertheless seek to explore these opportunities further as part of future works particularly those which enhance the creek system through the Dumfries Conservation Area.

Conceptual plans of the stormwater retrofit facilities within the currently recommended sites have been developed and cost estimates generated accordingly for the capital works and long-term operation and maintenance of the facilities. A summary of the estimated capital costs for the construction of each facility is presented in Table 5.

Table 5: Construction Cost Estimates for Proposed Retrofit Facilities		
Facility ID	**Location**	**Total**
1	Outfall at Speed River (Chopin Dr./Hamilton St.)	$174,370
2	Outfall at Speed River (Russ St./CNR)	$144,490
3	Outfall at Speed River (Leisure Lodge Rd. /Speedsville Rd.)	$280,580
5	Outfall at Mill Creek (Alison Ave./Elgin St. N.)	$165,660
6	Dry Pond 130 (Maple Grove Rd.)	$1,108,930
7	Dry Pond 142 (Burnett Ave.)	$114,440

Capacity Assessment for Bridges and Culverts (City-owned)

Capacity analyses have been completed for the various open watercourses within the City of Cambridge in order to verify that the current structures (i.e. bridges and culverts) comply with the governing criteria for capacity (freeboard and clearance). The results of this assessment are presented in Table 6.

Table 6: Summary of Hydraulic Performance at Bridge and Culvert Crossings of Waterways				
Creek	**Crossing**	**Capacity**	**Standard**	**Adequate? (Y/N)**
Forbes	Black Bridge Rd. (east)	2 Year	25 Year	N
	Black Bridge Rd. (west)	50 Year	25 Year	Y
	Hespeler Rd. (west)	25 Year	10 Year	Y
	Baldwin Dr.	<2 Year	10 Year	N
Freeport	CNR	Regional		
Hespeler East, West Creeks	Beaverdale Rd.	100 Year	50 Year	Y
	Hal Rogers Dr.	10 Year	10 Year	Y
Bechtel	Blair Rd.	<2 Year	50 Year	N
	Langdon Dr.	<2 Year	10 Year	N
	Fallbrook Ln.	<2 Year	10 Year	N
Blair Creek	Blair Rd.	<2 Year	100 Year	N
	d/s Fountain St.	<2 Year	50 Year	N
	u/s Fountain St.	25 Year	100 Year	N
Mill Creek	Samuelson St.	5 Year	100 Year	N
	CNR	Regional		
	Marion/Elgin	100 Year	50 Year	Y
	Dundas St.	Regional	100 Year	Y
	Shade St.	<2 Year	10 Year	N
	Kerr St.	100 Year	25 Year	Y
Chilligo Creek	Beaverdale Rd.	<2 Year	25 Year	N
	Maple Grove Rd.	Regional	100 Year	Y
	Hespeler Rd.	100 Year	100 Year	Y
	Fisher Mills Rd.	Regional	100 Year	Y
	Chilligo Rd.	Regional	50 Year	Y
Devils Creek	Salisbury Ave.	5 Year	25 Year	N
	Blenheim Rd.	Regional	25 Year	Y
	CNR	Regional		
	Bismark Dr.	100 Year	25 Year	Y
	Blair Rd.	<2 Year	25 Year	N
	George St.	Regional	25 Year	Y
Moffat Creek	Dundas St.	100 Year	25 Year	Y
	Dundas St.	5 Year	25 Year	N
	Dundas St.	100 Year	25 Year	Y
	Main St.	<2 Year	25 Year	N
	Elgin St.	100 Year	50 Year	Y
	Champlain Dr.	100 Year	50 Year	Y
	Christopher Dr.	<2 Year	25 Year	N
	Pedestrian Bridge	<2 Year	10 Year	N
	Pedestrian Bridge	<2 Year	10 Year	N
	Pedestrian Bridge	<2 Year	10 Year	N
Groff Mill Creek	Langs Dr.	2 Year	25 Year	N
	Dunbar Rd.	10 Year	50 Year	N

The results of the capacity assessment at the bridges and culverts have been reviewed in order to develop a prioritization based upon the classification of the local roadway crossing. The resulting prioritization for replacement of bridges and culverts is as follows:

Subwatershed	Crossing	Priority
Forbes Creek	Black Bridge Rd. (east)	Medium
	Baldwin Dr.	Low
Bechtel Creek	Blair Rd.	High
	Langdon Dr.	Low
	Fallbrook Dr.	Low
Blair Creek	Blair Rd.	High
	Fountain St. (ds)	High
	Fountain St. (us)	High
Mill Creek	Samuelson St.	High
	Shade St.	Low
Chilligo Creek	Beaverdale Rd.	Medium
Devils Creek	Salisbury Ave.	Medium
	Blair Rd.	Medium
Moffat Creek	Dundas St.	Medium
	Main St.	Medium
	Christopher Dr.	Medium
	Pedestrian Bridge	Low
	Pedestrian Bridge	Low
	Pedestrian Bridge	Low
Groff Mill Creek	Langs Dr.	Medium
	Dunbar Rd.	Medium

Preliminary analyses have been completed for the structures where replacement is required in order to determine the estimated configuration of the replacement structure required to satisfy the freeboard criteria. In most instances, it has been determined that structural replacement alone would not be sufficient; this was due to either the proximity of the structure to the watercourse outlet to the major receiving system (i.e. the Grand River or the Speed River) and the associated tailwater condition, or else the limitations imposed by the existing road profile. Consequently, further investigations are considered necessary in order to determine the attainable works required (i.e. revisions to road profile, adjustments to creek profile/cross-section, etc.) in order to provide sufficient freeboard at the crossings. Due to the anticipated scope of these works, it is recommended that these proceed under an integrated Class Environmental Assessment process, and should include further public consultation.

The estimated costs for the hydraulic structure replacements are summarized in Table 7.

Table 7: Cost Estimates for Replacement of City Hydraulic Structures at Watercourse Crossings

Watercourse	Crossing Location	Estimated Replacement Structure	Estimated Cost
Forbes Creek	Black Bridge Rd. (east)	n/a	TBD
	Baldwin Dr.	n/a	TBD
Bechtel Creek	Blair Rd.	n/a	TBD
	Langdon Dr.	n/a	TBD
	Fallbrook Dr.	n/a	TBD
Blair Creek	Blair Rd.	n/a	TBD
	Fountain St. (ds)	n/a	TBD
	Fountain St. (us)	7.5 x 2.5	$600,000
Mill Creek	Shade St.	n/a	TBD
	Samuelson St.	n/a	TBD
Devils Creek	Salisbury Ave.	n/a	TBD
	Blair Rd.	n/a	TBD
Moffat Creek	Main St.	n/a	TBD
	Dundas St.	2.0 x 1.25	$300,000
	Pedestrian Bridge	n/a	TBD
	Pedestrian Bridge	n/a	TBD
	Pedestrian Bridge	n/a	TBD
	Christopher Dr.	n/a	TBD
Chilligo Creek	Beaverdale Rd.	n/a	TBD
Groff Mill Creek	Langs Dr.	n/a	TBD
	Dunbar Rd.	n/a	TBD

Next Steps

This Stormwater Management Master Plan has satisfied the Phase 1 and Phase 2 requirements of the Municipal Engineers Association Class Environmental Assessment process (2000, as amended 2007). The detailed design and implementation of the various recommendations advanced in this study should, where the work constitutes a Schedule B activity, proceed to a Notice of Completion. All other works are anticipated to fall under a Schedule A or A+ and as such be “pre-approved”. The following summarizes the processes required for the works covered under this Stormwater Management Master Plan.

Project Activity	***Process***
Routine Annual Maintenance of SWM Facilities	*No Follow-up EA Required*
Sediment/Vegetation Removal and Replanting within SWM Facilities	*Schedule A*
Facility Rehabilitation at End of Design Life	*Schedule A+*
Storm Sewer Replacement	*Schedule A*
Design and Construction of Retrofits for Stormwater Quality	*Schedule B*
Replacement of City's Hydraulic Structures (bridges and culverts)	*Schedule B*

The following are recommended for the next steps emanating from this Stormwater Management Master Plan:

Hydrologic Hydraulic Modelling

- The hydrologic/hydraulic models developed for the storm sewers should serve as the basis for supporting the detailed design of the replacement storm sewers and road rehabilitation.
- Further refinements may be incorporated into the hydrologic/hydraulic models, such as extending the limits of the simulated sewer networks to include smaller size hydraulic elements, refinements to drainage boundaries based upon more detailed grading information of the contributing drainage area, and the incorporation of private stormwater quantity control facilities (should this information become available).
- Further refinements may also include calibration of the hydrologic/hydraulic models based upon local rainfall and streamflow data for the Subwatersheds or, if available, specific sewersheds.

Stormwater Quality Program for Future Infill and Redevelopment Areas

- Stormwater quality control for future infill and redevelopment areas should be implemented under a cash-in-lieu of on-site stormwater quality control program.
- A funding program should be established for the implementation of the stormwater quality retrofit program to support future infill and redevelopment areas by way of Development Charges.
- The stormwater quality program should be implemented in a phased manner, concurrent with the timing and phasing of redevelopment and infill development within the City.
- Other opportunities to provide stormwater quality control retrofits should be investigated within the City, and the stormwater quality retrofit program updated as required.

Stormwater Management Facility Maintenance Program

- The maintenance of the City-managed stormwater management facilities should be funded through the City's Capital Budget.
- The specific maintenance duties of the City's Public Works Department and Community Services Department should be established.
- The maintenance requirements for each facility should be revised as required, based upon the information gathered under the annual facility inspection program.
- The City should initiate a project in order to obtain as-built information for the City's stormwater management facilities, in order to better information future analyses regarding the performance of the City managed stormwater quality and quantity facilities.

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Cambridge/Waterloo Region Homebuilders
General Public

Stormwater Management Master Plan Cost Analysis and Summary

Item	Breakdown		COST 0 - 5 Year Total	6 - 15 Year Total	15 + Years Total	Total	Average Capital Annual	Average Operating Annual
Storm Sewer System	Major System Needs	Capital	TBD	TBD	TBD	TBD		
		Annual Maintenance	TBD	TBD	TBD	TBD		
		Major Maintenance	TBD	TBD	TBD	TBD		
		Study	250,000.00	500,000.00	250,000.00	1,000,000.00	50,000.00	
	Minor System Needs	Capital	6,944,000.00	4,157,000.00	6,424,000.00	17,525,000.00	876,300.00	
		Annual Maintenance	2,500,000.00	5,000,000.00	2,500,000.00	10,000,000.00		500,000.00
		Major Maintenance						
SWM Facilities	Existing Quality Facilities	Capital						
		Annual Maintenance	239,000.00	367,500.00	183,750.00	790,250.00		39,600.00
		Major Maintenance	1,784,000.00	1,300,000.00	3,240,000.00	6,324,000.00		316,200.00
	Existing Quantity only Facilities	Capital						
		Annual Maintenance	128,000.00	295,000.00	147,500.00	570,500.00		28,600.00
		Major Maintenance	1,171,000.00			1,171,000.00		234,200.00
	Intensification Facilities (SWM Retrofits)	Capital	397,700.00	795,400.00	795,400.00	1,988,500.00	99,500.00	
		Annual Maintenance						
		Major Maintenance						
		Study	100,000.00	200,000.00	200,000.00	500,000.00	25,000.00	
	OGS	Capital						
		Annual Maintenance	300,000.00	600,000.00	300,000.00	1,200,000.00		60,000.00
		Major Maintenance						
Bridges and Culverts	Capacity Needs	Capital Replacement	3,268,000.00	5,770,000.00	1,600,000.00	10,638,000.00	531,900.00	
		Capital retrofit / repair						
		Study	250,000.00	250,000.00		500,000.00	33,400.00	
	Maintenance	Annual Maintenance						
	Inspection		105,000.00	210,000.00	105,000.00	420,000.00		21,000.00
Total							1,616,100.00	1,199,600.00

1. INTRODUCTION

1.1 Study Purpose and Objectives

Over the past several years, the City of Cambridge, as well as many other southern Ontario urban centres, has been impacted by extreme storm events, leading to considerable flood and erosion damage. City of Cambridge Council and Senior Management have recognized the importance of developing and implementing capital programs to address the City's infrastructure needs in a co-ordinated and effective manner; it is recognized that in the absence of an integrated and balanced plan, City staff would struggle to meet the needs of residents and businesses.

In response to the apparent increase in the frequency and severity of storm events, and recognizing a need to better manage Municipal resources, the City of Cambridge initiated the preparation of a City-wide Stormwater Management Master Plan, which would evaluate existing infrastructure and policies, identify deficiencies, and develop an implementation plan, capital planning estimates and potential funding mechanisms on a long-term sustainable program and policy for the management of stormwater in Cambridge.

The Approved Work Plan for this project consisted of the following key tasks and objectives:

- Collection and review of background information (reports, drawings, databases, Certificates of Approval).
- Review of City of Cambridge stormwater management facility design standards.
- Physical reconnaissance of City-managed stormwater management facilities.
- Hydrologic/hydraulic modelling of major and minor trunk systems (i.e. storm sewers and corresponding overland flow paths).
- Hydraulic assessment of open watercourse systems and hydraulic structures (i.e. bridges and culverts).
- Identification of deficiencies within City-managed and operated infrastructure (i.e. stormwater management facilities, trunk sewers and overland flow paths, bridges and culverts).
- Development of Evaluation Criteria and Prioritization of Capital Projects to address deficiencies.
- Development of stormwater quality management plan to support future infill and redevelopment areas.
- Development of Maintenance Activities and Schedule for City-managed stormwater management facilities.
- Update of City Stormwater Management Policy and IDF relationships for sizing of stormwater infrastructure (i.e. storm sewers).

1.2 Master Plan Process

The Ontario Environmental Assessment Act provides for "*…the betterment of the people of the whole or any part of Ontario by providing for the protection, conservation and wise management in Ontario of the environment*." An approved Class Environmental Assessment (Class EA) document describes the process that a proponent must follow for a class or group of undertakings in order to satisfy the requirements of the Environmental Assessment Act, and represents a method of obtaining an approval under the Environmental Assessment Act and provides an alternative to carrying out individual environmental assessments for each separate undertaking or project within the class.

Master Plans are one form of Class EA document which represent long range plans which integrate infrastructure requirements for existing and future land use with environmental assessment planning principles. The following characteristics distinguish the Master Planning Process from other processes:

a) The scope of Master Plans is broad and usually includes an analysis of the system in order to outline a framework for future works and developments. Master Plans are not typically undertaken to address a site-specific problem.

b) Master Plans typically recommend a set of works which are distributed geographically throughout the study area and which are to be implemented over an extended period of time. Master Plans provide the context for the implementation of the specific projects which make up the plan and satisfy, as a minimum, Phases 1 and 2 of the Class EA process (ref. Figure 1.1). Notwithstanding that these works may be implemented as separate projects, collectively these works are part of a larger management system. Master Plan studies in essence conclude with a set of preferred alternatives and, therefore, by their nature, Master Plans will limit the scope of alternatives which can be considered at the implementation stage.

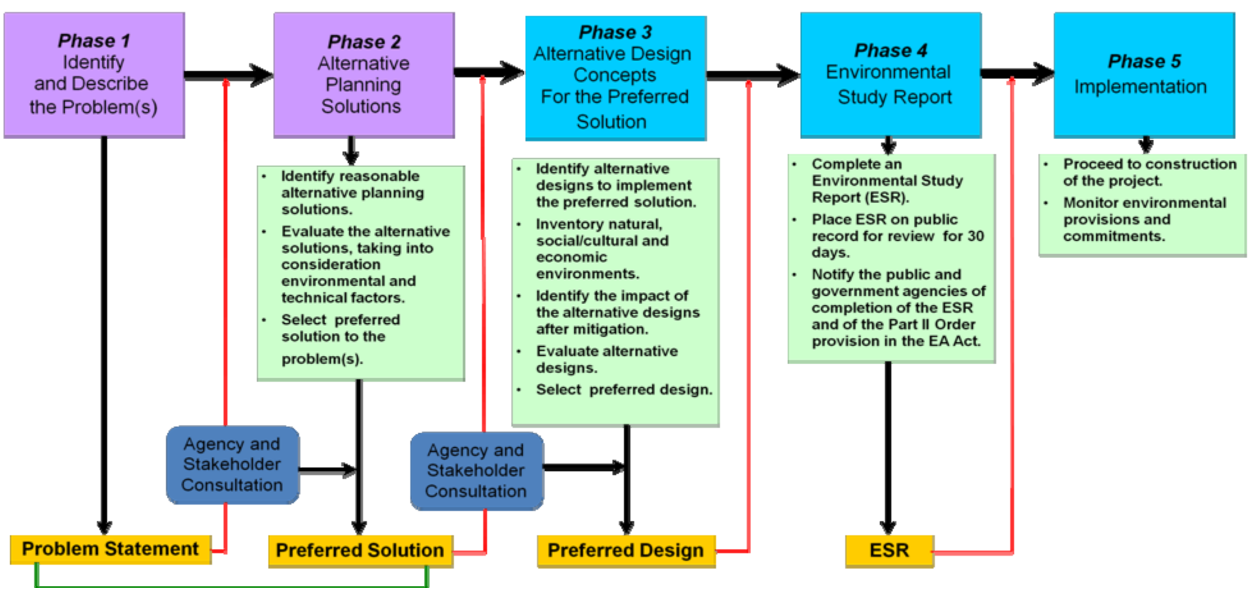

Figure 1.1: Municipal Class EA Process

The City of Cambridge Stormwater Management Master Plan has been prepared in accordance with the Municipal Engineers Association (MEA) Class Environmental procedures. The Master Plan has adopted Approach #1 in the 2007 MEA Documentation, which addresses Phases 1 and 2 of the Class EA process (ref. Figure 1.1); subsequent Schedule B projects which are implemented in accordance with the recommendations provided in this Master Plan may proceed directly to the *Notice of Completion* and then the detailed design and implementation stages.

The development of this Master Plan has been directed and reviewed by a Project Team, which has been comprised of representatives from various departments at the City of Cambridge, the Region of Waterloo, and the Grand River Conservation Authority. A total of thirty-one meetings have been convened with this Project Team during the course of this three-year study for the review and comment of the analyses completed for this study as well as the updates to the stormwater management policies. Sub-groups of the Project Team comprised the Technical Team and Focus Groups, which were established in order to address key technical, analytical, or procedural issues which arose during the process (i.e. background information, modelling, maintenance, financing, stormwater management policy).

Two Public Information Centres were held during this project, in order to present the study process, findings, and recommendations to the general public. In addition, presentations have been made to the local Homebuilders Association in order to solicit input from the local development industry, as well as Cambridge's Environmental Advisory Committee (CEAC). Records of the agency and public consultation process are provided in Appendix 'A'.

1.3 Report Outline

This document represents the General Report for the City of Cambridge Stormwater Management Master Plan. Separate sections have been prepared to summarize the background information provided in this study, the field reconnaissance and inventory of the City-managed stormwater management facilities, analyses of the City's drainage system, the stormwater quality master plan to support the future infill and redevelopment areas, and the maintenance program for the City-managed stormwater management facilities. Details regarding the analyses completed, including field notes, hydrologic/hydraulic models, and calculations are provided within the respective appendices.

In addition, the City's stormwater management policy has been updated under this process. While the policy has been issued under separate cover, a summary of the key revisions is provided within this report. A separate database has also been prepared in Microsoft Access™ format, which summarizes the information collected regarding the City-managed stormwater management facilities (i.e. type/function, location, condition, Certificate of Approval Number); this database has been provided to the City in digital form as a separate deliverable from this report.

2. BACKGROUND INFORMATION

Background information has been provided for this study by way of reports, mapping (digital and hard copy), field notes, and databases. The following provides a brief summary of the background information furnished for this study.

Flooding Locations

The City of Cambridge has provided a list of 108 unique flooding sites, including specific locations and a description where relevant. A map has been created which identifies the location of the observed problems and categorizes them as follows (ref. Drawing 1: Historic Flooding Location Plan):

- Basement Flooding
- Private Property Surface Flooding
- Sewer Surcharging
- Street Flooding
- Miscellaneous

A summary of the reported information for each site is included in Appendix B.

Stormwater Management Reports

An extensive collection of reporting has been collected from the City of Cambridge, including over 120 Stormwater Management Reports and 7 Subwatershed Studies. This information has served as a basis for delineating the drainage boundaries to the open watercourses and sewer networks, the development of a stormwater management practice summary, as well as identifying the approximate age of the various City-managed stormwater management facilities. A full list of the reports provided for this study is presented in Appendix 'B'.

The majority of the reports have pertained to stormwater management facilities which lie on private property, and thus preclude the City-managed stormwater management facilities. Consequently, City staff was consulted during the course of the study in order to fill the "gaps" in the characterization of the facility ages, types, and functions. Further details on the City-managed stormwater management facilities are provided in Section 3 of this report.

Mapping and Databases

Various maps and GIS databases have been provided by the City of Cambridge for the development of base information for this study. These have served as the sources for the following key information for this study:

- Stormwater management facility reference ID's and locations.
- Roads names and bridge and culvert locations.
- Watercourses.
- Subwatershed boundaries.
- Storm sewer and manhole locations, dimensions, inverts, and ages.

- Preferred sites for intensification and redevelopment under the City's Growth Management Strategy Study.

Design Standards and Stormwater Management Policy

Digital versions of the City's Stormwater Management Policy (1997) have been provided for this study. This document has served as the basis for the Stormwater Management Policy Update component of this study. Further details on this document are provided in Section 4 of this report.

Geodetic Survey and Field Reconnaissance

Where information gaps have been identified within the City's storm sewer database or the bridges and culverts within the City, field reconnaissance and geodetic survey information has been obtained by City staff, and forwarded for use in this study.

Hydrologic and Hydraulic Models

Hydrologic and hydraulic models for various watercourses and subwatersheds within the City of Cambridge have been provided by the GRCA for use in this study. In most instances, the models were developed as part of Subwatershed Studies, and in some cases were recognized as not reflecting the current condition of the Subwatershed and/or the watercourses and hydraulic structures. Notwithstanding, this information has provided the base hydrologic information and has served as a basis for the hydraulic analyses completed for the open watercourses and hydraulic structures.

Rainfall Records and IDF Relationships

Rainfall data has been provided by the City for updating the City's Intensity Duration Frequency (IDF) Relationships as part of the overall Stormwater Management Policy Update. This has included rainfall data for formative events which occurred during 2008 and 2009, as well as the historic rainfall from the Environment Canada Rainfall Gauge in Waterloo, which has been previously applied to generate the IDF relationships for the City.

3. STORMWATER MANAGEMENT FACILITY INVENTORY

A total of 76 City-managed stormwater management facilities are dispersed throughout the City of Cambridge. More than 120 reports have been reviewed in order to identify the specific facility types (i.e. wet ponds/wetlands, dry detention, vegetative systems, etc.) and functions (i.e. stormwater quality, erosion, and/or quantity control), as well as the boundary of the contributing drainage area to the facilities. The following have been noted based upon the review of this information:

- With few exceptions, available stormwater management reports provide information on privately-owned facilities which generally serve small drainage areas (i.e. 70 % of drainage areas are less than 10 ha); many are sited in order to harmonize or utilize natural drainage features (i.e. woodlots, wetlands, natural depressions, etc.); limited information is available on city-managed stormwater management facilities.

- Stormwater management practices within private holdings tend to emphasize maintaining water budget and encourage infiltration for drainage areas greater than 10 ha; certain facilities were designed on the basis capturing runoff from the 100 year event and allowing that runoff to infiltrate.

- Stormwater quality functions have not been specified for most of the sites (60 % +/-); these generally tend to be smaller site developments (i.e. less than 5 ha).

- Stormwater management requirements commonly specified in the form of quantity controls for most sites (70 % +/-). Stormwater quantity control requirements are generally defined by hydraulic constraints imposed by local infrastructure (i.e. sewer capacities) or requirements to maintain the functions of natural features rather than conventional subwatershed-based targets for post-to-pre control.

- Rating curves are available for approximately half of the stormwater management systems, either in the main body of the report or appended model data; many facilities do not have rating curves; this remains an important data gap.

- Drainage area plans are available for just over half of the reports (60 %+/-).

- Stormwater management recommendations prescribed in the Subwatershed Studies consist of various strategies other than conventional post-to-pre control within end-of-pipe facilities at strategic locations (i.e. over-control of runoff, limiting the amount of future impervious cover, maintaining existing depression storage, promoting infiltration, completing works around the perimeter of various natural heritage features in order to enhance/encourage infiltration).

In order to characterize the type and function of the City-managed stormwater management facilities, interviews have been held with key City staff that have been charged with managing the City-managed stormwater management facilities over the years. Through this process, each of the 76 City-managed stormwater management facilities has been characterized on the basis of year of construction, type and function. The results of this inventory process are presented in Appendix C; the characterization of each facility by type is depicted graphically in Drawing 3: Stormwater Management Facility Classification by Type of Facility, and the characterization of each facility by function is depicted graphically on Drawing 4: Stormwater Management Facility Classification by Facility Function. The following general observations are noted based upon the results of this inventory and characterization process:

- Construction dates extend as far back as the late 1970's; some of the earliest facilities provided stormwater quality functions, although they well predate the MOE guidelines for stormwater quality control hence would not have been constructed to current standards.
- 7 facilities provide offline storage for the minor system which tends to be an atypical practice.
- 2 facilities provide offline storage for minor system, as well as informal stormwater quality control.
- 5 facilities provide stormwater quality control only.
- 23 facilities provide stormwater quality and quantity control (one of which is currently being retrofitted for stormwater quality control).
- 1 facility provides stormwater quality, quantity, and erosion control.
- 12 facilities provide stormwater quantity control only.
- 1 facility is suspected to be providing stormwater quality control, although, due to its age, this is not known for certain.
- 21 facilities consist of systems constructed and/or incorporated into natural features (i.e. kettle ponds, wetlands) with or without forebays.
- 16 facilities were constructed prior to 1990; most of these provide quantity management only along with offline storage functions.
- 6 oil/grit separators within residential areas have been identified as being owned and operated by the City.

City staff has conducted research into the archives and various departments in order to locate the Ministry of the Environment (MOE) Certificates of Approval for the City-managed stormwater management facilities. This research yielded Certificates for all except thirteen of the total 76 facilities. Subsequently, the City contacted the Ministry of the Environment and has requested that the Ministry research its archives in an effort to locate the Certificates for the remaining thirteen facilities. The Certificate Numbers have been incorporated into the database which has been compiled for the City of Cambridge, in order to maintain a linkage between the specific facility and the conditions of approval as established by the Province under the Certificate of Approval.

Field reconnaissance has been completed for each of the City-managed stormwater management facilities in order to summarize the conditions and appurtenances at each facility, as well as to photograph the conditions observed at the time of inspection. Inspection forms were completed for each facility, which documented the following for each facility:

Pond ID
Address
Facility Type
Forebay Type/Condition
Inlet Type/Condition
Outlet Type/Condition
Overflow Type/Condition
Vegetation Type
Maintenance Access
Signage
Fencing
Forebay/Pond Depth
Maintenance Requirements
Photographs
Sketches

The data and photographs collected during the field reconnaissance have been incorporated into a Microsoft Access™ Database which has been issued to the City under separate cover. The observed conditions for the City-managed stormwater management facilities which require maintenance are provided within the database. These requirements are summarized in Table 3.1.

Table 3.1: Short-Term Maintenance Activities for Stormwater Management Facilities

Maintenance Activity	Stormwater Management Facility ID Number
Inlet/Outlet Inspection	All
Debris Removal	All
Outlet Adjustment	As required, depending upon field observations
Grass Cutting/Weed Control	Based upon field inspection (101, 102, 103, 106, 109, 110, 112, 115, 118, 120, 122, 123, 129, 130, 133, 134, 135, 136, 138, 142, 143, 144, 145, 146, 147, 152, 155, 157, 163, 164, 166, 167, 168, 169, 170, 171, 173, 175, 177)
Sediment Removal from Forebays (facilities approximately 10 years and older)	104, 119, 120, 124, 125, 129, 132, 133, 135, 145, 149, 150, 152, 155, 157, 158, 163, 164,
Inspect for Sediment Depth within forebay	107, 114, 115, 116, 117, 127, 141, 166, 167, 168, 169, 170, 171
Replace Filter Medium	111, 112, 140, 160
Inspect for standing water	104, 113, 116, 121, 124, 125, 127, 131, 137, 151, 154, 158, 159, 172
Verify standing water level sufficient for on-site fire protection	173
Verify limits of permanent pool to confirm condition of synthetic liner	170
Measure depth of sediment within oil/grit separators	All OGS's
Remove sediment from OGS's	As required, based upon measured sediment depths

During the course of reviewing the background information provided for this study, as-built information for the City-managed stormwater management facilities was noted to represent a significant gap in the dataset. It is recommended that the City initiate a project in order to obtain this information and address this data deficiency. The alternatives to obtain this information, in the recommended sequence, are as follows:

i) Further review of City archives and files.
ii) Contacting design consultants for information.
iii) Complete Total Station Survey of the facility.

Various stormwater management facilities within the City have been constructed with the intent of providing stormwater quality control, but which pre-date the earliest Provincial standards. By way of example, the sediment basin at Cowan and Avenue Road (ref. Facility ID 141), which is formally owned by the GRCA but managed by the City of Cambridge, was constructed approximately sixteen years before the earliest Provincial standards for stormwater quality control facilities; the facility is recognized as being currently deficient with respect to the current design standards for stormwater quality control facilities (i.e. volume, grades, landscaping, etc.). During the course of this Stormwater Management Master Plan, the GRCA has indicated an interest in decommissioning this facility, however the Authority has also indicated that the stormwater quality function currently afforded by the facility would need to be retained. For the specific purpose of the decommissioning of this facility, it is recommended that the City pursue opportunities to partner with the GRCA to implement a stormwater quality retrofit program within the upstream drainage area.

4. DRAINAGE POLICY OVERVIEW

The City of Cambridge originally established a City-wide Stormwater Management Policy in 1983, and subsequently updated the Policy in 1997. While the 1997 Policy provides information to direct practitioners in the design of stormwater management facilities (i.e. side slopes, fencing requirements, landscaping), it also provides direction to City staff and departments on matters such as maintenance and the planning of stormwater management facilities. As part of this Stormwater Management Master Plan, the City's Stormwater Management Policy (1997) has been updated to reflect current standards of practice and Regional/Provincial guidelines, as well as to address some noted deficiencies in the 1997 standards which have been recognized since its application within the City of Cambridge.

The updated Stormwater Management Policy is provided under separate cover to this report, and incorporates the specific comments provided by City Staff from various departments. Specific comments and the associated revisions to the policy are summarized in Table 4.1.

Table 4.1: Summary of Comments and Revisions to City of Cambridge Stormwater Management Policy

Comment	Revision
1. Fencing of facilities should control encroachment and debris in low-visibility, low-use areas such as employment zones and should demark the limits between non-municipal and private lands. In all other instances, the use of safety benching, terracing, and deterrent planting should be applied.	Policy 7 h) has been revised accordingly.
2. The City requires sufficient detail at the planning level in order to account for appurtenances (i.e. access, decanting zones, etc.). The Stormwater Management Policy should reference the City's Planning Policy	Policy 2 and Section 4.2 have been revised accordingly.
3. The Stormwater Management Policy should distinguish between Site Plans and Plans of Subdivision with respect to the planning of private facilities.	Policy 2 has been revised accordingly.
4. Rooftop and parking lot storage should include requirements for a control structure within a Manhole within the City's right-of-way, or the MTO approach of having a short pipe within the ground to act as the control.	Section 5.1.4.2 has been revised accordingly. Further revisions recommended to be implemented following further dialogue with City Legal.
5. Private stormwater management facilities should require an annual report and an easement placed over the facility to allow for the municipality to conduct the work in the event that the owner is delinquent.	Section 4.3.2 d has been revised accordingly. Further revisions recommended to be implemented following further dialogue with senior City Staff regarding overall Site Plan compliance requirements.

Table 4.1: Summary of Comments and Revisions to City of Cambridge Stormwater Management Policy (Cont'd)	
Comment	**Revision**
6. The use of natural areas for stormwater quantity control should be discouraged for controlling frequent storm events. The use of natural areas for stormwater quantity control may be acceptable for mitigating existing flooding issues for less frequent events (i.e. above 10 year) or for controlling Regional Storms, subject to City and GRCA approval, and the submission of a Terrestrial Impact Assessment.	Policy 7 i) and Section 4.3.2 d) have been revised accordingly.
7. Specifics regarding acceptable practices for groundwater control should be reflected in the Stormwater Management Policy.	Section 4.3.1 b) revised according to the information provided.
8. Multi-developer facilities need to be maintained by the first developer constructing the system until the facility is assumed by the City.	Section 4.3.2 d and Section 7 have been revised accordingly.
9. The Stormwater Management Policy should indicate that specific criteria for quantity and quality controls for future development should be embedded within the Master Drainage Plans, Subwatershed Plans, and associated Class Environmental Assessments rather than Policy and Guidelines.	Policy 1 and Section 4.1 have been revised accordingly.
10. Dry ponds are generally not part of the formal water quality control system; nevertheless, the extended detention component as well as any swales through the dry pond could contribute to the overall water quality improvements through the treatment train approach.	Policy 7 a) and Section 5.1.1 have been revised accordingly.
11. Reference to the MOE Stormwater Management Planning and Design Manual 2003 should be incorporated into the City's Stormwater management Policy.	Section 4.3.2 d) has been revised accordingly; Table 3.3.2 from the current MOE Guidelines is to be included in Appendix B.
12. Minimum length-to-width ratios for Stormwater Management Facilities should be included.	Policies 7 b), 7 c), and 7 f), as well as Sections 5.1.1, 5.1.2, and 5.1.3 have been revised accordingly.
13. Section 4.3.1 a) should reflect a need to demonstrate safe conveyance from the site to the receiving watercourse.	Section 4.3.1 a) has been revised accordingly.
14. The Erosion and Sediment Control Guidelines for Urban Construction (2006) should be included.	Section 4.5 has been revised to include reference to the Greater Golden Horseshoe Conservation Authorities Publication.
15. The Water Balance approach needs to be incorporated along with an overall discussion on Low Impact Development measures.	Section 4.3.1 a) has been revised accordingly
16. The Glossary of Terms needs to include definitions of "pre-development", "post-development", "on-line facility", "off-line facility", "infill", and "intensification".	Glossary of Terms has been revised accordingly.

Table 4.1: Summary of Comments and Revisions to City of Cambridge Stormwater Management Policy (Cont'd)	
Comment	**Revision**
17. The generic reference to "stormwater management pond" should be changed to "stormwater management facility".	Changes incorporated throughout the document.
18. Prohibiting/discouraging surface storage within parking lots may preclude the application of on-lot measures (i.e. bio-retention facilities).	Policy 7 k) has been revised accordingly.
19. Silt fences and dust suppressants should be included as erosion and sediment control measures.	Section 4.5 has been revised accordingly.
20. The Stormwater Management Policy should specify that requirements for wetlands pertain specifically to constructed wetlands.	Section 5.1.2 has been revised accordingly. References to wetlands within the document have been revised to specify constructed wetlands.
21. Children's play equipment should not be permitted within stormwater management facilities.	Policy 7 n) has been added accordingly.

During discussions with City Staff, it was noted that further revisions to the Stormwater Management Policy may be incorporated into the document in the future, in response to evolving standards of practice, Provincial Standards, Subwatershed Studies, and practices within the Municipality. Revisions which may be incorporated into the document in the near future include the following:

- Additional level of detail regarding division of maintenance practices between Public Works and Community Services; City Staff recognize, however, that this relates more to Municipal practices rather than standards for design and thus need not necessarily be incorporated into the Stormwater Management Policy

- The required setback around stormwater management facilities from the fencing areas.

- Additional details regarding groundwater controls may be included within the City Stormwater Management Policy; this should also recognize potential conflicts with City's Engineering Standards and Development Manual, and make appropriate cross-references to these additional standards.

- Policy may be updated to reflect City perspective on emerging Low Impact Development practices and acceptable technologies/techniques.

- Cross-references to additional documents (i.e. Source Water Protection as well as Regional Policy) as studies are completed.

- Policy may be updated to include updated signage for stormwater management facilities.

5. DRAINAGE SYSTEM PERFORMANCE ASSESSMENT

5.1 Standards

5.1.1 Historical Application of Stormwater Management

Stormwater management facilities have been implemented within the City of Cambridge since the 1970's. Presently, the City of Cambridge manages 76 stormwater management facilities of various forms and functions. Municipal standards for stormwater management facilities within the City of Cambridge were fist established in the City's 1983 stormwater policy and subsequently updated in 1997. Provincially, requirements for stormwater quantity control practices first became common practice during the late 1970's and early 1980's, and formal standards for stormwater quality control were first implemented in 1994 (subsequently updated in 2003).

Historic air photos have been reviewed in order to correlate urban areas within the City of Cambridge with the associated eras of stormwater management practices. For this assessment, the following historic air photos, representative of stormwater management practices, have been reviewed:

- 1984 historic air photos, which depict development within the City of Cambridge prior to stormwater management practices for quantity and/or quality control (i.e. no stormwater quantity or quality control practices would be in-place for these development areas).

- 1997 historic air photos; the urban areas which have been constructed between 1984 and 1997 would likely provide stormwater quantity controls for flood protection, however the majority of these areas would likely not provide stormwater quality control practices.

In addition to the above historic air photos, the City's storm sewer database has been reviewed in conjunction with available recent air photos in order to identify urban areas which have been constructed since 1997, and which would therefore likely include stormwater management practices to provide stormwater quantity and quality controls. The foregoing information has been used in order to identify development areas by stormwater management practice eras. The results of this compilation are presented on Drawing 2: Development Era Reference Plan. As the information in Drawing 2 indicates, the majority of the urban areas within the City of Cambridge pre-date stormwater management practices for either stormwater quantity or quality control; these areas tend to be within the historic centre's of Preston, Hespeler, and Galt.

5.1.2 Rainfall

A component of the update to the City of Cambridge Stormwater Management Policy has involved updating the City's Rainfall Intensity Duration Frequency (IDF) relationship to include more current meteorological data in order to account for the impacts associated with the more extreme storm events which have occurred in July 2005 and September 2006 towards determining the potential influence of Climate Change. The City's IDF parameters were updated as part of the Groff Mill Creek Flooding Assessment Class EA (Philips Engineering Ltd., 2007) based upon meteorological data between 1971 and 2003 (excluding the years 1999 and 2001), as well as a preliminary comparison of the simulated hydrologic response to the July 2005 and September 2006 storms versus runoff response from the synthetic design storms generated based upon the updated IDF data.

The current IDF relationships for the City of Cambridge have been developed based upon the data collected at the Waterloo Wellington gauge which is maintained by the Ontario Climate Centre on behalf of Environment Canada. As part of this update, raw and unprocessed hourly rainfall data for the years 2005 and 2006 has been obtained from the National Climate Data and Information Archive for the Waterloo Wellington Airport station. The rainfall data from the Waterloo Wellington gauge has been compared to rainfall data collected at the Cover Street South gauge for the July 2005 and September 2006 storm events, which was applied for the hydrologic analyses completed for the Groff Mill Creek Class Environmental Assessment. The initial review of the rainfall datasets has indicated that the recorded rainfall at the Waterloo Wellington rainfall gauge for the events of July 2005 and September 2006 are not reflected within the dataset collected at that gauge; as such, the data collected at the Waterloo Wellington gauge is not considered representative of the formative events which occurred within the City of Cambridge for 2005 and 2006. Consequently, the IDF relationships have been updated based upon the local rainfall data which was collected for the rainfall events of July 2005 and September 2006, and premised upon these events representing the formative storms for those years; based upon conditions reported within the City of Cambridge for those years, this is considered a reasonable assumption. In 2009, additional rainfall data was provided by the City of Cambridge from several sources; this included hourly rainfall data from the Shades Mills Conservation Area for the January 2000 – July 2008 period, as well as data from 4 sites for the August – November 2008 period from XCG Consultants Ltd. Data from the Shades Mills site was used for 2001, 2004, 2007, and April – July 2008. The largest rainfall depths from the 4 additional sites were used for the August – October 2008 period. This allowed for the generation of a nearly complete 1971 – 2008 dataset (missing only 1999).

IDF parameters for all datasets were generated based on the methodology employed in the Groff Mill Creek Watershed Class EA (2007). Environment Canada's Consolidated Frequency Analysis program (CFA) was used to fit a Generalized-Extreme-Value (GEV) probability distribution to the annual maximum series data for all durations. The GEV distribution was employed in the previous report, thus for consistency it has been applied in this analysis. IDF parameters "A" and "C" were then fit to the various results using a linear regression of terms. The IDF parameter "B" was assumed to be identical to those used for the 1971-2003 dataset analyzed in the Groff Mill Creek Watershed Class EA (2007). The new IDF parameters are provided in Table 5.1, along with the values generated from the previous IDF relationships applied within the City of Cambridge. Full results of this assessment are provided in Appendix 'D', along with the Climate data which has been used for this assessment.

Table 5.1: IDF Parameters							
Data	Parameter	Return Period (Years)					
		2	5	10	25	50	100
1971 - 2003[1]	A	613.2	1265.6	1843.3	2604.9	3258.4	4027.2
	B	5	10.5	14	17	19	21
	C	0.775	0.837	0.868	0.893	0.909	0.926
1971 – 2006[2]	A	626.3	1215.1	1722.3	2246.5	2777.2	3252.4
	B	5	10.5	14	17	19	21
	C	0.771	0.820	0.846	0.865	0.873	0.880
	R^2	0.9999	0.9993	0.9986	0.9978	0.9962	0.9948
1971 - 2008[3]	A	573.1	1219.8	1728.6	2226.9	2640.0	3015.1
	B	5	10.5	14	17	19	21
	C	0.761	0.823	0.849	0.865	0.866	0.870
	R^2	0.9998	0.9995	0.9990	0.9984	0.9963	0.9949

[1] Excludes the years 1999 and 2001
[2] Excludes the years 1991, 2001, and 2004
[3] Excludes the year 1999 only

The high values for the coefficient of determination (R^2) in Table 5.1 indicate that the IDF parameters generated under this update closely correspond to the relationships obtained from the analysis of the raw rainfall data.

The updated IDF parameters shown in Table 5.1 have been used to generate rainfall depths for 2, 4, 6, 12, and 24 hour durations. The results are presented in Table 5.2.

Table 5.2: Comparison of Rainfall Depths (mm)							
Duration (hrs)	Data	Return Period (Years)					
		2	5	10	25	50	100
2	1971 – 2003	29.1	42.9	52.5	64.4	73.5	82.4
	1971 – 2006	30.3	44.8	54.7	63.7	74.8	83.5
	1971 – 2008	29.1	44.3	54.1	63.2	73.6	81.4
4	1971 – 2003	34.5	49.7	60.3	73.4	83.4	93.2
	1971 – 2006	36.0	52.4	63.6	74.0	86.9	97.2
	1971 – 2008	34.8	51.8	62.8	73.3	85.9	95.3
6	1971 – 2003	38.0	53.7	64.6	78.2	88.5	98.5
	1971 – 2006	39.8	57.1	68.8	79.6	93.5	104.5
	1971 – 2008	38.6	56.3	67.8	78.9	92.6	102.8
12	1971 – 2003	44.7	60.9	72.0	86.0	96.5	106.3
	1971 – 2006	46.8	65.4	77.8	89.2	104.3	116.4
	1971 – 2008	45.8	64.4	76.5	88.4	103.9	115.3
24	1971 – 2003	52.3	68.6	79.6	93.5	104.0	113.4
	1971 – 2006	55.0	74.5	87.3	98.9	115.2	128.1
	1971 – 2008	54.2	73.2	85.7	98.1	115.3	127.7

The results in Table 5.2 indicate that, in general, rainfall depths are largest for the 1971 –2006 dataset. Rainfall depths for the 1971 – 2008 dataset are larger than the original 1971 – 2003 dataset, however not quite as large as the 1971 – 2006 dataset. The results for the 24 hour duration storms indicate a shift in the storm frequency based upon the updated meteorological datasets, whereby the higher depth storms would be anticipated to occur more frequently.

One objective of the IDF update has been to account for or consider the influence of Climate Change, and the more frequent occurrence of more severe events. This concept is reflected in the results of the foregoing assessment, whereby the inclusion of the data from 2005 to 2008 has effectively shifted the return period (i.e. risk); specifically, the 24 hour duration 10 year return period storm, which was determined based upon the 1971 – 2003 dataset alone, corresponds approximately to a 5 year return period storm for the same duration when the rainfall data from 2005 and 2006 are included in the dataset. In effect, these results indicate that, potentially, storm sewers would need to be designed to the current (2003) 10 year design standard in order to provide capacity for a 5 year storm event under a Climate Change perspective for the longer duration storm events. Similarly, the results suggest that stormwater management facilities which are currently designed to a 100 year standard would be sufficient for approximately a 50 year return period under a Climate Change for the 24 hour duration storm. Clearly the datasets used in this assessment are too short to definitively conclude that the Climate Change influences are absolute. Notwithstanding, these types of trends are widely speculated to become more pronounced and common over time. However, these trends become significantly less pronounced for the shorter duration storms.

Current research regarding Climate Change has applied global climate models, and has established probable meteorological adjustment factors at a coarse scale. The Ministry of Natural Resources has undertaken an initiative to develop Regional scale adjustment factors to account for the anticipated effects of Climate Change, however this initiative is generally limited to a daily scale of prediction, hence is of limited utility to storm infrastructure design. As research into the effects of Climate Change develop, it is recommended that the City update its IDF relationships accordingly in order to account for the potential risks associated with Climate Change.

At present, the 1971 – 2008 is considered the most complete dataset, and is recommended to be applied within the City of Cambridge under the Updated Stormwater Management Policy. As additional rainfall data becomes available, the IDF relationships should be updated accordingly. Based upon the apparent discrepancy in recorded rainfall between the proximate Environment Canada station and the local rainfall records, it is recommended that the IDF updates apply local rainfall data for the City of Cambridge.

5.1.3 Infrastructure

Current practice for stormwater management system design requires the design of a major-minor drainage system (overland and subsurface networks).

The minor system for stormwater conveyance infrastructure is intended to convey runoff from the more frequent storm events in such a manner as to minimize or prevent nuisance flooding of the surface system. Typically, the minor system consists of storm sewers, swales, gutters and catchbasins within urban areas, and ditches and swales within rural areas. The majority of these systems are located within the public right-of way in order to allow the Municipality or Region which owns the systems, access for maintenance, repair, or replacement. While storm sewers may also be located on private properties (i.e. under parking lots, between adjacent residential properties), the maintenance requirements are generally the responsibility of the property owner in the case of commercial or institutional properties, or else are done in response to concerns from the public in the case of residential properties, and are thus not included within the Municipality's maintenance program. All minor systems within the City of Cambridge are currently required to be designed to a 5 year design storm standard.

The major system for stormwater infrastructure is intended to convey runoff from the less frequent storm events in such a manner as to minimize flooding of private properties and prevent flooding of structures during these storm events. The major system is generally comprised of natural streams, valleys, constructed channels, ponds, and roads, and represents the routes of the storm runoff during events which exceed the capacity of the minor system (i.e. events above the 5 year standard). The major system is required to be designed in order to convey runoff from the Regulatory Storm event, which for Cambridge is the greater of the 100 year or the Regional Storm (Hurricane Hazel); for urban drainage systems which serve relatively smaller drainage areas (i.e. roads which would convey flows for areas less than 50 ha) the 100 year standard is typically applied and for natural or constructed channels and valleys which convey runoff from relatively large drainage areas (i.e. greater than 100 ha), the Regional Storm standard is generally applied. Current practice for the design of the major system generally requires verification of the Regulatory Storm event which is to be applied.

The formal application of a major-minor system design standard, as well as the associated criteria for the design, were established by the City of Cambridge in 1983. Prior to that time, design standards and requirements for the major-minor system were prescribed by the original member Municipalities (i.e. Preston, Galt, and Hespeler). Much of the infrastructure within the current City of Cambridge, particularly within the historic urban centres of the original Municipalities, pre-dates the 1983 design standards. In some areas, the original infrastructure dates back nearly a century, and has been replaced or maintained as per the original size and geometry; in these instances, the criteria applied for the original design is unknown. In either instance, the infrastructure, while compliant with the prevailing standards and criteria of the day, would be considered sub-standard compared to the current standards which are applied for new designs.

Flood protection requirements for bridges and culverts are defined by the freeboard, which represents the height of the minimum edge of travelled way above a prescribed water surface elevation for a given design storm related to the specific class of roadway. Current requirements for freeboard at hydraulic structures are specified in the Highway Drainage Design Standards (Ontario Ministry of Transportation, January 2008). Based upon these standards, the storm event (i.e. Design Storm) for which 1.0 m freeboard is required is determined based upon the classification of the roadway (i.e. freeway, arterial, collector, local), the type of cross-section (i.e. urban or rural), and the span of the opening. These criteria are summarized in Table 5.3.

Table 5.3: Design Standards for Hydraulic Structures

Functional Road Classification	**Return Period of Design Event (years)**	
	Total Span ≤ 6 m	**Total Span > 6 m**
Freeway, Urban Arterial	50	100
Rural Arterial, Collector	25	50
Local Road	10	25

Freeboard criteria were originally established by the Ministry of Transportation as part of Ministry Directive B-100, which was issued in October 1981. As indicated previously, much of the hydraulic infrastructure within the City of Cambridge preceded formal hydraulic design criteria, in some instances by more than 70 years; consequently, while the freeboard capacity of certain bridges and culverts within the City may be compliant with the prevailing practices at the time they were constructed, the freeboard capacity may be deficient compared to the current criteria, and may thus be susceptible to frequent flooding (i.e. overtopping) of the roadway during storm events.

5.2 Major/Minor System Modelling

Computer modelling of the City's major and minor system has been completed in order to identify any deficiencies with respect to the City's current drainage policy and criteria, and to thereby evaluate alternatives for remediation and to provide the City with estimated costs for remediation which would serve to guide the City's Capital Planning. The following section discusses the approach which has been applied for this assessment, and summarizes the results. Full details of the analyses are provided in Appendix 'E'.

5.2.1 Model

Hydrologic and hydraulic analyses of the City's major and minor system have been completed using the XP-SWMM methodology. The XP-SWMM methodology combines hydrologic modelling to generate storm runoff response (i.e. hydrographs) from land areas with hydraulic modelling to evaluate water surface elevations and velocities within the conveyance system (i.e. sewers, road surfaces, open watercourses, culverts). The integration of hydrologic and hydraulic analyses allows XP-SWMM to account for detention in ponding areas, backflow in pipes, surcharging of manholes, tailwater conditions (which may affect upstream storage and flow capacity within pipes), capacity at inlets to the sewer network (which would reduce the amount of runoff entering the sewer network and increase the amount of runoff conveyed overland during storm events), and depth of flooding of overland conveyance systems; these capabilities of the XP-SWMM methodology make it particularly well-suited for analyzing urban drainage systems.

The model applies the Event Methodology for storm events only (i.e. simulates individual discrete storm events versus continuous simulation of a long-term period of record of multiple storm events). Consequently, synthetic design storms are typically used with the XP-SWMM methodology in order to evaluate flood frequency or risk, as opposed to long-term continuous simulation based upon historic rainfall data. While the model is capable of accounting for various conditions at the outlet (i.e. open/unobstructed/free-flowing, partially/completely submerged to a constant depth, tidal/time-varying depth conditions, gated conditions), model instabilities may arise under more complex or temporally varying outlet conditions (i.e. submerged, tidal, or gated). The hydraulic routing component within XP-SWMM can be completed for unsteady state (i.e. time-varying flow) conditions using Kinematic Wave or Dynamic Wave routing techniques, however these methods frequently require that the network being analyzed be modified from the physical network in order to remove or refine any atypical elements of the network (i.e. pipes which are of markedly short or long length, large or small slope, or steep or gentle slope) compared to the remainder within the network , in order to avoid any numerical instabilities within the assessment. Consequently, it is not always feasible or practical to develop a model of a sewer network which corresponds precisely to the design or as-built condition (i.e. adjustments to the network are often required in order to eliminate instabilities or oscillations to the modelling results).

5.2.2 Data

The XP-SWMM methodology requires the following input for completing a coupled hydrologic and hydraulic analysis:

- Areas and impervious coverages for the land segments contributing to the conveyance system of interest.
- Soils information (i.e. SCS Curve Numbers) for the soils underlying the land segments.
- Surface slopes for the contributing drainage areas.
- Land use characteristics for both the pervious and impervious components of the land segments in order to establish the “roughness” of the surface.
- Length, size, and inverts of the sewer network.
- Material of the sewer network.
- Cross-section and elevations of the surface drainage system (i.e. roads).
- Locations of sewer inlets.
- Elevation and surface area relationships for surface storage zones (i.e. channels or designated off-line storage areas).

The above data input for the City’s storm sewer network has been obtained based upon the following information provided by the City for the development of the models for the major-minor system:

- GIS database of the City’s storm sewers and manholes (provided by the City of Cambridge)
- GIS database of the City’s road classifications (provided by the City of Cambridge)
- Various stormwater management reports (provided by the City of Cambridge for City-managed and privately owned and managed stormwater management facilities).
- Land use plan for the City of Cambridge (provided by the City of Cambridge)
- Soils mapping from the Ministry of Agriculture
- Sites of historic flooding within the City of Cambridge (provided by the City of Cambridge)
- Locations of publicly-owned properties within the City of Cambridge (provided by the City of Cambridge)
- 1 m contour data (provided by the City of Cambridge)
- Watercourse mapping (provided by the GRCA)
- HEC-2 and HEC-RAS hydraulic models (provided by the GRCA)
- Mapping of the roads within the City of Cambridge (provided by the City of Cambridge)

The sewer database has been reviewed in order to identify the City’s trunk sewers to be modelled (i.e. generally sewers greater than 600 mm). Catchment boundaries for the City’s sewer network have been developed based upon the sewer locations and the contour and road data provided by the City; these boundaries have been reviewed and verified with City staff input prior to initiating the hydrologic/hydraulic modelling. Data gaps in the City’s database have been provided to the City, and City staff have conducted supplemental survey and field reconnaissance in order to obtain the information necessary to fill these gaps in the hydrologic/hydraulic models.

The first stage in this process has consisted of delineating the various sewersheds within the City of Cambridge, with particular emphasis on those within which historic flooding issues had been reported (ref. Drawing 1). The delineation of the sewersheds has been completed based upon the topographic mapping provided by the City, as well as the sewer alignments provided within the GIS database which was initially provided at the outset of this project. As additional sewershed data was received over the course of this project (i.e. sewer diameters and inverts, and updated information regarding the network connections), the boundaries were refined as required in order to reflect the most current information for the City's sewers. Through this process, the boundaries for some 80 sewer networks within the City of Cambridge have been delineated.

The second stage in this process has consisted of further discretizing the trunk sewer networks with pipe sizes of 600 mm or greater, which represented the higher capacity networks within the City (i.e. the networks serving the larger drainage areas in the City of Cambridge). Through this refinement, the total number of sewer networks to be analyzed was screened to 53; the remaining smaller sewer networks which were screened from this assessment predominantly consist of small runs of sewers which serve relatively small drainage areas (i.e. typically less than 1 ha), and which discharge directly to the Grand River. The 53 networks (ref. Drawing 5) which were advanced for more detailed analyses has been discretized within the limits of the network in order to reflect the contributing drainage areas to key segments within the network; these key segments represented potentially critical or important lengths of sewer of relatively constant size and slope.

5.2.3 Analysis Approach

The following methodology has been applied for the development of the integrated hydrologic and hydraulic models, as well as the analyses being completed:

- Storm sewer system in each network has been simulated for 5 year and 100 year Chicago Design Storms for 4 hour and 12 hour durations (based on updated IDF relationships).
- Generally trunk sewer pipes equal to or bigger than 600 mm diameter have been included in the model. In some cases, pipes under 600 mm diameter have been included where they are between trunk sewer pipes or the extension of the trunk sewer system has been considered appropriate for modelling a particular area of impact.
- For hydrologic parameters, contour maps, soil maps, air photos, and land use maps have been used.
- For hydraulic parameters, storm sewer information has been directly entered into the model from the database provided from the City. Missing data have been additionally provided by the City upon request over the course of the study.

- Some of the pipes in the trunk sewer network have been combined considering their lengths, diameters and slopes to assist in attaining numerical stability.

- Major drainage system is defined to simulate the overland flow during events in excess of the minor system capacity; it has been assumed that the inlet capacity to the minor system would be restricted only by the capacity of the sewers themselves (i.e. reduced capacity at catchbasins has not been considered for this assessment).

- Two generic road cross-sections, representative of a typical 2-lane and 4-lane road have been developed and incorporated into the models for the purpose of simulating the major overland system. The selection of the cross-section to be applied to the overland element has been based upon a visual inspection of air photos.

- Where the overland flow route does not follow a roadway (i.e. open ditching), and where contour data has been insufficient to define a typical cross-section for the conveyance element, a typical 15 m wide trapezoidal section has been assumed.

- Storage-discharge relationships of Stormwater management facilities have been obtained primarily from reports. Design drawings provided by the City have been used when the report did not provide the information or when no related report was available. Contour maps and orifice equations have been used when the neither of the above two sources were available.

- Boundary conditions at outfalls have been set to free for 5 year storms and at 5-year water surface level for 100 year storms except for certain conditions. Water surface levels for specific storm events have been obtained from HEC-RAS/HEC 2 models where available. Exceptions to the boundary conditions noted have been specified in the summary of the results for each network.

Hydrologic and hydraulic analysis for the trunk sewers within the Groff Mill Creek Watershed have been completed using the currently approved XP-SWMM model which was developed for the Groff Mill Creek Flooding Assessment Class Environmental Assessment (Philips Engineering Ltd., June 2007). The modelling which has been completed for that study evaluated the watershed as a complete drainage system, and thus explicitly accounted for the tailwater conditions at the trunk sewer outlets to the Groff Mill Creek.

5.2.4 Minor System Assessment

The hydrologic/hydraulic analyses have been completed specifically in order to identify deficiencies within the City's trunk sewer network, based upon simulated incidences of flooding and surcharging within the City's minor system during a 5 year and 100 year storm event, with particular emphasis upon the occurrence of flooding during the former. Digital copies of the model input files are provided in Appendix 'E', and the corresponding catchment boundary plans are provided in Appendix 'F'. The results of this assessment are presented in Table 5.4, and the incidences of flooding and surcharge during the 5 year storm event are presented graphically on Drawing 6; more detailed graphical depictions within the sewersheds are provided with the catchment boundary plans in Appendix 'F'. The results of this assessment are also presented by percentages in Table 5.5.

Table 5.4: Summary of Simulated Minor System Performance During 5 Year Storm for City-Wide Drainage Networks

City Area	Network	Total Number of Sewers Modeled	Number of Sewers Unsurcharged	Number of Sewers Surcharged	Number of Sewers Flooded
Blair	55	15	14	1	0
	67	5	5	0	0
	68	10	10	0	0
	69	6	6	0	0
	70	17	17	0	0
Freeport	Freeport	36	32	4	0
Galt	3	17	17	0	0
	4	10	4	5	1
	5	21	13	4	4
	6	23	7	11	5
	7	44	30	9	5
	11	46	8	26	12
	13	15	13	2	0
	14	105	81	21	3
	18	5	3	2	0
	19	10	10	0	0
	20	12	5	4	3
	25	35	33	0	2
	27	15	3	12	0
	28	23	8	15	0
	32	9	9	0	0
	33	8	8	0	0
	37	3	3	0	0
	47	98	98	0	0
	48	12	12	0	0
	49	3	0	3	0
	50	3	3	0	0
	52	26	19	7	0
	53	12	10	2	0
	54	5	5	0	0
	56	64	59	5	0
	57	42	39	1	2
	58	20	20	0	0
	59	4	4	0	0
	61	6	4	2	0
	63	12	12	0	0
	65	19	14	5	0
Groff	Groff	7	0	4	0
Hespeler	1	17	3	5	9
	2	32	25	1	6
	8	69	49	19	1
	9	75	56	19	0
	10	64	63	1	0
	38	32	28	4	0
	39	29	26	3	0
	41	28	28	0	0
Preston	15	31	12	15	4
	16	28	27	1	0
	17	9	9	0	0
	23	22	10	12	0
	24	70	65	5	0
	26	11	0	1	10
	44	12	12	0	0
	45	40	31	5	4

Table 5.5: Summary of Simulated Minor System Performance during 5 Year Storm for City-Wide Drainage Networks as Percentage of Total Network Length Analyzed					
City Area	**Network**	**Total Number of Sewer Lengths Modeled**	**Percent Unsurcharged**	**Percent Surcharged**	**Percent Flooded**
Blair	55	15	93.3	6.7	0.0
	67	5	100.0	0.0	0.0
	68	10	100.0	0.0	0.0
	69	6	100.0	0.0	0.0
	70	17	100.0	0.0	0.0
Freeport	Freeport	36	88.9	11.1	0.0
Galt	3	17	100.0	0.0	0.0
	4	10	40.0	50.0	10.0
	5	21	61.9	19.0	19.0
	6	23	30.4	47.8	21.7
	7	44	68.2	20.5	11.4
	11	46	17.4	56.5	26.1
	13	15	86.7	13.3	0.0
	14	105	77.1	20.0	2.9
	18	5	60.0	40.0	0.0
	19	10	100.0	0.0	0.0
	20	12	41.7	33.3	25.0
	25	35	94.3	0.0	5.7
	27	15	20.0	80.0	0.0
	28	23	34.8	65.2	0.0
	32	9	100.0	0.0	0.0
	33	8	100.0	0.0	0.0
	37	3	100.0	0.0	0.0
	47	98	100.0	0.0	0.0
	48	12	100.0	0.0	0.0
	49	3	0.0	100.0	0.0
	50	3	100.0	0.0	0.0
	52	26	73.1	26.9	0.0
	53	12	83.3	16.7	0.0
	54	5	100.0	0.0	0.0
	56	64	92.2	7.8	0.0
	57	42	92.9	2.4	4.8
	58	20	100.0	0.0	0.0
	59	4	100.0	0.0	0.0
	61	6	66.7	33.3	0.0
	63	12	100.0	0.0	0.0
	65	19	73.7	26.3	0.0
Groff	Groff	7	56.2	43.8	0.0
Hespeler	1	17	17.6	29.4	52.9
	2	32	78.1	3.1	18.8
	8	69	71.0	27.5	1.4
	9	75	74.7	25.3	0.0
	10	64	98.4	1.6	0.0
	38	32	87.5	12.5	0.0
	39	29	89.7	10.3	0.0
	41	28	100.0	0.0	0.0
Preston	15	31	38.7	48.4	12.9
	16	28	96.4	3.6	0.0
	17	9	100.0	0.0	0.0
	23	22	45.5	54.5	0.0
	24	70	92.9	7.1	0.0
	26	11	0.0	9.1	90.9
	44	12	100.0	0.0	0.0
	45	40	77.5	12.5	10.0

5.2.5 Major System Assessment

The results of the XP-SWMM hydrologic/hydraulic analyses for major overland flow have been reviewed in order to identify the incidences of flooding of the major system (i.e. roadways) during sever storm events. Recognizing that current practice for drainage system design provides for safe and positive conveyance of flows within road right-of-ways (i.e. conveyance of flows overland within the public right-of-way and outside of private properties) during less frequent storms, this assessment has also considered the depth of flooding within the right-of-way during the 100 year storm event in order to evaluate the risk of flooding to private properties during the design event for overland storm conveyance. The depths of flooding have been subdivided into specific ranges, corresponding approximately to the key stages associated with the height of the curb along the urban roadways, and associated flood risks or hazards associated with the road right-of-way, and the potential for flooding of adjacent private properties. The results of this assessment are presented in Table 5.6.

Table 5.6: Summary of Simulated Major System Performance During 100 Year Storm for City-Wide Drainage Networks					
City Area	Network	Total Number of Roadway Lengths Modeled	Number of Lengths related to Depth of Flooding Range		
			0 – 0.08 m	0.08 – 0.15 m	> 0.15 m
Blair	55	15	13	2	0
	67	5	5	0	0
	68	9	7	2	0
	69	5	4	0	1
	70	16	8	4	4
Freeport	Freeport	26	14	0	12
Galt	3	15	12	1	2
	4	9	2	5	2
	5	19	10	1	8
	6	22	7	6	9
	7	38	18	6	14
	11	44	9	3	32
	13	14	5	4	5
	14	103	36	11	56
	18	5	2	0	3
	19	9	8	1	0
	20	11	0	1	10
	25	33	4	7	22
	27	14	1	0	13
	28	22	5	2	15
	32	7	5	2	0
	33	7	4	2	1
	37	3	1	0	2
	47	95	19	56	20
	48	14	7	7	0
	49	3	2	1	0
	50	3	3	0	0
	52	25	7	3	15
	53	10	3	4	3
	54	3	1	2	0
	56	64	19	15	20
	57	40	7	14	19
	58	19	17	0	2
	59	4	2	2	0
	61	5	1	2	2
	63	11	4	2	5
	65	17	0	7	10
Hespeler	1	17	2	2	13
	2	29	5	9	15
	8	49	10	14	25
	9	37	2	11	24
	10	62	16	15	31
	38	31	2	9	20
	39	23	7	9	7
	41	27	11	9	7
Preston	15	32	3	11	18
	16	27	16	7	4
	17	8	1	2	5
	23	21	8	3	10
	24	38	7	13	18
	26	10	2	0	8
	44	11	3	3	5
	45	25	4	3	18

The results presented in Table 5.6 indicate that all of the networks analyzed would be susceptible to some surface flooding during the 100 year storm event, which is generally consistent with current practice for drainage system designs. The results further indicate that the majority of the networks analyzed would be anticipated to be susceptible to flooding to depths above 0.15 m during the 100 year storm event, and thus the depth of flooding for the 100 year storm event could exceed the capacity of the curb and gutter system within the road, and thus extend beyond the road right-of-way for a portion of the network.

The information presented in Table 5.6 has been further reviewed in order to determine the proportion (i.e. percentage) of each network analyzed which would be susceptible to flooding within the range of depths specified above, and to thereby obtain an indication of the extent and relative magnitude of the flood risk and associated hazard potential for each of the networks analyzed. The results of this assessment are presented in Table 5.7, and are depicted graphically on Drawing 7; more detailed graphical depictions of the results are provided with the catchment boundary plans in Appendix ‘F’.

Table 5.7: Summary of Simulated Major System Performance during 100 Year Storm for City-Wide Drainage Networks as Percentage of Total Network Length Analyzed					
City Area	**Network**	**Total Number of Roadway Lengths Modeled**	**Percent of Network Flooded to Between 0 – 0.08 m**	**Percent of Network Flood to Between 0.08 – 0.15 m**	**Percent of Network Flooded to > 0.15 m**
Blair	55	15	86.7	13.3	0.0
	67	5	100.0	0.0	0.0
	68	9	77.8	22.2	0.0
	69	5	80.0	0.0	20.0
	70	16	50.0	25.0	25.0
Freeport	Freeport	26	53.8	0.0	46.2
Galt	3	15	80.0	6.7	13.3
	4	9	22.2	55.6	22.2
	5	19	52.6	5.3	42.1
	6	22	31.8	27.3	40.9
	7	38	47.4	15.8	36.8
	11	44	20.5	6.8	72.7
	13	14	35.7	28.6	35.7
	14	103	35.0	10.7	54.4
	18	5	40.0	0.0	60.0
	19	9	88.9	11.1	0.0
	20	11	0.0	9.1	90.9
	25	33	12.1	21.2	66.7
	27	14	7.1	0.0	92.9
	28	22	22.7	9.1	68.2
	32	7	71.4	28.6	0.0
	33	7	57.1	28.6	14.3
	37	3	33.3	0.0	66.7
	47	95	20.0	58.9	21.1
	48	14	50.0	50.0	0.0
	49	3	66.7	33.3	0.0
	50	3	100.0	0.0	0.0
	52	25	28.0	12.0	60.0
	53	10	30.0	40.0	30.0
	54	3	33.3	66.7	0.0
	56	64	35.2	27.8	37.0
	57	40	17.5	35.0	47.5
	58	19	89.5	0.0	10.5
	59	4	50.0	50.0	0.0
	61	5	20.0	40.0	40.0
	63	11	36.4	18.2	45.5
	65	17	0.0	41.2	58.8
Hespeler	1	17	11.8	11.8	76.5
	2	29	17.2	31.0	51.7
	8	49	20.4	28.6	51.0
	9	37	5.4	29.7	64.9
	10	62	25.8	24.2	50.0
	38	31	6.5	29.0	64.5
	39	23	30.4	39.1	30.4
	41	27	40.7	33.3	25.9
Preston	15	32	9.4	34.4	56.3
	16	27	59.3	25.9	14.8
	17	8	12.5	25.0	62.5
	23	21	38.1	14.3	47.6
	24	38	18.4	34.2	47.4
	26	10	20.0	0.0	80.0
	44	11	27.3	27.3	45.5
	45	25	16.0	12.0	72.0

The results in Table 5.7 indicate that, in general, the conveyance capacity of the major systems analyzed would be anticipated to be exceeded during the 100 year storm event, and hence the depth of flooding would be anticipated to exceed the capacity of the roadway curb and gutter, and would thus extend beyond the limits of the roadway and, quite potentially, outside of the public right-of-way. These areas are generally located within the historic areas of the City of Cambridge, and the results are thus considered attributable to the prevailing design standards of the day which likely did not account for major system conveyance as part of the road design.

5.2.6 Assessment of Alternatives

Minor System Capacity

Based upon the results of the integrated hydrologic/hydraulic assessment, a long list of alternatives to mitigate the surcharge and flooding conditions for the minor system during the 5 year storm event, as well as to alleviate the depth of flooding during the 100 year storm event has been developed. Based upon discussions with City Staff and the full Project Team during this process, the following alternatives have been advanced for consideration in order to address the deficiencies associated with minor system performance during the 5 year storm event:

i) "Do Nothing".
ii) Increase size of affected storm sewers.
iii) Implement stormwater management on-site for adjacent private properties for quantity control.
iv) Implement off-line storage areas within available public spaces.
v) Implement super pipes to provide on-line stormwater quantity control.
vi) Retrofit existing stormwater management facilities to provide additional quantity control to mitigate these conditions.
vii) Combinations of above.

The following alternatives have been eliminated from further consideration, based upon a consultative screening process:

- Alternative i) "Do Nothing" would allow the current issues of nuisance flooding and deficient capacity to continue, hence this alternative has been screened from further consideration.

- While the implementation of on-site stormwater quantity control within adjacent private properties could mitigate a portion of the surcharging and flooding conditions, it would depend entirely upon participation of private property owners, and is not considered a readily attainable solution. On this basis, it has been screened from further consideration.

- Limited public property is available adjacent to or within the sewer network for the construction of off-line storage areas. While this alternative may be available for some networks, it is not readily attainable "on the whole", and thus has been screened from further consideration.

- The majority of the existing stormwater management facilities within the City of Cambridge lie outside of the areas which would be subject to surcharging of the minor system during the 5 year storm event, and thus would provide no benefit to those systems. Moreover, the stormwater management facilities within the networks which currently experience surcharge during the 5 year storm event are typically well within the headwaters of those areas and service relatively small drainage areas; hence, retrofitting of these facilities to provide additional flood control would not be anticipated to provide any appreciable benefit. On the basis of the foregoing, this alternative has been screened from further consideration.

Based upon the foregoing, two alternatives have been advanced for further consideration: Increase the size of the affected storm sewers to provide sufficient capacity to prevent surcharge and flooding during the 5 year event, or implement on-line super pipes to provide stormwater quantity control. Of the two alternatives, the latter requires additional functional considerations for the location and size of the super pipe, as well as the costs associated with each sub-alternative within this alternative, in order to define the "optimal" configuration for this particular alternative; by contrast, the option of increasing the pipe size of only the affected storm sewers is more readily assessed, since the siting of the replacement pipe is defined by the incidences of surcharge and flooding. On this basis, additional analyses have been completed for the affected minor systems in order to determine the change in pipe sizes which would be required in order to mitigate the incidences of surcharge and flooding of the minor system during the 5 year storm event. This assessment has involved an iterative adjustment to the pipe sizes which experience surcharging and flooding, until these conditions were mitigated within the respective network. The results of this assessment are summarized in Table 5.8.

Table 5.8: Summary of Storm Sewer Upgrade Requirements to Achieve 5 Year Capacity

Network	Pipe ID	Existing Sewer			Proposed Sewer		
		Diameter (mm)	Length (m)	Slope (%)	Diameter (mm)	Length (m)	Slope (%)
1	15937	600	199.4	2.09	900	199.4	2.09
	15931	600	39.4	1.52	750	39.4	1.52
	16034	450	73.4	3.00	600	73.4	3.00
	16032 & 16033	450	31.6	2.15	600	31.6	2.15
	15929 & 15932	600	90.1	0.63	900	90.1	0.63
	15928	600	110.2	1.38	900	110.2	1.38
	15927	600	76.6	1.97	825	76.6	1.97
	15926	600	81.1	1.75	750	81.1	1.75
	15924 & 15925	600	57.4	1.46	750	57.4	1.46
2	15648	600	22.2	0.14	1050	22.2	0.14
	15647	450	72.9	0.03	1050	72.9	0.03
	15646	450	114.3	0.24	1050	114.3	0.24
	15645	450	52.5	0.02	900	52.5	0.02
	15644	450	61.9	0.10	900	61.9	0.10
	15643	450	84.3	0.52	900	84.3	0.52
	15832 & 15833	450	108.9	1.48	600	108.9	1.48
4	12657	600	120.6	2.00	750	120.6	2.00
	13232	600	50.4	0.63	900	50.4	0.63
	18464	600	66.1	0.30	900	66.1	0.30
	18463	600	58.3	0.02	1050	58.3	0.02
	18462	600	108.5	0.17	1050	108.5	0.17
	18461	600	105.4	0.31	1050	105.4	0.31

Table 5.8: Summary of Storm Sewer Upgrade Requirements to Achieve 5 Year Capacity							
Network	Pipe ID	Existing Sewer			Proposed Sewer		
		Diameter (mm)	Length (m)	Slope (%)	Diameter (mm)	Length (m)	Slope (%)
5	10112 & 10131	600 & 525 (797 equiv.)	94.8	3.51	750	94.8	3.51
	10124 & 10122 & 10125	600 & 200 (632 equiv.)	149.3	2.36	750	149.3	2.36
	12904	750	45.8	1.83	900	45.8	1.83
	12905	750	66.6	1.58	825	66.6	1.58
6	11467**	600	56.2	0.32	750	56.2	0.32
	11466**	600	39.2	0.31	825	39.2	0.31
6	11464**	600	17.8	0.11	825	17.8	0.11
	11421 & 11090	450	64.8	0.79	600	64.8	0.79
7	10926	750	63.8	0.08	1500	63.8	0.08
	10925	1050	66.9	1.17	1200	66.9	1.17
	10922	1050	81.1	0.16	1200	81.1	0.16
	10927	1050	95.4	0.69	1200	95.4	0.69
	11369	600	66.0	0.65	750	66.0	0.65
	11432	900	80.8	4.12	1050	80.8	4.12
	11474	1200	76.1	0.39	1350	76.1	0.39
8	15408	600	71.5	0.28	675	71.5	0.28
	15413	750	91.6	0.60	825	91.6	0.60
	15414	825	91.1	0.40	975	91.1	0.40
	15415	900	74.6	0.42	1050	74.6	0.42
	15320	975	67.4	0.39	1050	67.4	0.39
	15321	1050	91.7	0.39	1200	91.7	0.39
	15323	1200	76.0	0.55	1350	76.0	0.55
	15319	1200	83.5	0.67	1350	83.5	0.67
	19841	900	90.5	0.10	1200	90.5	0.10
	15318***	750	139.3	1.39	750	139.3	0.36
	15597	600	117.9	2.37	675	117.9	2.37
9/10/39	15138	750	98.7	0.42	900	98.7	0.42
	18689	900	31.4	0.51	975	31.4	0.51
	16083	900	80.0	0.34	975	80.0	0.34
	16105	900	28.4	0.28	975	28.4	0.28
	16104	900	14.1	0.28	975	14.1	0.28
11	12673	900	93.8	1.52	1050 (1200)	93.8	1.52
	12664	900	64.2	1.40	1050 (1200)	64.2	1.40
	12666	900	77.0	1.09	1050 (1200)	77.0	1.09
	12667	900	85.1	0.81	1050 (1200)	85.1	0.81
	12710+12711	900	71.2	0.70	1050 (1200)	71.2	0.70
	12661	900	53.0	1.58	1200 (1350)	53.0	1.58
	12663	900	108.6	1.58	1200 (1350)	108.6	1.58
	12665	900	121.5	1.06	1200 (1350)	121.5	1.06
	12675	900	144.3	0.69	1350	144.3	0.69
	12723+12677	900	42.3	1.06	1350	42.3	1.06
	12713	900	103.7	0.79	1350	103.7	0.79
	12717	900	158.9	0.53	1350	158.9	0.53
	12827	900	154.6	0.54	1350	154.6	0.54
	12857+12816	900	170.2	0.32	1350	170.2	0.32
	12862	900	40.7	0.31	1350	40.7	0.31
	19528+19527***	600	103.8	0.20	675	103.8	0.50
	13004	750	18.3	3.44	1050	18.3	3.44

Table 5.8: Summary of Storm Sewer Upgrade Requirements to Achieve 5 Year Capacity							
Network	Pipe ID	Existing Sewer			Proposed Sewer		
		Diameter (mm)	Length (m)	Slope (%)	Diameter (mm)	Length (m)	Slope (%)
	13005	750	85.2	0.46	1050	85.2	0.46
	13007	750	82.8	0.46	1050	82.8	0.46
	13010	750	84.2	0.30	1050	84.2	0.30
	13184	750	108.0	1.38	900	108.0	1.38
	13651+13652	675	63.8	0.77	900	63.8	0.77
	13028	675	78.4	0.87	900	78.4	0.87
	13029	675	76.4	0.82	900	76.4	0.82
	13031+13033	675	77.5	1.05	900	77.5	1.05
	13116	675	115.8	0.18	900	115.8	0.18
13	16739	450	89.3	0.73	675	89.3	0.73
	16740	450	45.3	1.41	600	45.3	1.41
14	13599***	600	54.6	0.75	825	54.6	0.37
14	13619+18408***	600	69.6	0.19	900	69.6	0.37
	13601***	600	50.3	0.14	975	50.3	0.37
	18340+18341 +18342+18343 +18344***	600	83.9	0.15	975	83.9	0.19
	18345+18346 +13630***	600	80.3	0.50	975	80.3	0.19
	13717	750	82.0	0.40	825	82.0	0.40
	13590	750	86.1	0.42	825	86.1	0.42
	13589	750	90.0	0.51	825	90.0	0.51
	13752***	525	69.1	1.20	600	69.1	0.50
	13922+13923***	750	97.5	0.21	900	97.5	0.25
	13893***	750	90.3	0.33	900	90.3	0.25
15	20193	900	96.0	1.00	1350	96.0	1.00
	14940	900	57.3	1.17	1350	57.3	1.17
	14941	900	59.4	0.82	1350	59.4	0.82
	11249	900	89.3	0.49	1350	89.3	0.49
	10836***	750	97.2	0.87	750	97.2	1.32
16	11556	375	92.5	0.59	450	92.5	0.59
18/19	10861	525	48.1	1.25	600	48.1	1.25
	10907	525	36.0	1.11	600	36.0	1.11
20	12901	750	162.8	0.50	975	162.8	0.50
	11482	600	109.5	7.48	675	109.5	7.48
	11436 & 10253	600	130.8	0.57	750	130.8	0.57
	10963 & 10962	450	100.5	4.02	675	100.5	4.02
23	11659 & 11658	900	42	0.21	1050	42	0.21
	11657	900	67.4	0.53	1050	67.4	0.53
	11656	900	66.6	0.36	1200	66.6	0.36
	11655	900	50.8	0.91	1050	50.8	0.91
	18953	900	47.6	0.34	975	47.6	0.34
	11653	900	101.6	0.34	975	101.6	0.34
	11652	900	111.8	0.28	1050	111.8	0.28
	11651 & 11203	750	41.4	1.86	900	41.4	1.86
24	11733	525	23.9	0.04	600	23.9	0.04
	11732	525	50.7	0.47	600	50.7	0.47
	11775	525	52.9	0.25	600	52.9	0.25
	11281***	750	32.0	1.84	825	32.0	0.50
	11280***	750	20.1	0.50	825	20.1	0.50

Table 5.8: Summary of Storm Sewer Upgrade Requirements to Achieve 5 Year Capacity							
Network	Pipe ID	Existing Sewer			Proposed Sewer		
		Diameter (mm)	Length (m)	Slope (%)	Diameter (mm)	Length (m)	Slope (%)
25	18946	300	39.8	1.76	600	39.8	1.76
	12895	300	33.6	0.86	600	33.6	0.86
26	14851	600	70.4	0.04	750	70.4	0.04
	14684	600	35.6	0.22	750	35.6	0.22
	14801	525	98.7	0.35	600	98.7	0.35
	14803	375	82.3	1.20	450	82.3	1.20
27	11923	1050	22.2	1.00	1200	22.2	1.00
	11910	1050	83.0	0.69	1200	83.0	0.69
	11963	900	88.5	0.51	975	88.5	0.51
	11957	600	31.1	0.32	675	31.1	0.32
28	13316 & 13317	900	71.3	1.89	1050	71.3	1.89
	13327 & 13332	900	76.3	1.99	975	76.3	1.99
	13305	900	96.3	0.53	1200	96.3	0.53
	13304	900	90.6	0.50	1200	90.6	0.50
	13331	900	75.0	0.53	1200	75.0	0.53
	13330	900	52.3	0.46	1200	52.3	0.46
	11987	900	74.2	0.47	1200	74.2	0.47
28	11990	825	74.8	0.32	900	74.8	0.32
	13051	825	76.8	0.39	900	76.8	0.39
38	15845***	675	28.6	1.96	1500	28.6	1.96
	15846***	600	75.5	3.35	975	75.5	3.35
	15896***	600	135.7	2.20	825	135.7	2.20
	15861	450	91.6	7.02	675	91.6	7.02
45	11532	750	131.2	0.43	825	131.2	0.43
	10706+10689	375	49.1	0.37	450	49.1	0.37
	10688	375	75.5	0.75	450	75.5	0.75
	10690	375	69.9	0.79	450	69.9	0.79
	10694	375	93.1	0.73	525	93.1	0.73
	10695	525	79.1	0.42	675	79.1	0.42
	10696	525	105.9	0.54	675	105.9	0.54
	10697+10691	525	48.7	0.51	675	48.7	0.51
52	13952 & 13953	1200	137.9	0.33	1350	137.9	0.33
	13864	1050	109.6	0.40	1200	109.6	0.40
	13727	900	91.2	0.50	975	91.2	0.50
	13741 & 13740	900	49.4	0.49	975	49.4	0.49
	18547***	300	99.5	1.32	525	99.5	1.32
56	12301	525	87.8	0.50	600	87.8	0.50
	18910	450	46.4	0.84	525	46.4	0.84
	12385	600	85.0	0.51	675	85.0	0.51
57	13220	300	62.1	1.38	375	62.1	1.38
	13221	300	103.9	0.56	450	103.9	0.56
61	13775	600	89.8	0.24	675	89.8	0.24
65	11497	375	14.8	0.20	525	14.8	0.20
	11494	375	40.4	2.82	450	40.4	2.82
Freeport	19164	750	60.8	0.30	825	60.8	0.30
	19163	825	49.0	0.31	900	49.0	0.31
	19162	825	53.1	0.30	900	53.1	0.30
	11681	750	69.6	0.47	900	69.6	0.47
	11680	750	60.6	0.33	900	60.6	0.33

*** Indicates a slope modification. Where pipe size is given in brackets, first value is required size, value in brackets indicates size of upstream storm sewers.

The analyses completed for the trunk sewers within the Groff Mill Creek Watershed have indicated that the surcharge condition during the 5 year event is attributable to the tailwater conditions at the outlet to the Groff Mill Creek. Consequently, the condition cannot be successfully mitigated by the replacement of the storm sewers, but could require alternative strategies in order to fully mitigate those conditions (i.e. implement off-line storage areas within public spaces, implement super-pipe to provide on-line stormwater quantity control, regrade watermain to reduce tailwater elevations, or combinations of the above). The evaluation of these alternatives would necessarily require a more detailed assessment of the constraints within the subject area, which is beyond the scope of this Master Plan. It is therefore recommended that the above alternatives and additional alternatives be evaluated in conjunction with the Capital Projects within the City.

Cost estimates have been developed based upon estimated requirements to replace the deficient infrastructure as presented in Table 5.8, in order to provide the requisite minor system capacity to a 5 year design standard. The total replacement cost includes the pipe and also accounts for installation, replacement appurtenances (i.e. catchbasins and manholes), and resurfacing of the roads (ref. Table 5.9).

Table 5.9. Preliminary Cost Estimates For Sewer Upgrades To 5 Year Capacity

City Area	Total Length to be Replaced (m)	Estimated Total Cost ($)
Blair	99.5	$36,000
Freeport	293.1	$335,000
Galt	7,437	$11,054,000
Groff	0	$0
Hespeler	2,855	$3,707,000
Preston	2,140	$2,393,000
Entire City	**12,825**	**$17,525,000**

Major System Capacity

A long list of alternatives to mitigate the impacts of flooding of private property during the 100 year storm event has been developed. The following specific alternatives have been advanced for consideration:

i) Do Nothing.
ii) Increase size of storm sewers within network in order to increase the minor system capacity to reduce depth of flooding of the major system to less than 0.15 m.
iii) Implement stormwater management on-site for adjacent private properties for quantity control.
iv) Implement off-line storage areas within available public spaces.
v) Implement super pipes to provide on-line stormwater quantity control.
vi) Retrofit existing stormwater management facilities to provide additional quantity control to mitigate these conditions.
vii) Modify grading on private property to mitigate flooding.
viii) Modify grading within road right of way to mitigate flooding.
ix) Combinations.

The following alternatives have been eliminated from further consideration, based upon a consultative screening process:

- Alternative i) "Do Nothing" would allow the current issues of flooding and deficient capacity to continue in perpetuity. While this alternative is not preferred, various constraints imposed by grading, infrastructure, property boundaries, and economics may preclude the possibility of addressing the deficiencies to the conveyance capacity within the right-of-way.

- While the implementation of on-site stormwater quantity control within adjacent private properties could mitigate a portion of the surcharging and flooding conditions, it would depend entirely upon participation of private property owners, and is not considered a readily attainable solution. On this basis, it has been screened from further consideration.

- Limited public property is available adjacent to, or within, the sewer network for the construction of off-line storage areas. While this alternative may be available for some networks, it is not readily attainable "on the whole", and thus has been screened from further consideration.

- Opportunities to implement super pipes to provide on-line stormwater quantity control or to modify the grading of public and private properties would require additional details regarding the constraints within the specific areas (i.e. grading within and adjacent to right-of-way, utilities, sewer connections, outfall conditions and obstructions, etc.), which are beyond the scope of this Master Plan. While these alternatives cannot be evaluated in detail at this time, it has nevertheless been advanced as a potential solution to be considered as part of future work within the City.

- The majority of the existing stormwater management facilities within the City of Cambridge lie outside of the areas which would be subject to flooding of private properties during the 100 year storm event due to the capacity of the City's road right-of-way, and thus would provide no benefit to those systems. On the basis of the foregoing, this alternative has been screened from further consideration.

In an effort to develop an initial understanding of the potential cost implications associated with modifying the minor system in order to mitigate the risk of flooding to private property during the 100 year storm event (i.e. oversizing storm sewers to 100 year capacity), additional analyses have been completed for selected networks (Networks 1 and 20) in order to determine the potential increase in sewer size which would be required to reduce the depth of major system flooding during the 100 year storm event to the gutter depth of the road (i.e. 0.15 m). The results of this assessment are summarized in Table 5.10.

Table 5.10: Summary of Storm Sewer Upgrade Requirements to Achieve Reduce Major System Flooding for 100 Year Storm							
1	Outlet	600	13.5	6.07	1350	13.5	6.07
1	15937	600	199.4	2.09	1350	199.4	2.38
1	15931	600	39.4	1.52	750	600	39.4
1	16034	450	73.4	3.00	750	450	73.4
1	16033 & 16032	450	31.6	2.15	750	450	31.6
1	15929	600	90.1	0.63	1350	90.1	0.63
1	15928	600	110.2	1.38	1200	110.2	1.38
1	15927	600	76.6	1.97	1050	76.6	1.97
1	15926	600	81.1	1.75	1050	81.1	1.75
1	15925 & 15924	600	57.4	1.46	750	57.4	1.46
20	12901	750	162.8	0.50	1650	162.8	0.50
20	12900	900	88.0	0.92	1500	88.0	0.92
20	12930	900	62.9	1.29	1500	62.9	1.29
20	11482	600	109.5	7.48	675	109.5	7.48
20	10972	600	86.6	1.50	675	86.6	1.50
20	10968	600	85.5	0.88	675	85.5	0.88
20	10967	600	100.5	0.85	675	100.5	0.85
20	11438	600	137.0	1.96	750	137.0	1.96
20	11436 & 10253	600	130.8	0.57	900	130.8	0.57
20	10962 & 10963	450	100.5	4.02	750	100.5	4.02

The information provided in Table 5.10 has been used in order to develop cost estimates for the replacement of the storm sewers. Consistent with the approach applied for the cost estimates to achieve a 5 year capacity within the minor system, the total replacement cost has been estimated as three times the supply cost of the sewers, in order to account for installation, replacement appurtenances (i.e. catchbasins and manholes), and resurfacing of the roads. The results of this assessment are summarized in Table 5.11.

Table 5.11: Preliminary Cost Estimates for Minor System Upgrades to 5 Year Capacity

Network Reference Number	Total Length to be Replaced (m)	Estimated Total Cost ($)
1	2182.3	$2,876,300
20	1064.1	$1,850,500

The results in Table 5.11 have been compared with the results provided in Table 5.9 for the respective networks, in order to determine the relative increases in cost required for upgrades to the minor system in order to mitigate 100 year flooding impacts. The results of this assessment indicate that the cost for upgrading the minor system to accommodate a portion of the flow during the 100 year storm event would be approximately 3.4 times the cost for upgrading the minor system in order to mitigate incidences of surcharge and flooding alone; consequently, opportunities to mitigate deficiencies related to the 100 year storm event through upgrades to the City's minor system are considered cost-prohibitive.

Alternative strategies to mitigate the impacts of flooding of private property during the 100 year storm event include:

- Implement off-line storage areas within available public spaces.
- Implement super pipes to provide on-line stormwater quantity control.
- Modify grading on private property to mitigate flooding.
- Modify grading within road right of way to mitigate flooding.
- Combinations.

The evaluation of each of the above alternatives would necessarily require a more detailed and site specific assessment of the constraints within each identified area which has been noted as flood prone during a major event (i.e. grading within and adjacent to right-of-way, utilities, sewer connections, outfall conditions and obstructions, etc.), which are beyond the scope of this Master Plan. It is therefore recommended that the above alternatives and additional alternatives be evaluated wherever and whenever opportunities unfold to address these issues in conjunction with other Capital Projects within the City.

5.3 Supplemental Field Reconnaissance at Historic Flooding Sites

Various sites of historic flooding lie upstream of the most discrete element of the hydrologic/hydraulic models, or in some cases the results of the modelling have not indicated any issues with respect to the existing stormwater infrastructure which would explain the cause of the flooding. Hence, supplemental field reconnaissance have been recommended for each of the historic flooding sites, in order to document the conditions in the area, and provide further insight into the likely causes of the flooding previously observed.

A total of 64 of the historic flooding sites have been identified, which require field reconnaissance in order to better explain the cause of the flooding. Field reconnaissance has been completed for 39 of those as part of this study and the results of this assessment are provided in Appendix 'G', and the results are summarized in Table 5.12.

Table 5.12: Flooding Location And Potential Issues And Causes

Issues and Causes	Sites (By ID)
Flat grading along roads	5, 7, 11, 29, 31, 44, 65, 88, 90, 97
Adverse grading along private property	38, 43, 78, 81
Condition of ditches and culverts	33, 59, 61, 82
Debris at catch basins	6, 8, 86, 92, 101
Unknown	1, 10, 16, 27, 42, 50, 62, 63, 67, 71, 77, 93, 94, 100, 103, 105
Specific location undefined	2, 17, 20, 22, 23, 24, 26, 32, 34, 35, 39, 45, 47, 48, 49, 51, 53, 54, 56, 57, 69, 70, 73, 76, 87

The information provided in Table 5.12 provides some indication that the historically observed flooding issues generally range from grading issues along within the road right-of-way (i.e. low points along the road, relatively few catchbasins or relatively small inlets to catchbasins, grading issues along roadside ditches), to grading issues on private properties (i.e. low points on private property where water can collect), to observed accumulation of debris at the catchbasin inlets. The mitigation opportunities would similarly vary by location (i.e. regrading within road right-of-way, regrading on private property, replacement of hydraulic appurtenances, maintenance activities).

The results also indicate that the cause of the flooding could not be determined for sixteen (16) of the sites visited; these causes could be attributed to minor local capacity issues and constraints with the minor system, as well as flooding mechanisms not visible from the road right-of-way (i.e. basement flooding through window wells). In some instances, the uncertainly is associated, in part, to the lack of clear definition as to the precise location of the flooding problem, as well as the severity of the conditions identified in the field (i.e. issues considered to be associated with flooding issues may not have been as substantial or significant at these locations). Additional information would be required in order to more conclusively determine the cause of the flooding at these sites; at present, it is recommended that these sites be inspected during more severe storm events in order to better determine flooding issues and potential causes.

Finally, as indicated in Table 5.12, field reconnaissance was not completed for 25 of the sites. The description for the location of flooding associated with these sites is quite general (i.e. a street name has been provided, but without any intersecting roadway or street address). Additional insight for these locations will be required in order to better determine the location of historic flooding and define the potential flood mechanism.

5.4 Culvert/Bridge Hydraulics

Hydraulic analyses have been completed for City-owned crossings of the open watercourses within the City of Cambridge in order to verify whether or not the conveyance capacity of the crossings complies with current Provincial standards for freeboard and clearance, and to obtain preliminary estimates of requirements to evaluate the crossings as required.

5.4.1 Modelling Approach

Hydraulic analyses for the open watercourse systems and the associated hydraulic structures (i.e. bridges and culverts) within the City of Cambridge have been completed using the HEC-RAS Version 3.1.3 methodology. The HEC-RAS methodology calculates hydraulic conditions (i.e. water surface elevations and velocities) based upon geometric data for the system and flow rates established from hydrologic analyses. Geometry data representing cross-sections within the open watercourse system is required, along with "roughness coefficients" which represent the surface treatment of the channel and the floodplain (i.e. rock, concrete, type and density of vegetation, etc.), distances from adjacent cross-sections in the model, obstructions to flow, and rates of change to flow area (i.e. expansion and contraction coefficients). Information is also entered into the model with respect to hydraulic structures (i.e. bridges and culverts); various analytical methods are available for the analysis of these structures (i.e. nomographs, pressure/weir calculations, energy equations). Conditions at the outlet can be specified based upon known water surface elevations, estimated water surface elevations based upon the slope of the channel, or else based upon critical depth.

Current practice for hydraulic analyses at bridges and structures requires that the HEC-RAS model be executed under steady-state conditions under a subcritical profile. Under these conditions, the flow is assumed to be constant (i.e. the available volume of water is not restricted by the amount generated by the storm runoff which produces the corresponding peak flow rate), and the water surface elevation is defined by the "potential energy" component of the energy equation as opposed to the "kinetic energy" component of the energy equation.

5.4.2 Data Requirements

The required input data for the analysis of open watercourse hydraulics and the City's bridges and culverts has been generated from the following information:

- Existing HEC-RAS hydraulic models for open watercourses (where available).
- 1 m contour data.
- As-built survey information for the bridges and culverts within the City.
- Return period or frequency flows generated from current hydrologic models (where available).
- Return period flows generated from XP-SWMM hydrologic/hydraulic modelling (where no current models were available).

The locations of the hydraulic structures assessed under this component of the work plan are presented on Drawing 8: Hydraulic Structure Reference Location Plan.

5.4.3 Analysis

During the course of the review of the background information, it was determined that, the modelling available for the Regulated open watercourses within the City of Cambridge varied across the City. In some instances, no hydraulic models were available or were not considered reflective of the actual hydraulic structures, and, in a few instances, no hydrologic or hydraulic modelling was available for the Regulated open watercourses. Consequently, the analyses completed for the hydraulic structures along the open watercourses varied according to the information available. The tasks completed by watercourse for the assessment of the hydraulic structures within the City of Cambridge are summarized in Table 5.13.

Table 5.13: Hydraulic Model Modifications Completed for City of Cambridge Watercourses			
Watercourse	**Generate Flows**	**Generate Geometric Data (i.e. Cross-Sections)**	**Import HEC-2 into HEC-RAS**
Forbes Creek			
Chilligo Creek	X	X	
Hespeler East Creek			
Hespeler Middle Creek			
Hespeler West Creek			
Freeport Creek	X	X	
Blair Creek			
Bechtel Creek	X	X	
Groff Mill Creek			
Mill Creek			
Moffat Creek	X[1.]	X[2.]	X[3.]
Devil's Creek	X	X	

NOTE: 1. Flows for the Moffat Creek generated for the reaches upstream of Dundas Street, unless available from other sources.
2. Cross-sections generated only for the reaches upstream of Dundas Street; geometric data for cross-sections downstream of Dundas Street retained from the current hydraulic model.
3. The importing of HEC-2 into HEC-RAS included a review and revision of the hydraulic structures within the model, in order to comply with the HEC-RAS methodology.

Although the hydraulic analyses have been completed using the currently approved hydrologic and hydraulic models, (where available), the objective of the assessment has been to evaluate the hydraulic performance of specific structures within the City of Cambridge, and to estimate requirements to mitigate deficiencies. Consequently, the information presented, as well as the models which have been used in order to complete the requisite analyses, should not be regarded as sufficient indicators or bases for generating Regulatory Floodplains within the City of Cambridge. Digital copies of the HEC-RAS hydraulic models are provided in Appendix 'H'.

As indicated by the information provided previously in Section 5.1, the freeboard criteria for hydraulic structures (i.e. the frequency of the freeboard design event) depends upon the roadway classification, which relates to the frequency and level of use of the roadway. The classifications of the roadways within the City of Cambridge, as provided by City staff, are summarized in Table 5.14.

Table 5.14: Roadway Classifications Applied for Freeboard Assessment at Hydraulic Structures				
Creek	**Crossing**	**Reference ID**	**Ownership**	**Roadway Classification**
Forbes	Black Bridge Rd.	1	Cambridge	Collector
	Black Bridge Rd.	2	Cambridge	Collector
	Hespeler Rd.	3	Not Specified	Local
	Baldwin Dr.	4	Cambridge	Local
Freeport	CNR	5	CNR	n/a
Hespeler West, East Creeks	Beaverdale Rd.	6	Not Specified	Arterial
	Hal Rogers Dr.	7	Cambridge	Local
Bechtel	Blair Rd.	8	Not Specified	Arterial
	Langdon Dr.	9	Not Specified	Local
	Fallbrook Ln.	10	Not Specified	Local
Blair Creek	Blair Rd.	11	Not Specified	Arterial
	d/s Fountain St.	12	Not Specified	Arterial
	u/s Fountain St.	13	Not Specified	Arterial
Mill Creek	Samuelson St.	14	Region	Arterial
	CNR	15	CNR	n/a
	Marion/Elgin	16	Cambridge	Arterial
	Dundas St.	17	Not Specified	Arterial
	Shade St.	18	Cambridge	Local
	Kerr St.	19	Cambridge	Local
Chilligo Creek	Beaverdale Rd.	20	Not Specified	Collector
	Maple Grove Rd.	21	Not Specified	Arterial
	Fisher Mills	22	Cambridge	Collector
	Hespeler Rd.	23	Not Specified	Arterial
	Chilligo Rd.	24	Cambridge	Collector
Devils Creek	Salisbury Ave.	25	Not Specified	Collector
	Blenheim Rd.	26	Not Specified	Collector
	CNR	27	CNR	n/a
	Bismark Dr.	28	Not Specified	Collector
	Blair Rd.	29	Cambridge	Collector
	George St.	30	Not Specified	Collector
Moffat Creek	Main St.	31	Not Specified	Collector
	Dundas St.	32	Not Specified	Collector
	Dundas St.	33	Not Specified	Collector
	Dundas St.	34	Not Specified	Collector
	Elgin St.	35	Cambridge	Collector
	Champlain Dr.	36	Cambridge	Collector
	Christopher Dr.	37	Cambridge	Collector
	Pedestrian Bridge	38	Not Specified	n/a
	Pedestrian Bridge	39	Not Specified	n/a
	Pedestrian Bridge	40	Not Specified	n/a
Groff Mill Creek	Langs Dr.	41	Cambridge	Collector
	Dunbar Rd.	42	Cambridge	Collector

5.4.4 Results

The results of the open watercourse hydraulic analyses have been reviewed in order to determine the maximum return period/frequency of the storm event during which the water surface elevation would provide 1.0 m freeboard from the edge of travelled way. This has then been compared with the requisite design event, as determined based upon the criteria presented in Table 5.3, the roadway classifications presented in Table 5.14, and the span of the opening as determined based upon the Total Station survey completed for the various hydraulic structures, in order to determine whether or not the existing structures are considered deficient in terms of the current hydraulic standards for freeboard capacity. The results of this assessment are presented in Table 5.15 and are depicted graphically on Drawing 9.

Table 5.15: Summary of Hydraulic Performance at Bridges and Culverts

Creek	Crossing	Existing Size	Freeboard Capacity	Roadway Classificatio n	Freeboard Design Event	Adequate? (Y/N)
Forbes	Black Bridge Rd. (east)	3.25m span x 1.30m rise	2 Year	Collector	25 Year	N
	Black Bridge Rd. (west)	1.50m diameter	50 Year	Collector	25 Year	Y
	Hespeler Rd. (west)	1.50m diameter	25 Year	Local	10 Year	Y
	Baldwin Dr.	5.00m span x 0.91m rise	<2 Year	Local	10 Year	N
Freeport	CNR	Twin 0.90m diameter	Regional	n/a		
Hespeler East, West Creeks	Beaverdale Rd.	0.90m diameter	100 Year	Arterial	50 Year	Y
	Hal Rogers Dr.	4.00m span x 1.10m rise	10 Year	Local	10 Year	Y
Bechtel	Blair Rd.	1.05m span x 0.70m rise ellipse	<2 Year	Arterial	50 Year	N
	Langdon Dr.	1.00m diameter	<2 Year	Local	10 Year	N
	Fallbrook Ln.	0.75m diameter	<2 Year	Local	10 Year	N
Blair Creek	Blair Rd.	6.30m span x 1.00m rise	<2 Year	Arterial	100 Year	N
	d/s Fountain St.	3.00m span x 1.50m rise	<2 Year	Arterial	50 Year	N
	u/s Fountain St.	6.00m span x 2.50m rise	25 Year	Arterial	100 Year	N
Mill Creek	Samuelson St.	Twin 6.10m span x 2.08m rise	5 Year	Arterial	100 Year	N
	CNR	7.30m span x 5.60m rise, 2.70m span x 2.70m rise, 6.10m span x 2.70m rise	Regional	n/a		
	Marion/Elgin	Twin 4.85m span x1.30m rise	100 Year	Arterial	50 Year	Y
	Dundas St.	5.68m span x 4.09m rise arch 4.09m span x 2.62m rise arch	Regional	Arterial	100 Year	Y
	Shade St.	5.50m span x 1.40m rise	<2 Year	Local	10 Year	N
	Kerr St.	Twin 4.90m span x 2.75m rise	100 Year	Local	25 Year	Y
Chilligo Creek	Beaverdale Rd.	0.75m diameter	<2 Year	Collector	25 Year	N
	Maple Grove Rd.	26.83m span x 6.55m rise	Regional	Arterial	100 Year	Y
	Hespeler Rd.	23.00m span x 3.70m rise	100 Year	Arterial	100 Year	Y
	Fisher Mills Rd.	19.58m span x 3.20m rise	Regional	Collector	100 Year	Y
	Chilligo Rd.	14.80m span x 4.55m rise	Regional	Collector	50 Year	Y
Devils Creek	Salisbury Ave.	1.20m diameter	5 Year	Collector	25 Year	N
	Blenheim Rd.	2.14m diameter	Regional	Collector	25 Year	Y
	CNR	4.30m span x 4.60m rise	Regional	n/a		
	Bismark Dr.	Twin 2.16m span x 1.50m rise	100 Year	Collector	25 Year	Y
	Blair Rd.	1.55m diameter	<2 Year	Collector	25 Year	N
	George St.	4.50m span x 2.36m rise ellipse	Regional	Collector	25 Year	Y
. Moffat Creek	Dundas St.	0.90m diameter	100 Year	Collector	25 Year	Y
	Dundas St.	1.25m diameter	5 Year	Collector	25 Year	N
	Dundas St.	2.70m span x 0.90m rise	100 Year	Collector	25 Year	Y
	Main St.	2.50m span x 1.30m rise	<2 Year	Collector	25 Year	N
	Elgin St.	Twin 4.60m span x 2.30m rise	100 Year	Collector	50 Year	Y
	Champlain Dr.	Twin 5.20m span x 2.30m rise	100 Year	Collector	50 Year	Y
	Christopher Dr.	Twin 1.00m span x 0.91m rise	<2 Year	Collector	25 Year	N
	Pedestrian Bridge	5.00m span x 1.06m rise	<2 Year	n/a	10 Year	N
	Pedestrian Bridge	15.00m span x 0.90m rise	<2 Year	n/a	10 Year	N
	Pedestrian Bridge	12.00m span x 0.90m rise	<2 Year	n/a	10 Year	N
Groff Mill Creek	Langs Dr.	3.54m span x 2.27m rise arch	2 Year	Collector	25 Year	N
	Dunbar Rd.	Twin 6.00m span x 3.00m rise	10 Year	Collector	50 Year	N

The results in Table 5.15 indicate that fifteen (15) of the thirty-two (32) hydraulic structures analyzed have been determined to be deficient in terms of the current hydraulic standards for freeboard capacity. This includes three (3) pedestrian bridges along the Moffat Creek, whereby the hydraulic capacity of the structures has been determined to be below the 2 year storm, whereas conventional practice prefers these structures remain above the 10 year water surface elevation; nevertheless, it is recognized that formal standards for the hydraulic design of pedestrian bridges are not well established, and that the general guidelines, which specify a "preferred" 10 year design standard, tend to vary by jurisdiction.

Additional hydraulic analyses have been completed in order to determine the size of replacement structure which would be required in order to achieve the requisite freeboard in accordance with current design standards. The results of this assessment are presented in Table 5.16.

Table 5.16: Estimated Size of Replacement Structures To Satisfy Current Standards for Freeboard

Subwatershed/Watershed	Crossing	Estimated Replacement Structure Size
Forbes Creek	Black Bridge Rd. (east)	n/a
	Baldwin Dr.	n/a
Bechtel Creek	Blair Rd.	n/a
	Langdon Dr.	n/a
	Fallbrook Ln.	n/a
Blair Creek	Blair Rd.	n/a
	Fountain St. (ds)	n/a
	Fountain St. (us)	7.5 x 2.5
Mill Creek	Shade St.	n/a
	Samuelson St.	n/a
Devils Creek	Salisbury Ave.	n/a
	Blair Rd.	n/a
Moffat Creek	Main St.	n/a
	Dundas St.	2.0 x 1.25
	Pedestrian Bridge	n/a
	Pedestrian Bridge	n/a
	Pedestrian Bridge	n/a
	Christopher Dr.	n/a
Chilligo Creek	Beaverdale Rd.	n/a
Groff Mill Creek	Langs Dr.	n/a
	Dunbar Rd.	n/a

The results in Table 5.16 indicate that only 2 of the 19 roadway structures which have been identified as being hydraulically deficient can be remedied through replacement of the size of the structure on its own. For the remaining sixteen (16) roadway crossings, additional works would be required in order to satisfy the current standards for hydraulic capacity and freeboard (i.e. raising the profile of the roadway, reducing flows to the structure), and which would require further consideration of the local constraints in order to establish a preferred alternative.

The estimated costs for the hydraulic structure replacements are summarized in Table 5.17.

Table 5.17: Cost Estimates for Replacement of City Hydraulic Structures at Watercourse Crossings

Watercourse	Crossing Location	Estimated Replacement Structure	Estimated Cost
Forbes Creek	Black Bridge Rd. (east)	n/a	TBD
	Baldwin Dr.	n/a	TBD
Bechtel Creek	Blair Rd.	n/a	TBD
	Langdon Dr.	n/a	TBD
	Fallbrook Dr.	n/a	TBD
Blair Creek	Blair Rd.	n/a	TBD
	Fountain St. (ds)	n/a	TBD
	Fountain St. (us)	7.5 x 2.5	$600,000
Mill Creek	Shade St.	n/a	TBD
	Samuelson St.	n/a	TBD
Devils Creek	Salisbury Ave.	n/a	TBD
	Blair Rd.	n/a	TBD
Moffat Creek	Main St.	n/a	TBD
	Dundas St.	2.0 x 1.25	$300,000
	Pedestrian Bridge	n/a	TBD
	Pedestrian Bridge	n/a	TBD
	Pedestrian Bridge	n/a	TBD
	Christopher Dr.	n/a	TBD
Chilligo Creek	Beaverdale Rd.	n/a	TBD
Groff Mill Creek	Langs Dr.	n/a	TBD
	Dunbar Rd.	n/a	TBD

As indicated above, the costs associated with those structures requiring additional works in order to address the hydraulic deficiencies cannot be determined at the present time, due to the uncertainty associated with the extent of additional works and associated costs (i.e. extent of road reconstruction required, infrastructure replacement, property acquisition, etc.). These details will necessarily need to be addressed as part of future studies.

5.5 Prioritization

The results of the analyses presented in the foregoing sections have been used in order to establish priorities for the City of Cambridge for the remediation of the flooding risks for the City's sewer and road networks and hydraulic crossings of open watercourses. Details regarding the considerations applied for the prioritization scheme for each system, as well as the results of this assessment, are provided within the following section.

5.5.1 Major/Minor System

Factors

The prioritization of the works for the major/minor system has been established based upon the nature of the deficiency (i.e. surcharge and/or flooding), the frequency of occurrence (i.e. during

5 year event or during 100 year event), as well as the extent of the deficiencies within the specific sewershed. The following ranking system, which has been established based upon on a functional characterization in recognition of the above factors, has been applied based upon the results of the hydraulic analyses:

5 Year Result	100 Year Result	Overall Ranking
Surcharging and Flooding	Surcharging and Flooding	High Priority
Surcharging only	Surcharging and Flooding	Moderately High Priority
No surcharging or flooding	Surcharging and Flooding	Moderate Priority
Surcharging only	Surcharging only	Moderate Priority
No surcharging or flooding	Surcharging only	Low
No surcharging or flooding	No surcharging or flooding	No action required

In addition to this hydraulic prioritization approach, storm sewer age has also been advanced as a factor, based on the construction date listed in the City of Cambridge's infrastructure database for those storm sewer segments identified as requiring replacement to meet the 5-year storm criteria. In this manner, the oldest storm sewer segments, which would likely be scheduled for maintenance earlier, can be targeted earlier for replacement. To summarize the classification scheme, if the average age of storm sewer segments requiring upgrades to meet 5-year capacity is:

- < 10 years – ***Low Priority***
- 10 – 30 years – ***Moderate Priority***
- > 30 years – ***High Priority***

If no surcharging was simulated under the 5-year event (and therefore no upgrades analyzed), a "Not Applicable" ranking has been applied. Hydraulic performance and age prioritizations have been combined to generate an overall ranking.

Results/Recommendations

The results of the application of the above prioritization approach for the City's major and minor systems is summarized in Table 5.18 and are depicted graphically on Drawing 10.

Table 5.18: Storm Sewer Upgrade Prioritization Summary				
City Area	**Network Number**	**Hydraulic Priority**	**Storm Sewer Age Priority**	**Overall Ranking**
Blair	55	Moderate	Low	Low
	67	No Action Required	Not Applicable	No Action Required
	68	Moderate	Not Applicable	Low
	69	Moderate	Not Applicable	Low
	70	Moderate	Not Applicable	Low
Freeport	Freeport	High	Moderate	Moderately High
Galt	3	Moderate	Not Applicable	Low
	4	High	High	High
	5	High	High	High
	6/7	High	High	High
	11	High	High	High
	13	High	Low	Moderate
	14	High	High	High
	18/19	High	High	High
	20	High	High	High
	25	High	High	High
	27	High	Moderate	Moderately High
	28	High	Moderate	Moderately High
	32	Moderate	Not Applicable	Low
	33	Moderate	Not Applicable	Low
	37	Moderate	Not Applicable	Low
	47	Moderate	Not Applicable	Low
	48/49/50/51/59	Moderate	Not Applicable	Low
	52	High	Moderate	Moderately High
	53/54	Moderate	Not Applicable	Low
	56	High	Low	Moderate
	57/65	High	High	High
	58	Moderate	Not Applicable	Low
	61	High	High	High
	63	Moderate	Not Applicable	Low
Groff	Groff	Moderate	Not Applicable	No Action Required
Hespeler	1	High	Moderate	Moderately High
	2	High	High	High
	8	High	Moderate	Moderately High
	9/10/39	High	Low	Moderate
	38	High	Moderate	Moderately High
	41	Moderate	Not Applicable	Low
Preston	15	High	High	High
	16	High	High	High
	17	Moderate	Not Applicable	Low
	23	High	High	High
	24	High	Moderate	Moderately High
	26	High	Moderate	Moderately High
	44	Moderate	Not Applicable	Low
	45	High	High	High

Those sewersheds which have been designated a “high” priority should be regarded as requiring short-term remediation while those designated as a “moderate” or “moderately high” priority should be regarded as requiring medium term action, and those designated as a “low” priority should be regarded as a long-term requirement for remediation. Opportunities to integrate the above priorities with other capital projects (i.e. road reconstruction, watermain and sanitary sewer replacements, etc.) should be explored as part of the City’s capital asset management program.

5.5.2 Open Watercourse Crossings

Factors

The results of the hydraulic analyses at the bridges and culverts have been reviewed in order to develop an initial prioritization for additional analysis and prescription of necessary works at the bridges and culverts. The following ranking system has been applied:

Road Classification	**Freeboard Criteria Met**	**Overall Ranking**
Arterial	No	High
Collector	No	Moderate
Local	No	Low
Any	Yes	No Action Required

Results/Recommendations

The application of this prioritization, based solely on the results of the hydraulic analyses, is presented below and are depicted graphically on Drawing 11:

Table 5.19: Prioritization of Works to Address Freeboard Deficiencies of Hydraulic Structures

Subwatershed/Watershed	Crossing	Priority Ranking
Forbes Creek	Black Bridge Road (east)	Medium
	Baldwin Drive	Low
Bechtel Creek	Blair Road	High
	Langdon Drive	Low
	Fallbrook Drive	Low
Blair Creek	Blair Road	High
	Fountain Street (ds)	High
	Fountain Street (us)	High
Mill Creek	Samuelson Street	High
	Shade Street	Low
Chilligo Creek	Beaverdale Road	Medium
Devils Creek	Salisbury Avenue	Medium
	Blair Road	Medium
Moffat Creek	Dundas Street	Medium
	Main Street	Medium
	Christopher Drive	Medium
	Pedestrian Bridge	Low
	Pedestrian Bridge	Low
	Pedestrian Bridge	Low
Groff Mill Creek	Langs Drive	Medium
	Dunbar Road	Medium

6. STORMWATER QUALITY MANAGEMENT ASSESSMENT

6.1 Process

A common problem in urban land development relates to the approach to effectively provide stormwater management for small to moderate infill developments and redevelopments (MOE Stormwater Management Planning and Design Manual, 2003). Infill developments and redevelopments generally involve parcels of land less than 5 ha in area, and are usually located in areas with established storm sewer infrastructure.

Due to the small areas involved, it is generally difficult or ineffective to implement "traditional" stormwater management techniques (i.e. ponds), whether it be for quantity or quality control. There is also the concern that implementing stormwater management for each new infill development will result in the proliferation of small facilities which will all require excessive maintenance and upkeep, and which may not be economically or environmentally effective.

The City of Cambridge has undertaken a study, termed the Growth Management Strategy, which identifies strategic locations within the City of Cambridge for redevelopment in accordance with the Province's "Places to Grow Act". This Growth Management Strategy was conducted as a parallel process to this Master Plan, and included preliminary assessments of the anticipated land use conditions within the redevelopment areas. Recognizing that stormwater management for these areas presented a particular issue for the City which would need to be addressed as the redevelopment of these locations proceeded, the scope of the Stormwater Management Master Plan was expanded to include the development of preferred alternatives for the provision of stormwater quality control for these redevelopment areas.

6.2 Growth Management Strategy

City of Cambridge Planning staff has provided details regarding the recommended sites for intensification as part of the City's Growth Management Strategy. The core areas for intensification are depicted on Drawing 12.

The existing land use types within each zone are summarized in Table 6.1, along with a comparison of the existing and currently proposed land uses within the overall intensification areas. As this information remains somewhat speculative, the following are noted with respect to the interpretation and application of the data:

1. Zoning has been used as the indicator of land use. In some cases the real land use will be different than the zoning.

2. The total projected land use numbers are a very general projection; a property by property evaluation remains to be completed. As more detailed work is completed during the subsequent stages of the planning process, the numbers are anticipated to change.

3. The amount of forecast Open Space lands is not shown to increase; however there is possibility there would be some slight increase – most likely on industrial properties that are close to rivers and flood plains. For the time being, it has been assumed that most of

the industrial properties would convert to residential, thus the change in use would be anticipated to increase the amount of permeable surface.

Table 6.1: Land Use Summary For Intensification Zones (ha)								
Land Use	**Intensification Zone**						**Total Existing**	**Total Projected**
	1	**2**	**3**	**4**	**5**	**6**		
Commercial	6.61	22.98	43.93	9.65	17.01	49.36	**150**	**167**
Industrial	49.42	91.67	9.29	31.21	37.23	0.25	**219**	**77**
Institutional	2.38	3.79	9.93	1.74	6.54	2.91	**27**	**27**
Low Density Residential	10.23	14.79	9.46	11.35	43.8	8.75	**98**	**93**
Medium High Density Residential	5.14	6.28	8.35	0.7	16.48	2.43	**39**	**169**
Open Space	11.71	5.21	12.58	9.25	41.54	15.58	**96**	**96**
Total	***85.49***	***144.72***	***93.54***	***63.9***	***162.6***	***79.28***	***630***	***630***

Initial estimates of the future impervious coverage associated with proposed infill and intensification which would require stormwater quality control have been developed based upon preliminary information provided by the City regarding the land use conditions within the recommended zones for intensification under the City's Growth Management Strategy, and applying the following impervious coverages for the redeveloped land uses:

Land Use	Imperviousness (%)
Commercial	90
Industrial	90
Institutional	65
Low Density Residential	55
Medium/High Density Residential	65
Open Space	5

The total anticipated impervious coverage by land use is summarized in Table 6.2.

Table 6.2: Impervious Area Associated with Future Intensification Zones within City of Cambridge			
Land Use	**Total Area (ha)**	**Imperviousness (%)**	**Impervious Area (ha)**
Commercial	167	90	150.3
Industrial	77	90	69.3
Institutional	27	65	17.6
Low Density Residential	93	55	51.2
Medium High Density Residential	169	65	109.9
Open Space	96	5	4.8
Total	***630***		***403.1***

The above information has been used in order to estimate the amount of future impervious coverage which would require stormwater quality control as a result of the redevelopment within the future infill and intensification zones. The impervious coverage for each land use under existing and future conditions has been calculated, based upon the proportions provided in

Table 6.1 for existing and future projected land use conditions. In accordance with current Provincial criteria, stormwater quality controls are required for all new, infill, and redevelopment; on this basis, the difference between existing and projected future impervious coverage for each land use has been considered to represent a conversion from one land use to another, and the increase in impervious coverage for a given land use as a result of redevelopment and infill development, is considered to represent the impervious area which requires stormwater quality control. The results of this assessment are summarized in Table 6.3.

Table 6.3: Future Impervious Area Requiring Stormwater Quality Control (ha)

Land Use	Impervious Area (ha)		
	Existing	Projected Future	Increase
Commercial	135.0	150.3	15.3
Industrial	197.1	69.3	0
Institutional	17.6	17.6	0
Low Density Residential	53.9	51.2	0
Medium High Density Residential	25.4	109.9	84.5
Open Space	4.8	4.8	0
Total	***433.8***	***403.1***	***99.8***

The results in Table 6.3 indicate that the total impervious coverage within the designated redevelopment zones is anticipated to decrease, primarily as a result of the conversion of existing industrial lands to medium density residential land use. Nevertheless, the increase in commercial and medium density residential land use requires that stormwater quality control be provided for approximately 99.8 ha of impervious area.

A long list of stormwater quality management approaches has been developed for the City's redevelopment and intensification areas, based on the MOE guidelines and current standards of practice. The following general alternatives have been considered for stormwater quality management and each has been evaluated based on effectiveness in providing water quality enhancements for the defined re-development and infill areas.

Alternative No. 1 – "Do Nothing"

Alternative No. 2 – Provide on-site stormwater quality management for re-development & infills (i.e. Status Quo)

Alternative No. 3 – Cash in lieu of on-site stormwater management

Alternative No. 4 – Combination of Alternatives 2 and 3

Under the "Do Nothing: Alternative, untreated runoff from re-development or infills would be allowed to discharge uncontrolled to the receiving watercourses. This approach would be contrary to current prevailing Provincial guidelines regarding stormwater quality, as the untreated discharge to the water bodies will result in the loss of habitat and destruction to the natural environment. Due to the issues associated with this practice, this alternative has not been advanced for further consideration.

Alternative No. 2 – Provide On-site Stormwater Quality Management for Re-development & Infills

Traditionally, stormwater management for small areas has been designed for each separate development area, as the development applications and engineering submissions are completed for the individual sites. Approved techniques for the provision of on-site stormwater quality control are provided in the Stormwater Management Practices Planning and Design Manual (MOE, 2003). Various techniques for stormwater quality control include:

- Soakaway pits
- Infiltration trenches
- Pervious pipe systems
- Pervious catchbasins
- Hybrids wet pond/wetland system
- Vegetated filter strips
- Buffer strips
- Wet ponds
- Wetlands
- Oil/Grit separators and/or Grassed Swales

The application of grassed swales and/or oil/grit separators is generally the most common BMP for smaller size developments (i.e. less than 5 ha) due to reduced land requirements compared to the other alternatives, as well as their applicability regardless of soil conditions (i.e. infiltration technologies require relatively permeable soil conditions). Of these two options, oil/grit separators are commonly used for commercial/industrial applications where the impervious coverage for the site is relatively high (i.e. greater than 85%) and the site plan is developed such that the maximum developable area is utilized.

For larger size developments (i.e. greater than 5 ha), end-of-pipe wet ponds, wetlands, or hybrid facilities are considered appropriate, due to the drainage area limitations associated with other techniques. Increasingly, wet ponds are preferred by municipalities over wetlands as a result of public concerns regarding perceived hazards, associated with shallow waters and West Nile Virus issues.

Under the traditional on-site stormwater management alternative, each parcel of re-development or infill and/or a group of neighbouring development sites, would provide separate stormwater management systems at the source. The facility could be a wetland, wet pond, oil/grit separator (OGS), enhanced grassed swale or combinations, depending upon impervious area and the total drainage area to the facility.

The implementation of on-site facilities would provide quality control to Provincial standards, however it is generally costly in terms of capital costs and operations and maintenance requirements by the Municipality, compared to the other alternatives available. On-site quality controls provide benefits by controlling contaminants at the source; however these benefits may be functionally lost due to subsequent discharge to storm sewers and mixing with untreated/contaminated water before outletting to watercourses sustaining habitat. Furthermore, the operation and maintenance of the smaller facilities (i.e. swales, oil/grit separators, and wet facilities for smaller development areas) is generally the responsibility of the owner; thus, under this approach, the Municipality's approach would be reactive rather than proactive in ensuring that stormwater management controls on private property are operational and functioning as per the designs. For these reasons, this alternative has not been advanced as the preferred alternative for providing stormwater quality control for the City's intensification zones.

Alternative No. 3 – Cash in Lieu of On-Site Stormwater Management

The Province has recognized that applying financial contributions (FC), or "cash-in-lieu" requirements to infill developments would limit the number of stormwater facilities being constructed. Monies, which would have been used for stormwater management by individual infill developments, would be directed into larger, more centralized facilities, or for upgrading of existing facilities and/or infrastructure. This approach of "compensating" for the absence of on-site SWM facilities would typically only be applied when the construction and/or installation of such facilities may be ineffective, or impractical, given the physical constraints of the property (MOE Stormwater Management Planning and Design Manual, 2003). Commercial and industrial infill development susceptible to spills would still be required to provide spill prevention and management on-site, such as oil/grit separators.

Various methods for calculating the FC have been proposed (ref. Chapter 5, MOE Stormwater Management Planning and Design Manual, 2003). The method most commonly used is the "Area/Imperviousness Basis" method, which links imperviousness and runoff volumes to the FC through using a generic formula. Although this method considers the water quality parameters of each individual development site, it fails to consider the required funds necessary to provide for water quality measures that would be implemented on a watershed and Municipal basis. By preparing and implementing this Master Plan, the total required FC for the City of Cambridge can be determined and then divided proportionally for each development site where implementing "traditional" stormwater management techniques would be considered ineffective.

The two fundamental approaches to establishing off-site retrofits, consist of modifications to Existing (or Planned) SWM Facilities and/or treatment provisions at Existing Storm Outfalls.

Existing/Planned SWM Facilities

This method of stormwater quality control involves modifying existing stormwater management facilities (quantity or quality control) to provide targeted water quality control. Although this method is primarily intended for existing stormwater facilities, it can also be considered during the planning stages for new quantity facilities, if it is expected that upstream stormwater runoff (i.e. pond outflow) would adversely affect downstream watercourses and habitat through water quality degradation. When possible, retrofitting existing/planned facilities is considered to be a cost-effective approach since land costs (if any) would generally be less than that required for a new facility. Also, the majority of the infrastructure of an existing facility is already in place (headwalls, access paths, berms) and hence would only require modification. A reduction in future maintenance costs could be realized since both quantity and quality control functions have been consolidated into one facility, therefore, the number of facilities requiring maintenance would be reduced.

There are four (4) methods generally considered available for the retrofitting of an existing or planned SWM facility:

1. Construct a permanent pool, or in the case of an existing quality facility, deepen or expand the existing permanent pool
2. Modify the facility to provide for extended detention storage
3. Provide longer, extended, flow paths through the facility to promote settling of suspended solids
4. Provide additional, or enhanced vegetation within the facility to promote nutrient uptake, water polishing, and temperature control (shading)

In determining the feasibility of retrofitting an existing or planned stormwater management facility, a number of factors must be considered:

- Ability to physically enlarge/retrofit a facility. Is land available (i.e. public lands, parks etc…) adjacent to the facility? Is it possible to implement retrofits within the confines of the existing/planned facility?
- Tributary area draining to the facility
- Type of upstream land use
- Sensitivity of downstream (receiving) watercourses and the need for improved stormwater quality
- Cost-benefit of retrofit. Is maximum benefit being realized from monies spent, or should monies be directed elsewhere to realize greater water quality benefits?

The retrofit design approach would be unique for each existing/planned stormwater management facility under consideration. Whenever possible, designs should work toward the "Water Quality Storage Requirements based on Receiving Waters" (MOE Stormwater Management Planning and Design Manual, 2003). However, given that limitations may exist in providing water quality storage volumes in strict compliance with the SWMP Manual, facilities can still be retrofitted to provide some level of stormwater quality control, as this would likely remain beneficial, subject to an economic review. The "criteria" in such cases when full quality volumes cannot be realized will take the form of runoff volumes expressed in millimetres (mm) of runoff; this would follow the equivalent removal principle.

Existing Storm Outfalls

Existing storm outfalls provide opportunities to implement online treatment of various upstream land uses within the context of new retrofit facilities typically constructed on existing available public lands. Water quality facilities in the form of wetlands, wet ponds or hybrids would provide both permanent pool and extended detention volumes. Possible sites would be evaluated on factors similar to those listed in the foregoing for retrofit of existing/ planned SWM facilities. Candidate sites for providing stormwater quality control at existing storm outfalls are generally evaluated based upon the following additional criteria:

(i) Land availability, land use flexibility and ownership
(ii) Storm outfall location within the available land
(iii) Storm outfall tributary drainage area and respective characteristics

(iv) Potential outlet location with respect to receiving waters
(v) Downstream aquatic resource benefit potential and water quality requirements
(vi) Financial resource allotment and potential cost/benefit ratio

GRCA has expressed concern with respect to potential implications and impacts associated with constructing certain facilities within or in the vicinity of sensitive terrestrial features and systems, particularly Provincially Significant Wetlands. The siting and design of any retrofit facilities for stormwater management would need to be refined and finalized as part of subsequent Schedule B Class Environmental Assessments.

Alternative No. 4 – Combination of Alternatives 2 and 3

Under this alternative, a combination of on-site stormwater management measures (at source techniques) and centralized stormwater management retrofits would be implemented for the future infill and redevelopment areas. Ideally, the areas to be treated under each alternative would be strategically selected, in an effort to address the requirements of both the City and the GRCA. This alternative has been advanced as the most viable alternative for implementing stormwater quality control for future infill and redevelopment areas within the City of Cambridge. Under this approach, on-site stormwater management facilities would be implemented for future development areas; this would be supplemented with cash contributions toward the construction of centralized stormwater management retrofits, which would incorporate a level of redundancy to address the City's requirements for the long-term reliability of stormwater quality control for these areas. Several factors related to on-site (at-source) stormwater management will need to be considered including:

- Sensitivity of receiver
- Form of development
- Size of drainage area/development
- Soils

An important consideration will relate to the amount of on-site stormwater management which is practically attainable, as well as the potential for "loss" over time (functionally or otherwise).

City staff has consulted with GRCA in order to establish a mutually acceptable approach toward establishing the "triggers" for implementing centralized stormwater management retrofits, which would be carried forward in subsequent Schedule B Class Environmental Assessments for establishing the stormwater quality strategy for the City of Cambridge infills and intensification area. These studies would also establish, among other details, the level of redundancy which would be applied for the construction of centralized stormwater quality controls to complement on-site stormwater management measures, final siting and detailed design of centralized stormwater management facilities, and the locations within the City which would be considered most suitable for on-site stormwater management versus those which would be most appropriately serviced by centralized stormwater management facilities.

6.3 Retrofit Opportunities

As indicated above, Alternative 4 has been advanced for further consideration as the currently acceptable approach for both the City and the GRCA. Various candidate locations have been identified within the City of Cambridge for retrofitting existing storm sewer outfalls and stormwater management facilities in order to provide stormwater quality control based upon the criteria previously provided, in an effort to assess the financial and functional requirements and constraints associated with implementing centralized stormwater management facilities. Field reconnaissance has been completed at these locations in order to supplement the high-level screening based upon the mapping provided for this study (ref. Appendix 'I'). Based upon this screening criteria, seven (7) candidate sites for construction of possible stormwater quality retrofit facilities have been advanced as preferred candidates for the construction of retrofit facilities for stormwater quality control and two (2) existing facilities have been identified as potential candidates for retrofitting to provide stormwater quality control. During the course of the study, consultation was held with GRCA staff regarding environmental constraints at the proposed retrofit locations, as well as incidental observations of stormwater quality management issues at the proposed locations of the retrofit sites, in order to further screen the candidate sites for the stormwater quality retrofits; through this process, one of the original seven candidate sites (ref. Site 4) was screened from further consideration, principally predicated upon questions surrounding the actual contributing drainage area to this location versus that which was estimated based upon the sewershed data originally provided.

The GRCA has attempted to contact the MNR through this study process, in an effort to obtain additional information regarding the sensitivity and classification of the environmental features in the vicinity of the proposed retrofit sites (i.e. wetland and watercourse classifications), in an effort to further screen and evaluate these opportunities; despite efforts to secure this information, the requisite information was not provided. Consequently, further screening and evaluation of the opportunities advanced through this study is recommended at the next stages of planning and design, in order to harmonize the retrofit facility design with the surrounding environmental features.

The characteristics of the contributing drainage areas for the retrofit locations which have been advanced through this study are summarized in Table 6.4.

Table 6.4: Drainage Area Characteristics at Designated Candidate Retrofit Sites within City of Cambridge

Retrofit Site Reference Number	Total Area (ha)	Imperviousness (%)	Impervious Area (ha)
1	9.7	40	3.9
2	25.2	50	12.6
3	112.6	90	101.3
5	231.8	50	115.9
6	201.0	30	60.3
7	61.2	40	24.5
Total	***641.5***		***318.4***

Analyses have been completed for the contributing drainage areas to the outfalls of the preferred candidate sites in order to determine the impervious area contributing to each of the potential sites, which represents the optimal impervious area which could receive stormwater quality control through the construction of retrofit facilities, as well as the associated permanent pool and extended requirements in order to achieve "optimal" stormwater quality control for the contributing drainage area (i.e. the highest Provincial standard of stormwater quality control for the full contributing drainage area). The results of this assessment are summarized in Table 6.5; the corresponding retrofit site locations are provided on Drawing 12.

Table 6.5: Impervious Area and Optimal Stormwater Quality Requirements at Designated Candidate Retrofit Sites Within City of Cambridge

Retrofit Site Reference Number	Total Area (ha)	Imperviousness (%)	Impervious Area (ha)	Water Quality Volume Requirements (m^3)	
				Permanent Pool	Extended Detention
3	9.7	40	3.9	1091	388
2	25.15	50	12.6	1820	1006
3	112.6	90	101.3	25037	4504
5	231.8	50	115.9	31873	9272
6	201.0	30	60.3	17229	8040
7	61.2	40	24.5	6885	2448
Total	***641.5***		***318.4***	***83935***	***25658***

The results of this assessment have indicated that the total impervious area discharging to the designated preferred sites for construction stormwater quality control retrofits is approximately 318 imp. ha.

Pre-design concepts for retrofits at the above candidate sites have been developed, in order to evaluate functionally the level of treatment which could be achieved at each candidate site, and the associated "treatable" impervious coverage. The pre-design concepts have been developed based upon the 0.5 m contour data provided by the City of Cambridge, as well as the current hydraulic models provided by the GRCA for the receiving watercourses at the facility outlets. The spatial constraints to the facilities have been established based upon a required 15 m setback from the receiving watercourse, natural heritage sites, property boundaries, and sewershed data provided by the City of Cambridge. For the purpose of this assessment, retrofit facilities which are proposed within the floodplains adjacent to receiving watercourses have been pre-designed as wetland facilities (due to the prevailing vegetation and flat topography, and in an effort to mimic features which likely naturally occur in those areas). The proposed retrofits within existing dry pond stormwater management facilities have been pre-designed as wet pond facilities in order to optimize the available space. The pre-design of the facilities has included provisions for maintenance access and decanting zones, consistent with current practice for stormwater management facility designs. The pre-design concepts of the facilities are presented in Appendix 'J', and the operational details of the pre-design concepts are summarized in Table 6.6.

Table 6.6: Summary of Proposed Retrofit Facility Operational Characteristics			
Facility	**Facility Function**	**Volume (m^3)**	**Water Surface Elevation (m)**
1	Permanent Pool	1165	271.00
	Extended Detention	898	270.74
2	Permanent Pool	1141	274.75
	Extended Detention	1820	273.31
3	Permanent Pool	4368	276.50
	Extended Detention	3948	276.21
5	Permanent Pool	1891	276.50
	Extended Detention	2440	276.06
6	Permanent Pool	14438	301.50
	Extended Detention	16619	301.14
7	Permanent Pool	846	296.50
	Extended Detention	1221	295.97

6.4 Water Quality Management Assessment

The information provided in Table 6.6 has been compared with the current MOE criteria for stormwater management facility designs in order to determine the area within the contributing catchment which would receive stormwater quality control to *Enhanced* standard of treatment. The results of this assessment are summarized in Table 6.7.

Table 6.7: Summary of Treatment Potential within Stormwater Management Facility Retrofits						
Facility	**Contributing Drainage Area**		**Permanent Pool Volume (m^3)**	**Extended Detention Volume (m^3)**	**Equivalent Area Treated to Enhanced**	
	Total Area (ha)	**Imperviousness (%)**			**Total Area (ha)**	**Impervious Area (ha)**
1	9.67	40	1165	898	9.67	3.9
2	25.15	50	1141	1820	19.42	9.7
3	112.62	80	4368	3948	48.53	38.8
5	231.33	50	1891	2440	32.19	16.1
6	201.00[1.]	30	14438	16619	201.00	60.3
7	61.20	40	846	1221	18.29	7.3
					Total	136.1

NOTE: [1.] Total Contributing Area to Freeport Basin determined based upon existing land use conditions, and does not account for future development areas to the basin. Ultimate facility footprint can be established based upon ultimate land use conditions to Freeport Basin. Current footprint design capable of providing treatment for approximately twice the development area.

The information presented in Table 6.7 suggests that, based upon spatial and functional constraints imposed at each site, the pre-designs as currently dimensioned for the retrofit facilities would be capable of providing treatment for approximately 136 ha of impervious area. This is greater than the anticipated future impervious area which would require stormwater quality control (i.e. 99.8 ha), hence it is anticipated that stormwater quality control for the future infill and redevelopment areas within the City of Cambridge can be provided using a cash-in-lieu of on-site stormwater management approach toward funding the retrofitting of existing stormwater management infrastructure. The results also indicate that Retrofit Site 6, which is the Freeport Basin, provides the greatest potential area yield for retrofitting to provide stormwater quality control. As well, Retrofit Site 3, which lies on the west bank of the Hespeler West west tributary, represents a high yield location for providing stormwater quality control. Beyond these two locations, the opportunities for providing stormwater quality control diminish in terms of available area treated.

Although six candidate locations have been advanced through this study, it is recognized that additional opportunities currently exist within the City of Cambridge for the provision of stormwater quality control. Among these additional locations is the Dumfries Conservation Area within the Groff Mill Creek Watershed. Opportunities to provide stormwater quality control within this area have been advanced previously as part of the Groff Mill Creek Flood Mitigation Class Environmental Assessment (Philips Engineering Ltd., June 2007). Due to the limited stormwater quality control currently provided within the predominantly commercial and industrial drainage area, as well as the associated efficiencies associated with providing stormwater quality control for this area and the benefits to both the local system and the ultimate receiver (i.e. the Grand River) which would result from the provision of stormwater quality control in this area, further consideration to implementing stormwater quality retrofits for the Groff Mill Creek should be pursued.

In addition to these opportunities which have been identified, further opportunities for the provision of stormwater quality control retrofits within the City of Cambridge may become available through future strategic land acquisitions by the City of Cambridge. These opportunities would be identified as the future infill development and intensification and redevelopment proceeds within the City.

Capital cost estimates have been prepared for the construction of each of the candidate retrofit facilities. The cost estimates have been prepared predicated upon the following assumptions:

- $1/m^2 for site preparation (clearing and grubbing)
- $10,000 for erosion and sediment controls and site unwatering
- $20/m^3 for earth excavation
- $5/m^2 for landscaping
- $60/m^2 for maintenance access
- $5,000 for outlet structure

The construction cost estimates for each of the candidate retrofit facilities is presented in Table 6.8, based upon the foregoing assumptions for construction.

Table 6.8: Construction Cost Estimates for Proposed Retrofit Facilities

Facility ID	Location	Total
1	Outfall at Speed River (Chopin Dr./Hamilton St.)	$174,370
2	Outfall at Speed River (Russ St./CNR)	$144,490
3	Outfall at Speed River (Leisure Lodge Rd. /Speedsville Rd.)	$280,580
5	Outfall at Mill Creek (Alison Ave./Elgin St. N.)	$165,660
6	Dry Pond 130 (Maple Grove Rd.)	$1,108,930
7	Dry Pond 142 (Burnett Ave.)	$114,440

The above information has been used in combination with the treatable impervious area to each facility in order to establish a prioritization for the construction of the retrofit facilities based upon the efficiency of treatment. For this assessment the construction cost per impervious hectare has been calculated; the lower the unitary construction cost for the facility, the higher the efficiency (i.e. yield) for the retrofit. The results of this assessment are presented in Table 6.9.

Table 6.8: Construction Cost Estimates for Proposed Retrofit Facilities

Facility ID	Impervious Area Treated (ha)	Construction Cost ($)	Yield ($/Imp. Area Treated)
1	3.9	$174,370	$44,710
2	9.7	$144,490	$14,896
3	38.8	$280,580	$7,231
5	16.1	$165,660	$10,289
6	60.3	$1,108,930	$18,390
7	7.3	$114,440	$15,677

The results of this assessment indicate that the greatest yield (i.e. lowest construction cost per impervious hectare treated) would be associated with the construction of the retrofit facility at Site 3. The lowest yield (i.e. highest construction cost per impervious hectare treated) would be associated with the construction of the facility at Site 1.

The construction of stormwater quality retrofit facilities is typically financed through development charges, in accordance with Section 5.59 of the Development Charges Act. Through this process, funds to finance the construction of the retrofit facility are collected with the development applications. The financing for construction of the facilities solely upon the collection of Development Charges requires that development proceed in advance of the construction of the retrofit facility, and that the facility be constructed once the development reaches certain levels (i.e. trigger points corresponding to percentage buildout of the full development area). This approach would clearly result in some development proceeding in advance of stormwater quality control being provided for an interim condition; the duration of this condition would be contingent upon many factors (i.e. specific trigger points for construction of the retrofit facilities, market and economic factors influencing the rate of development, status of detailed design for the retrofit facilities, etc.).

An alternative mechanism for financing and staging the construction of the retrofit facilities would be for the Municipality to front-end the cost for construction of the retrofit facilities, and then recoup the costs (including gap financing) through Development Charges which would be collected as each development proceeds. Based upon discussions with City staff during the course of this project, this approach is inconsistent with current financing practices at the City, and is thus considered less preferable than the above alternative.

The information presented in Table 6.8 has been used in order to establish a preferred sequence for the construction of the retrofit facilities, as well as to establish an overall rate which would be applied through the Development Charges to finance the construction of the retrofit facilities. The sequencing has been established based upon a qualitative assessment of the impervious area treated by the retrofit facility, as well as the yield calculated. The recommended sequencing for implementing the retrofit facilities is presented in Table 6.10.

Table 6.10: Prioritization for Construction of Retrofit Facilities	
Facility ID	**Priority**
3	1
6	2
5	3
2	4
7	5
1	6

As indicated by the above, the proposed retrofit facilities at Sites 3 and 6 would provide the greatest treatment for the future impervious area, and are recommended as the first facilities for construction. In order to accommodate a staged approach for the implementation of the retrofit program based upon the Development Charges collected (i.e. the available funds) and the associated established trigger points, it is likely that the construction of these retrofit facilities would need to be staged in order to correspond to the prescribed trigger points for construction and thereby avoid requiring that the City front-end any costs for construction of the retrofit facilities.

The proposed amount which would be carried forward into the Development Charges has been calculated based upon the total construction cost for the retrofit facilities and the total impervious area which could be treated at the proposed locations based upon the contributing drainage areas and conceptual facility designs. Based upon this information, the average cost for construction of the retrofit facilities, to be incorporated into the City's Development Charges for redevelopment and infill development areas, would be ***$14,610.00 per impervious hectare***. It is recommended that this cost be applied to future development applications using the Area/Imperviousness Method outlined in Chapter 5 of the MOE 2003 Stormwater Management Guidelines (i.e. the charge paid by the proponent would be calculated as the product of the impervious hectares from the proposed development and the unitary cost of $14,610.00 per impervious hectare).

7. STORMWATER SYSTEM MAINTENANCE

7.1 Scope

Current municipal maintenance practices for stormwater management infrastructure have been evolving as technology changes. In some circumstances, the rate of change has understandably lagged behind the technological advances. In order to bring the City's Maintenance Program into harmony with the needs of existing and future infrastructure, the current maintenance practices within the City have been reviewed, and compared against practices within other jurisdictions, general requirements as provided within Provincial design standards, as well as the requirements as established in the MOE Certificates of Approval which have been issued for the City managed stormwater management facilities. This has also included meetings and interviews with responsible City staff in order to better understand the current division of maintenance requirements among the City departments, as well as the general practices which have been implemented based upon the various types of stormwater management facilities which have been constructed within the City. Based on this comparative assessment, as well as integral research into best practices for maintenance, a set of recommendations has been formulated for maintenance of stormwater management infrastructure.

7.2 Existing Program

City staff on has, during the course of the study, been consulted to review the issues associated with Operations and Maintenance of stormwater systems (i.e. culverts, bridges, stormwater management facilities, watercourses, storm sewer system, other BMP's). Attending staff provided the current perspective on how maintenance is performed and what some of the issues are with respect to maintaining design performance of the infrastructure. Key points arising included:

i) Need to be compliant with MOE Certificate of Approvals
ii) Current maintenance tends to be more “reactive” that “proactive”
iii) Sediment disposal costs and procedures are a concern
iv) Likely that there is a current backlog of maintenance
v) Certain maintenance will need to be contracted out (i.e. ADP, terrestrial evaluations, etc.)
vi) Access to stormwater management facilities do not have contemporary provisions for maintenance (i.e. decanting areas)
vii) Catch basin clean out program very successful
viii) “hot spots” or trouble areas are investigated/inspected more frequently and vigilantly due to a history of flooding
ix) Oil and Grit separators are not maintained by the Municipality

The current budget (2009) for maintenance of the Storm Drainage system (City-wide) is as follows:

Labour	$88,300	(FTE = 0.61)
Equipment	26,500	
Contract Maintenance	50,000	
	$164,800 (+/-)	

City staff was requested to provide unitary costs associated with current efforts. Component costs related to specific current maintenance activities include:

a)	Driveway Culvert Replacement (300 CSP – 15 m length)	$5,450.00
b)	Driveway Culvert Flushing	120.00
c)	Catchbasin Cleaning ($20 for clean out; $20 for disposal)	40.00
d)	Catchbasin Replacement	7,700.00
e)	Catchbasin Frame/Grate Adjustment	560.00
f)	Bridge Washing	415.00
g)	Wash out Repairs	300.00 to 10,000.00 (scope dependent)
h)	Storm Sewer Cleaning	120.00 to 500.00 (scope dependent)

Of the foregoing, only (b), (c), (f), and (h) would constitute proactive routine maintenance. The other items would generally be considered capital costs, related to system upkeep and repair.

Division of Stormwater Management Maintenance Requirements

During the course of this Stormwater Management Master Plan, meetings have been convened with staff from the City's Community Services and Public Works Departments in order to better understand the current division of maintenance practices for the City's stormwater management infrastructure. Previous practice within the City has required that Community Services complete all maintenance above the waterline of the wet facilities, and Public Works undertake all maintenance practices below the waterline for the end of pipe facilities. Maintenance for the remainder of the City's storm infrastructure (i.e. sewers, culverts, watercourses) has typically been associated with the location of the infrastructure (i.e. infrastructure within parks maintained by Community Services with the balance maintained by Public Works).

Various alternatives have been proposed for consideration by City staff for the division of maintenance responsibilities, including maintenance of all stormwater management infrastructure by Public Works or separation of maintenance requirements determined based upon location of infrastructure (i.e. all storm infrastructure within parks to be maintained entirely by Community Services and all remaining storm infrastructure to be maintained by Public Works). While no agreement was reached through this study process regarding the division of maintenance among City staff, it is recommended that dialogue continue between Public Works and Community Services Department in order to establish an agreement regarding the maintenance responsibilities of each department regarding the City managed stormwater infrastructure.

7.3 Bathymetric Survey of City Managed Stormwater Management Facilities

As sediment accumulates within the stormwater management facilities, the total suspended solids removal efficiency is reduced; current Provincial standards of practice require that sediment removal be completed once the removal efficiency of a facility is reduced to 5 % below the design removal efficiency. As part of this study, various facilities have been surveyed based upon function, age, and configuration; specifically, the facilities surveyed had a permanent pool and provided a stormwater quality control function, and have been in operation for more than five years (preferably much longer), and of sufficient size to accommodate an Acoustic Doppler Profile of the water surface elevation (i.e. small facilities would not be anticipated to yield a reliable survey of the base). Based upon the above criteria, bathymetric surveys have been completed for twenty (20) City-managed end-of-pipe wet ponds, in order to determine the depth of sediment within the facilities. Copies of the surveyed information are provided in Appendix ‘K’. The surveyed information depicts the elevation of the sediment (pond bottom) below the water surface of the pond; the benchmark water surface elevation for each pond has varied by location.

The facilities surveyed, by reference ID and location, are summarized in Table 7.1, along with the age and type of each facility.

Table 7.1: Summary of Facilities for which Bathymetric Surveys Have Been Completed

Reference ID	Location	Type
105	1094 Fountain St. N.	Natural low-lying wetland area
114*	425 Pinebush Rd.	Overflow area retrofitted to sediment pond
116	390 Jamieson Pkwy.	Kettle area with forebays
117	585 Boxwood Dr.	Constructed wet pond
118*	155 Adler Ave.	Offline storage area
128	1780 Bishop St.. N.	Offline storage area
129*	105 Thompson Dr.	Constructed wet pond
131	526 Grand Ridge Dr.	Kettle area
132*	65 Kent St.	Natural pond with forebays
133	Newman Dr.	Constructed wetland
139	54 Devils Creek Dr.	Natural wildlife pond
153	274 Grand Ridge Dr.	Natural wetland
155*	911 Stonebrook Rd.	Constructed wet pond
160	313 Sheldon Dr.	Retrofitted infiltration basin
163*	275 Myers Rd.	Constructed wet pond
164*	245 Franklin Blvd.	Constructed wet pond
168*	Dellgrove Cir.	Constructed wet pond
169*	Can-Amera Pkwy.	Constructed wet pond
170*	Can-Amera Pkwy.	Constructed wet pond
177	Cherry Blossom Rd.	Dry pond

As the information in Table 7.1 indicates, the bathymetric surveys have been conducted on a wide variety of facility types within the City of Cambridge. The constructed wet ponds and wetlands are recognized as providing a formal stormwater quality function; hence, these facilities would be required to provide a specified level of stormwater quality treatment for a designated drainage area to the facilities, and would also be subject to maintenance in order to ensure that the facilities continue to function as designed. By contrast, the remainder of the facility types which have been surveyed (i.e. natural ponds and wetlands, retrofitted facilities, kettle basins), are recognized as providing informal stormwater quality control, principally due to the presence of forebays which have been constructed at the inlets to some of these facilities, as well as the presence of the permanent pool within these facilities; while sediment accumulation may be acceptable within the permanent pool of the offline storage areas, rapid or excessive sediment accumulation within the permanent pool of the natural wet facilities would be considered detrimental to the natural function of these facilities.

Design drawings for the City managed stormwater management facilities have been obtained by City Staff for facilities 133 and 155, which are a constructed wetland and a constructed wet pond, respectively. In both instances, the facilities provide stormwater quality control for residential land use conditions within the contributing drainage area. Current Provincial standards regarding the design of wetlands and wet ponds for stormwater quality control are specified in the Stormwater Management Planning and Design Manual (MOE, 2003). The standards prescribe permanent pool and extended detention storage volumes for stormwater quality control based upon the type of stormwater management facility, the impervious coverage of the contributing drainage area, and the prescribed total suspended solids removal efficiency. These current Provincial standards are presented in Table 7.2.

Table 7.2: Current Provincial Water Quality Storage Requirements as per MOE, 2003 (m^3/ha)

Protection Level	SWMP Type	Storage Volume for Impervious Level			
		35 %	**55 %**	**70 %**	**85 %**
Enhanced (80% long-term tss removal)	Infiltration	25	30	35	40
	Wetlands	80	105	120	140
	Hybrid Wet Pond/Wetland	110	150	175	195
	Wet Pond	140	190	225	250
Normal (70% long-term tss removal)	Infiltration	20	20	25	30
	Wetlands	60	70	80	90
	Hybrid Wet Pond/Wetland	75	90	105	120
	Wet Pond	90	110	130	150
Basic (60% long-term tss removal)	Infiltration	20	20	20	20
	Wetlands	60	60	60	60
	Hybrid Wet Pond/Wetland	60	70	75	80
	Wet Pond	60	75	85	95

NOTE: Volumes Provided Reflect Permanent Pool Volumes Plus 40 m^3/ha

The contributing drainage areas to facilities 133 and 155 have been measured from the storm sewer and contour data provided by the City of Cambridge, and the removal efficiency for each facility has been calculated assuming 55 % impervious coverage for the contributing residential land use conditions and the permanent pool volume calculated based upon the design drawings. The results of these calculations are provided in Table 7.3.

Table 7.3: Water Quality Performance of Facilities Based Upon Design Conditions (m^3)

Facility ID	Drainage Area	Imperviousness	Designed P.P. Volume	Unitary Designed P.P. Volume	Standard of Treatment
133 (wetland)	9.0 ha	55%	4200	470	Beyond Enhanced
155 (wet pond)	20.9 ha	55%	5000	240	Beyond Enhanced

The results of the Doppler survey have been used in order to determine the volume of sediment within the facilities. This has been calculated as the difference between the design volume of the facility and the available volume based upon the survey results. The results of this assessment are provided in Table 7.4.

Table 7.4: Estimated Accumulated Sediment Within Stormwater Management Facilities

Facility ID	Design P.P. Volume	Surveyed P.P. Volume	Accumulated Sediment
133	4200	3940	260
155	5000	3320	1680

The information in Table 7.4 has been used in conjunction with the estimated age of the facilities as provided by City of Cambridge staff, in order to calculate the rate of sediment accumulation within each facility. This information has been used in conjunction with the data provided in Table 7.2 in order to calculate the cleanout frequency of each facility which would be required in accordance with current Provincial standards of practice. The results of this assessment are provided in Table 7.5.

Table 7.5: Estimated Cleanout Frequency of Stormwater Management Facilities

Facility ID	Age (years)	Design P.P. Volume (m^3)	Rate of Sediment Accumulation (m^3/year)	P.P. Volume at Cleanout (m^3)	Estimated Cleanout Frequency
133	15	4200	20	473	>100 years
155	11	5000	149	2300	18 years

The information in Table 7.5 indicates that facility 133 would be subjected to very infrequent cleanout (i.e. >100 years cleanout frequency); this is likely attributable to the size of the constructed facility compared to the drainage area which is treated by the facility. By comparison, the results for facility 155 indicate that the cleanout frequency would be approximately every 18 years. While less frequent than conventional practice of 10 year cleanout, the results for facility 155 are nevertheless consistent with results obtained in other areas for similar wet pond facilities.

As indicated previously, design drawings for the balance of the constructed wetlands and wet ponds within the City of Cambridge were not available at the time this study was completed. It is anticipated that City staff will pursue this information, through research within the City's archives and department files or by contacting the designing consultants and requesting copies of this information. Once this information is received, the methodology provided in the foregoing assessment for facilities 133 and 155 can be similarly applied in order to estimate the cleanout frequencies of each facility and thereby establish a more fulsome and useable database for the City's stormwater management infrastructure.

The remaining stormwater quality facilities within the City of Cambridge are recognized as providing informal stormwater quality control. For the constructed facilities providing these functions, cleanout to remove accumulated sediment is less prescriptive compared to those facilities which are recognized as providing a formal stormwater quality control function. As such, the cleanout of these facilities should be conducted on an as-needed basis; preferably, this would be completed approximately every 5 years or when the accumulated sediment reduces the permanent pool within the facility by 20 % (whichever occurs sooner). Should it be determined that cleanout more frequently than every 5 years is required, the City should investigate alternatives to reduce the sediment loadings to the facilities.

For the natural facilities which provide stormwater quality control functions, the presence of the natural features within the facility footprint (as opposed to formally constructed and landscaped features) effectively precludes the possibility of removing sediment from the natural feature. Nevertheless, it is recommended that bathymetric surveys of these facilities continue in order to determine whether or not sediment is accumulating within these facilities, as well as to estimate the rate of sediment accumulation using the approach provided above. Should the rate of sediment accumulation be considered to be excessive or detrimental to the natural feature, the City should investigate alternatives to reduce the sediment loadings to the facilities accordingly.

7.4 Proposed Maintenance Practices

Culverts:

Current standards for inspection of culverts require visual inspections be completed every two years by a certified Structural Engineer in order to confirm the structural condition of the culverts. The cost for the visual inspection depends upon the size and type of structure, but generally ranges from $500 to $2000 per structure. For the purpose of establishing a budget for the City of Cambridge, an allowance of $1000 per structure every two years has been applied for visual inspections. Repairs or replacements of structures are contingent upon the results of the visual inspections, as well as any supplemental analyses which may be completed (i.e. hydraulic analyses). The annual budget for conducting visual inspections of culverts is thus $21,000.

The cost associated with repairing or replacing the culvert depends upon the results of the inspection, as well as the age, size and type of structure. It is recommended that City staff incorporate this cost into the capital plan as appropriate, based upon the past trends for culvert replacements. For the purpose of providing a preliminary budget item, an annual allowance of $250,000.00 has been advanced as part of this Master Plan for the purpose of completing broadscale minor structural repairs. Should more extensive works be warranted (i.e. structural replacement), more extensive study and design would necessarily be required.

Stormwater Management Facilities:

Typical maintenance requirements for stormwater management facilities are well documented in several guidelines (ref. excerpt Appendix 'K'). As indicated in the MOE excerpt, these requirements are applicable to fully constructed formal facilities (i.e. constructed wetlands, constructed wet ponds, constructed infiltration galleries, etc.), however limited guidance is available for the operation and maintenance of facilities which rely upon natural features (i.e. wetlands, kettle ponds) for stormwater quantity or quality control, such as those in many parts of Cambridge.

Operation and maintenance requirements for each facility type have been established based upon the type of each facility, as well as observations made during the field reconnaissance for this project. The general maintenance activities for each facility, due to its type and function, are summarized in Table 7.6.

Table 7.6: General Stormwater Management Facility Operation and Maintenance Requirements

Facility Classification	Maintenance Action	Frequency
Dry Pond without Forebay	Inlet and outlet inspection	Annual
	Outlet adjustment	As needed
	Debris Removal	Annual
	Grass cutting/weed control	Annually or as needed
Dry Pond with Forebay	Inlet and outlet inspection	Annual
	Outlet adjustment	As needed
	Debris Removal	Annual
	Grass cutting/weed control	Annually or as needed
	Sediment removal from forebay	5 – 10 years
Constructed Wetland	Inlet and outlet inspection	Annual
	Debris removal	Annual
	Vegetation Replanting	5 – 10 years
	Grass cutting/weed control	Annual or as needed
	Outlet adjustment	As needed
	Sediment removal from forebay	5 – 10 years
	Sediment removal from wetland area with replanting	25 – 35 years
Constructed Wet Pond	Inlet and outlet inspection	Annual
	Debris removal	Annual
	Vegetation Replanting	5 – 10 years
	Grass cutting/weed control	Annual or as needed
	Outlet adjustment	As needed
	Sediment removal from forebay	5 – 10 years
	Sediment removal from wet pond area with replanting	25 – 35 years
Forebay/Sediment Basin	Inlet and outlet inspection	Annual
	Debris removal	Annual
	Sediment removal	5 – 10 years

Table 7.6: General Stormwater Management Facility Operation and Maintenance Requirements		
Facility Classification	**Maintenance Action**	**Frequency**
Natural Wetland	Inlet and outlet inspection	Annual
	Debris removal	Annual
	Outlet adjustment	As needed
	Inspection for evidence of overflow	As needed
Natural Pond	Inlet and outlet inspection	Annual
	Debris removal	Annual
	Outlet adjustment	As needed
	Inspection for evidence of overflow	As needed
Sediment Basin	Inlet inspection	Annual
	Debris removal	Annual
	Inspection for evidence of overflow	As needed
	Sediment removal	5 – 10 years
Natural Depression (“Kettle Pond”)	Inlet inspection	Annual
	Debris removal	Annual
	Inspection for evidence of overflow	As needed
Infiltration Gallery	Inlet inspection	Annual
	Debris removal	Annual
	Condition of filter medium	Annual
	Removal and replacement of filter medium	5 – 10 years
Offline Storage for Sewer Network	Inlet and outlet inspection	Annual
	Debris removal	Annual
	Vegetation Replanting	As needed
	Grass cutting/weed control	Annual or as needed
Oil/Grit Separators	Inlet and outlet inspection	Annual
	Measure depth of sediment	Annual
	Sediment removal	As needed

The foregoing information has been used, in conjunction with the age and observed condition of each facility, in order to prescribe specific maintenance activities which should be scheduled for completion within the next two to three years in order to ensure the proper function of each facility; these requirements have generally been established assuming that no or limited formal maintenance for the facilities has been completed since they were constructed or retrofitted. Full details are provided in Appendix ‘K’, and are summarized in Table 7.7.

Table 7.7: Short-Term Maintenance Activities for Stormwater Management Facilities	
Maintenance Activity	**Stormwater Management Facility ID #**
Inlet/Outlet Inspection	All
Debris Removal	All
Outlet Adjustment	As required, depending upon field observations
Grass Cutting/Weed Control	Based upon field inspection (101, 102, 103, 106, 109, 110, 112, 115, 118, 120, 122, 123, 129, 130, 133, 134, 135, 136, 138, 142, 143, 144, 145, 146, 147, 152, 155, 157, 163, 164, 166, 167, 168, 169, 170, 171, 173, 175, 177)
Sediment Removal from Forebays (facilities approximately 10 years and older)	104, 119, 120, 124, 125, 129, 132, 133, 135, 145, 149, 150, 152, 155, 157, 158, 163, 164,
Inspect for Sediment Depth within forebay	107, 114, 115, 116, 117, 127, 141, 166, 167, 168, 169, 170, 171
Replace Filter Medium	111, 112, 140, 160
Inspect for standing water	104, 113, 116, 121, 124, 125, 127, 131, 137, 151, 154, 158, 159, 172
Verify standing water level sufficient for on-site fire protection	173
Verify limits of permanent pool to confirm condition of synthetic liner	170
Measure depth of sediment within oil/grit separators	All OGS's
Remove sediment from OGS's	As required, based upon measured sediment depths

The maintenance activities prescribed in the above and in Appendix 'K' should be modified based upon field observations during the inspection activities noted, and with consideration for the type and function of the facility.

The City database for the oil/grit separators indicates that they are all Stormceptor^{TM} units. Operation and maintenance requirements are currently specified based upon the size of the unit and the depth of sediment within the system (ref. Table 7.8).

Table 7.8: Sediment Depths Indicating Required Servicing (ref. Stormceptor System Owners Manual, Hanson Pipe and Products Canada, Inc., June 2004)	
Model	**Sediment Depth (mm)**
STC 300i	225
STC 750	230
STC 1000	275
STC 1500	400
STC 2000	350
STC 3000	475
STC 4000	400
STC 5000	500
STC 6000	425
STC 9000	400
STC 10000	500
STC 14000	425

It should be noted that the above requirements for the cleanout of these units does not specify the removal efficiency associated with the cleanout depth (i.e. the percent reduction in TSS loadings). Nevertheless, requirements for sediment removal for the oil/grit separators should be determined based upon the measured depths obtained from the inspections, and the information provided in Table 7.8.

The maintenance requirements provided above have been used in order to prioritize the maintenance activities for the City's stormwater management facilities. The following prioritization scheme has been applied for this assessment:

- Facilities designated as a "**high**" priority require sediment removal or replacement of filter medium, in addition to the routine inspection activities, in order to maintain the function of the facility for stormwater quality control.

- Facilities designated as a "**medium**" priority require inspection of the sediment depth within the forebay, in addition to the routine inspection activities, in order to determine whether or not sediment removal is required. Depending upon the results of these measurements, the facility may be reclassified as a "high" priority (i.e. sediment depth within forebay sufficient to warrant facility cleanout).

- Facilities designated as a "**low**" priority require routine maintenance activities only. Depending upon the results of these inspections, the facility may be reclassified as a "medium" or "high" priority.

The results of this classification system are presented in Drawing 13, and are summarized in Table 7.9.

Table 7.9: Stormwater Management Facility Maintenance Prioritization

Priority Ranking	Facilities Corresponding to Priority
High	104, 111, 112, 119, 120, 124, 125, 129, 132, 133, 135, 140 ,145, 149, 150, 152, 155, 157, 158, 160, 163, 164
Medium	107, 114, 115, 116, 117, 127, 141, 166, 167, 168, 169, 170, 171, all City-owned oil/grit separators
Low	All remaining facilities

Clearly there are significant gaps in the required proactive maintenance for storm drainage system maintenance. Key or primary activities related to the specific form of maintenance include:

Based upon the field inspection, maintenance requirements have been identified for 2011, which are in addition to the routine annual maintenance activities. These range from completing minor repairs in addition to routine annual maintenance, to dredging the facility to remove sediment, to removal of overgrowth within the facilities. The cost estimates for these activities is summarized in Table 7.10.

Table 7.10: Cost Estimates for 2011 Stormwater Management Facility Maintenance (2010 $)	
Type of Maintenance Required	**Cost**
Routine Annual Maintenance/Minor Repairs	$102,000
Sediment Removal	$1,202,000
Removal of Overgrowth	$1,171,000

Cost estimates for maintenance of stormwater management facilities have been developed for key maintenance activities over the design life of the city-managed stormwater management facilities. These have been categorized into routine annual maintenance costs (which would be incurred annually), sediment removal (which would be incurred every 8 years approximately), and facility reconstruction (which would incurred every 20 years approximately). The results of this assessment are summarized in Table 7.11.

Table 7.11: Cost Estimates for Stormwater Management Facility Maintenance Over Facility Design Life (2010 $)	
Type of Maintenance Required	**Cost**
Routine Annual Maintenance	$66,000/year
Sediment Removal	$1,300,000/8 years
Facility Reconstruction	$1,940,000/20 years

Watercourses:

Visual inspections of the watercourses within the City of Cambridge should be conducted every two to five years and after significant storm events, in order to identify any erosion which may have occurred in the creeks and valleys. These inspections should include obtaining a photo inventory of the watercourse, and the preparation of a monitoring report. The watercourses of particular interest for these inspections are

- Forbes Creek
- Freeport Basin
- Hespeler East
- Bechtel Creek
- Blair Creek
- Mill Creek
- Chilligo Creek
- Devils Creek
- Moffat Creek

For budgeting purposes, an annual allowance of $5,000 per watercourse has been advanced for the completion of the inspections, at an average annual cost of $45,000 for the completion of visual inspections of the City's watercourses.

The specific maintenance activities along the watercourses would depend upon the results of the visual inspections. For the purpose of preparing a budget for the City, an allowance of

$150,000 is recommended in order to accommodate small local repairs/rehabilitation to the watercourses in the vicinity of the culverts. Should more extensive repairs be warranted (i.e. realignments/reconstructions), more extensive study and design would necessarily be required.

Storm Sewer System:

The current budget for maintaining the City's storm sewer system should necessarily be increased in order to provide for the completion of video inspections, zoom camera inspections, catchbasin cleanout of sediment, and flushing of storm sewers. In order to allow for these activities, an allowance of $500,000.00 per annum is recommended to be incorporated into the City's current storm infrastructure budget; this allowance has been established based upon a unitary cost of $3.00/m for video inspection divided over 5 years, $150.00/catchbasin for cleanout divided over 5 years, and $50,000/annum for sewer flushing on an as-needed basis. The complete video survey and catchbasin cleanout of the City's storm sewer system should be completed over the course of a 5 year period, with priority given to the older infrastructure. Sewer flushing should be completed on an as-needed basis, based upon the results of the video survey.

Other Best Management Practices:

The City of Cambridge is required to maintain the six municipally-owned oil/grit separators. An annual allowance of $5,000 per structure, for a total annual cost of $30,000, is recommended for the inspection, cleanout and disposal of accumulated material within the City-owned oil/grit separators.

Total Maintenance Costs

Based upon the foregoing maintenance activities, the following annual total maintenance costs have been estimated for the City's stormwater management infrastructure:

Table 7.12: Total Average Annual Maintenance Cost Estimate for City-Managed Stormwater Infrastructure

Asset Type	Task	Frequency	Estimated Average Annual Cost
Culvert	Inspection	2 Years	$15,500
	Repairs	Variable	$250,000
SWM Facilities	Routine Inspection/Maintenance	Annual	$66,000
	Sediment Removal	8 Years	$162,500
	Facility Reconstruction	20 Years	$97,000
Watercourses	Inspection	2 – 5 Years	$45,000
	Repairs	Variable	$150,000
Storm Sewer	Video Inspection	5 Years	$225,000
	Catchbasin Cleanout	5 Years	$225,000
	Sewer Flushing	As Needed	$50,000
Other Practices	OGS Inspection/Cleanout	Annual	$30,000
Total			$1,316,000

8. SUMMARY OF RECOMMENDATIONS

The following summarizes the key recommendations which have been advanced based upon the information presented in the foregoing sections. These recommendations have been organized according to the following key elements related to financing and addressing the City's stormwater management infrastructure needs and requirements:

- Stormwater Management Facilities (i.e. database and information management, identification of deficiencies in database)
- Drainage Networks (i.e. deficiencies and next steps related to Storm Sewers, Major System, Culverts/Bridges and associated cost estimates for mitigation)
- Stormwater Quality Retrofits (i.e. currently identified opportunities for cash-in-lieu for future infill and redevelopment areas)
- Maintenance (i.e. recommended maintenance practices and budgets for Culverts, Stormwater Management Facilities, Watercourses, Storm Sewer Systems, Other Best Management Practices)
- Financing Alternatives

8.1 Stormwater Management Facilities

A1. The Access™ database developed for this project should serve as the basis for maintaining an inventory and log of findings for the annual maintenance program, as well as for tracking and managing the specific information related to the City-managed stormwater management facility (i.e. Certificate of Approval numbers, design rating curves, functions, etc.).

A2. The City should initiate a project in order to obtain as-built information for all City-managed stormwater management facilities, as outlined in Section 3 of this report.

A3. The City should follow-up with the Ministry of the Environment in order to obtain the Certificates of Approval for the City-managed stormwater management facilities for which certificates could not be located within the City's files and archives.

8.2 Drainage Networks

8.2.1 Storm Sewers

B1. The XP-SWMM hydrologic/hydraulic models developed for this project should serve as the basis for the analysis and design of future minor system infrastructure and should be revised as part of future studies (i.e. extend limits of model, calibrated based upon local data, etc.).

B2. The minor system deficiencies identified in this study should be addressed in accordance with the prioritization provided in Table 5.18.

B3. Detailed design projects which are initiated for storm sewer replacements should include an assessment of opportunities to address major system flooding issues within the same networks.

B4. Where possible, the upgrades to the storm sewers should be integrated with other City capital projects.

B5. The City continues to maintain its own rainfall database for the purpose of updating the IDF relationships for the design of storm sewers.

8.2.2 Major System

C1. Opportunities to address deficiencies in the City's major systems (i.e. road right-of-way) specifically related to conveyance of overland flow should be incorporated into future capital projects within the City.

C2. The City should continue to monitor and track sites of reported flooding and coordinate with other departments and agencies as required for the tracking and monitoring of these conditions.

8.2.3 Culverts/Bridges

D1. The HEC-RAS hydraulic models which have been developed for this project should serve as the basis for future floodline mapping studies and should be refined and modified as appropriate in support of those initiatives.

D2. The replacement of the hydraulic structures within the City (i.e. Bridges and Culverts) should proceed in accordance with the prioritization provided in Table 5.19 of this report. The replacement of the hydraulic structures should consider additional environmental criteria (i.e. geomorphic stability, terrestrial passage, aquatic constraints, etc.), and should include pre-consultation with City and GRCA staff to establish additional constraints beyond the scope of this Master Plan.

D3. The City should initiate follow-up studies in order to identify preferred solutions for the replacement of the hydraulic structures identified as having deficient freeboard but which would require additional works beyond replacement of the existing hydraulic structure.

8.3 Stormwater Quality Retrofits

E1. Stormwater quality control for future infill and redevelopments should continue to require on-site stormwater management. The City should pursue a stormwater management water quality retrofit program in order to provide stormwater quality control for future infill and redevelopment areas within the City of Cambridge as part of subsequent studies to establish a co-ordinated stormwater quality plan for the City of Cambridge's future infill and redevelopment areas. These studies should proceed under a Schedule B Class Environmental Assessment process, and include consultation with GRCA to define the acceptable sites for providing centralized stormwater management.

E2. The preferred sites identified in this Master Plan for the provision of stormwater quality control should be further evaluated as part of subsequent studies, and the designs refined as required as part of the implementation of the stormwater quality retrofit program.

E3. The City investigate and pursue other opportunities for the provision of stormwater quality control through the construction of stormwater management retrofits on currently privately held lands as they become available, and that the stormwater quality retrofit program provided herein be amended as required.

8.4 Maintenance

Culverts

F1. The City's maintenance program and budget be expanded as provided in Section 7.4 in order to include the inspection of culverts and the inlet and outlet conditions of the structures.

F2. The allowance provided in Section 7.4 for the annual inspection and completion of minor structural repairs at the City managed hydraulic structures be updated periodically and as required to reflect the observed trends regarding associated costs and effort.

F3. The City initiate future studies as required for significant repairs to City managed hydraulic structures.

Stormwater Management Facilities

F4. The City's maintenance program and budget be expanded as provided in Section 7.4 in order to reflect contemporary practice regarding the operation and maintenance of stormwater management facilities.

F5. The estimates provided in Section 7.4 for the inspection and maintenance of the City managed stormwater management facilities be updated periodically and as required to reflect observed trends regarding the associated costs and effort.

Watercourses

F6. The City's maintenance program and budget be expanded as provided in Section 7.4 in order to include the inspection and localized repairs of the City managed watercourses.

F7. The allowance provided in Section 7.4 for the annual inspection and completion of minor repairs for the City managed watercourses be updated periodically and as required to reflect the observed trends regarding the associated costs and effort.

F8. The City initiate future studies as required for significant repairs or realignments to City managed watercourses.

Storm Sewer System

F9. The City's maintenance program and budget be expanded as provided in Section 7.4 in order to include video inspections and flushing of the city's sewers, in addition to the current practices of catchbasin cleanout.

F10. The City develop a 5 year program for the video inspection and catchbasin cleanout of the City's sewers, with priority given to the older and more historically problematic areas.

F11. The allowance provided in Section 7.4 for the annual inspection of the City's storm sewer networks be updated periodically and as required to reflect observed trends regarding associated costs and effort.

Other Best Management Practices

F12. The City's maintenance program and budget be expanded as provided in Section 7.4 in order to include the maintenance of six (6) municipally-owned oil/grit separators.

F13. The allowance provided in Section 7.4 for the inspection and maintenance of the municipally-owned oil/grit separators be updated periodically and as required to reflect observed trends regarding associated costs and effort.

8.5 Financing Alternatives

Current funding practices for maintaining municipal stormwater management infrastructure are commonly through property taxes or Development Charges. Property taxes are established based upon the value of private properties and the services provided, and may be adjusted over time based upon changing property values and operating costs by the Municipality; in general, Municipalities seek to minimize both the frequency of adjustments and the rate of adjustment.

Development Charges are assigned to new developments, based upon the anticipated costs to implement (and maintain) the requisite infrastructure to support the new development. These represent a source of revenue for the Municipality, which is to be obtained at the time development is to be implemented, in order to support and maintain new infrastructure, hence it is not considered a viable source of revenue to support the maintenance of existing infrastructure implemented prior to the development.

Recently, Stormwater Service Fees (also referred to as Stormwater Utility Fees) have emerged across the United States as an increasingly popular source of dedicated stormwater funding; similar programs have been proposed and initiated in various Municipalities within Ontario. Stormwater services fees within the United States are incorporated within State Legislation, and are typically based on some measure of a property's contribution to stormwater runoff. The general standard applied to utility fees is that the rate methodology must be fair and reasonable, and resultant charges must bear a substantial relationship to the cost of providing services. However, the local government has a great deal of flexibility in attaining these objectives in the context of local circumstances. When stormwater utility rates have been subjected to legal challenges, the courts have tended to apply "judicial deference" to the decisions of locally elected officials. Under judicial deference, the courts will not intervene unless a plaintiff can demonstrate that the decision was arrived at arbitrarily and capriciously or that the result of the decision discriminates illegally.

Stormwater service fess typically provide more stable revenue than other funding options, offer the opportunity to design a service fee rate methodology that results in an equitable allocation of the cost of services and facilities, and, in some cases, can provide an opportunity to shift a portion of the community's stormwater management costs away from the General Fund. Service fee rate structures are designed to recover costs based on the demands place on the stormwater systems and programs.

The revenue generation capacity of a stormwater utility is similar to that of the real property tax, except that the utility fee is directly linked to the impervious surface cover or another measurable characteristic, rather than assessed value. Determining a legally defensible rate needed to generate revenue sufficient to finance the local stormwater needs would require the local government to engage in a "stormwater utility rate study". During this study, important policy decisions are made that can have significant implications for the selected rate. An important first step in the process is to determine the average impervious land cover in square metres for a single family residential lot. Although it is common for all single family lots to be charged a flat fee, the Equivalent Residential Unit (ERU) is applied to all other classifications of land. In addition to technical determinations, local governments must address a range of policy questions that ultimately impact the structure of the utility, as well as the stormwater utility rate.

Recognizing the challenges facing the City of Cambridge with respect to bridging the financial gap between the current budget allocations for stormwater management infrastructure and the anticipated requirements as determined through this Stormwater Management Master Plan, it is recommended that the City of Cambridge initiate a study to investigate the alternative means of financing the ongoing operation and maintenance of its stormwater management infrastructure, including a program for implementing a Stormwater Utility Fee.

Appendix A
Public Record

Appendix B
Background Information

Appendix C
SWM Facility Inventory and Certificates of Approval

Appendix D
Climate Data and IDF Update

Appendix E
XP-SWMM Input and Output Files (CD)

Appendix F
Sewershed Boundaries and System Deficiencies

Appendix G
Supplemental Field Reconnaissance at Historic Flooding Sites

Appendix H
HEC-RAS Input
and Output Files (CD)

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Appendix I
Field Reconnaissance for Candidate Retrofit Sites

Appendix J
Preliminary Designs for Stormwater Quality Retrofit Facilities

Appendix K
SWM Facility Maintenance Practices and Doppler Survey Results