MARKHAM EROSION RESTORATION IMPLEMENTATION PLAN

FINAL REPORT

Prepared for:

The Corporation of the Town of Markham
101 Town Centre Boulevard
Markham, Ontario
L3R 9W3

Prepared by:

Aquafor Beech Limited
8177 Torbram Rd.
Brampton, ON

June 30, 2007, (updated January, 2011)
Reference: 64550

EXECUTIVE SUMMARY

INTRODUCTION

The Town of Markham is drained by nineteen watercourses, which includes tributaries that flow into the East Don River and the Rouge River (see Figure 1.1). Both of these rivers are important resources of southern Ontario and the focus of specialized study by regulatory agencies and municipalities through which they flow. Development within the Town of Markham predates 1900 and has increased noticeably in the last 25 years.

Impacts of urbanization on the natural processes that occur within a watershed are generally understood to result in alterations of the receiving watercourse. Specific impacts include hydrology, erosion, sediment transport, and water quality. Each of these impacts can create a risk to public health and safety and affects the quality of terrestrial and aquatic habitat. The Town of Markham has recognized these impacts and, like many other municipalities imposes development charges against land to pay for increased capital costs required due to increased needs for services arising from development through its Development Charges by-law.

Included in the Development Charges is the Allocation of Costs for the purpose of addressing stream conditions that would be exacerbated by development (i.e., primarily through change in hydrologic regime). The Markham Erosion Restoration Implementation Plan was undertaken to identify areas of erosion concern within the Town and to develop a plan for addressing erosion with the Development Charges that have been collected to date. The focus of the study was to identify erosion sites, evaluate risk to public health and safety, and to identify alternatives for restoration and associated costs.

This study was carried out under the Municipal Class Environmental Assessment Planning and Design Process and is subject to requirements under the Environmental Assessment Act. Public Consultation was initiated with regulatory agencies and a public meeting to gain input on the erosion ranking criteria, erosion sites within the Town, and preferred restoration approaches. This study was intended to fulfill the Class Environmental Assessment process.

STUDY PURPOSE

The study purpose has been defined as follows:

- To identify priority erosion restoration sites along Markham's watercourses which may pose a risk to public health and safety and to develop a restoration plan to address the erosion sites.
- Study used as guide for capital budget program.

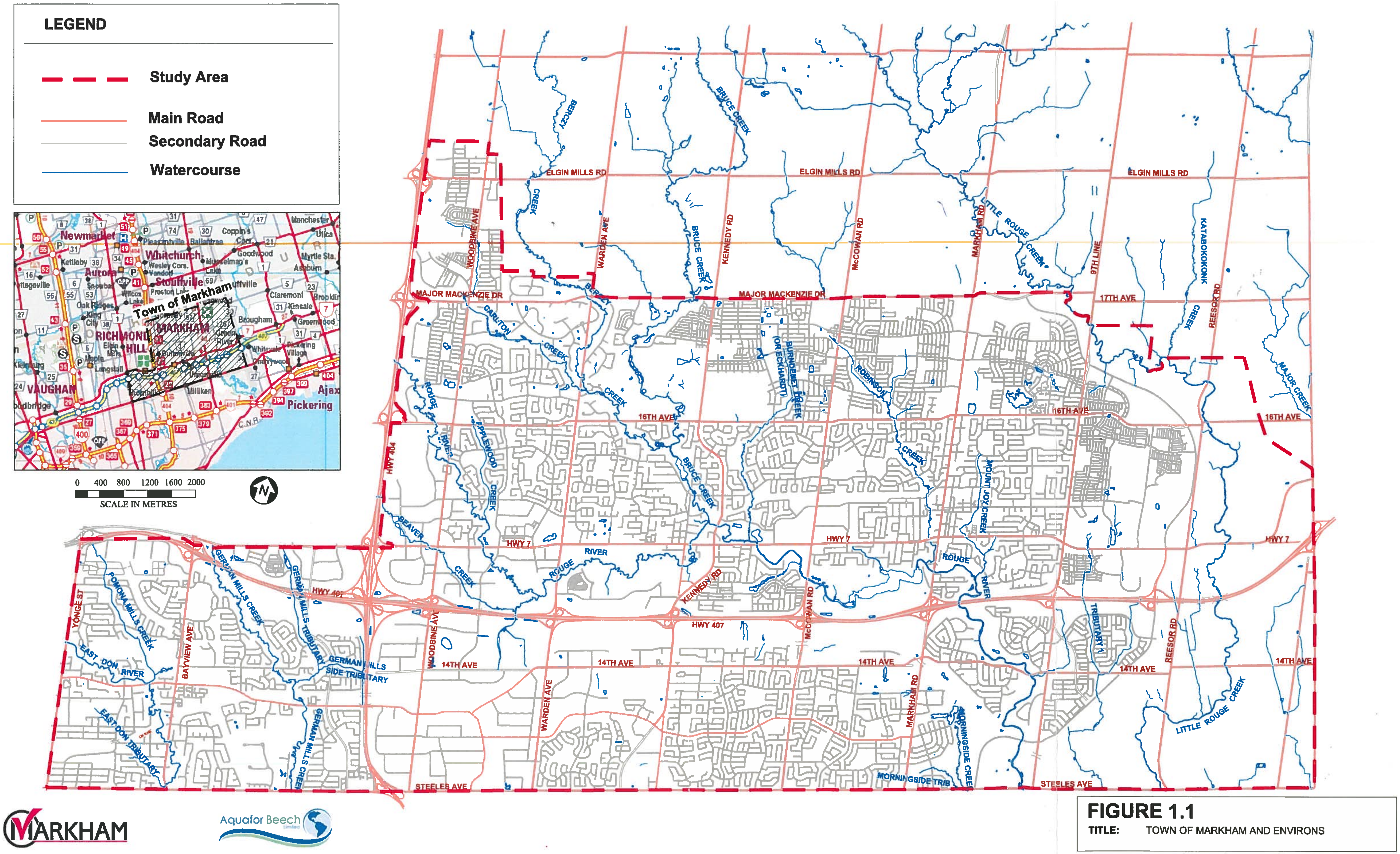

FIGURE 1.1

TITLE: TOWN OF MARKHAM AND ENVIRONS

Secondary goals were as follows:

- To gain insight into the controls and modifying influences of Markham watercourses;
- To develop a long term plan for restoring the river in a cost effective (considering both capital and maintenance costs) manner.
- To develop an approach for selecting, screening and recommending alternatives to stabilize and/or restore Markham watercourses, and
- To develop an Adaptive Environmental Management Plan which costs, categorizes and prioritizes the preferred rehabilitation alternatives

PHASE 1 – ESTABLISH EXISTING CONDITIONS

Problems

Chapter 2 outlined the general problems associated with urbanization and observed impacts within the Town of Markham. These include:

- risks to subsurface infrastructure,
- risks to public infrastructure,
- manholes in channel,
- exacerbation of erosion rates,
- erosion of private property, and
- outflanking of weirs and erosion remediation structures.
- risk to natural resources

Study Area

Background information pertaining to study area characteristics was assembled and reviewed as this would provide a context for field observations and subsequent analyses (Chapter 3). Background information focused specifically on:

- geology (predominantly glacial till),
- land use and development history:
  - urbanization predates 1900,
  - significant increases have occurred over the last 25 years
  - the west end of Markham is the oldest
- aquatic habitat – variable amongst watercourses

Erosion Inventory

In fulfillment of the goals and objectives of this study, a key component was the erosion inventory. Through a reconnaissance level field walk along all nineteen watercourses, which included approximately 105 km of channel, a detailed inventory was undertaken which included:

- identification of erosion sites – location, length, height, condition
- identification of potential fish barriers – location, height, material

- identification of areas requiring maintenance
- identify location of large woody debris
- photographic inventory of all erosion sites, fish barriers, maintenance sites
- documentation of extent of various previous erosion restoration works (e.g., gabion, rip-rap, armourstone)
- identify channel type (structural control, alluvial, semi-alluvial, till etc.)

Digital mapping was created to document these field observations and are presented in **Appendix B**. Tables outlining characteristics of the erosion sites, fish barriers and areas requiring maintenance were also compiled to provide further insight into each of these features (**Appendix C**). Details pertaining to the erosion inventory are outlined in **Chapter 6**

Markham Watercourse Conditions

Review of Markham's watercourse conditions was undertaken by examining the field mapping and compiling information collected through background investigations. Results of the erosion inventory were as follows:

- 308 erosion sites
- 63 fish barriers
- 27 areas identified as requiring maintenance

Areas situated in the west end of Markham exhibited more erosion sites per channel length than in the east end of Markham. The risks presented by the erosion were typically associated with private property or subsurface infrastructure, including manholes. Given the older development history in the west end of the Town, the results were not unexpected. Additional erosion concerns would be expected to occur in newer development areas, in the future.

While erosion is a natural and necessary process, some of the erosion rates appear to have been exacerbated due to urban development and some are clearly a result of altered flow regimes due to upstream changes in land use (i.e., urban). In addition to general impacts from land use alteration in the watersheds, human activity has also led directly to impacts on watercourse stability (e.g., removal of riparian vegetation, placement of dams and weirs across channel, etc.). All observations of channel conditions were illustrated on profiles of the watercourses to provide a spatial context that is intended to guide the selection of a short list of restoration options **(Appendix D)**.

Background materials presented in Chapter 5 were intended to provide an overview of the controlling and modifying influences of channel form and typical urban impacts on receiving watercourses. This information was used to identify dominant channel processes occurring along Markham's watercourses (enlargement, widening and some planform adjustments). The information should also form a basis for the selection of appropriate restoration alternatives during detailed design phases of the implementation plan.

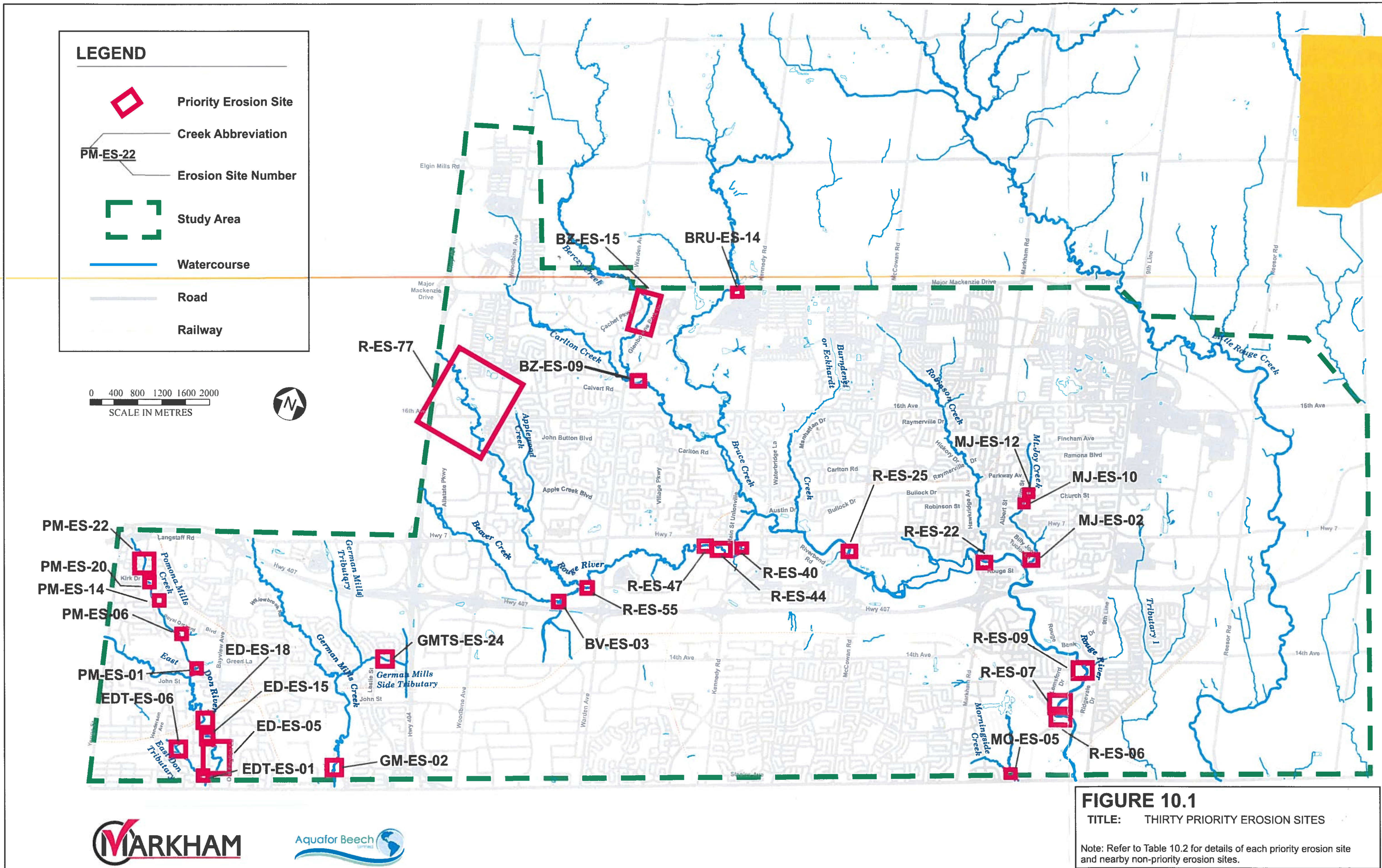

FIGURE 10.1

TITLE: THIRTY PRIORITY EROSION SITES

Note: Refer to Table 10.2 for details of each priority erosion site and nearby non-priority erosion sites.

Watercourses that would benefit from watershed level mitigative action and further study were identified.

PHASE 2 – EROSION PRIORITIZATION AND REHABILITATION

Erosion is a natural and necessary process that occurs along all watercourses, and thus it is important that erosion processes continue and is not unnecessarily impeded through restoration works. Identification of erosion sites that require restoration, to protect public health and safety, should be based on a thorough assessment of the risk. Input from the public and regulatory agencies are necessary to reach consensus on prioritization approach and rehabilitation alternatives.

Priority Ranking

A prioritization scheme was developed, with input from the Toronto and Region Conservation Authority, to identify those erosion sites that pose a risk to public health and safety. The prioritization scheme was based on the following components:

Screening Level Analyses – this was intended to prioritize erosion sites for the Town Capital budget purpose.

Erosion Priority Ranking – the erosion sites that were not eliminated after the screening level analyses were subjected to a thorough priority ranking analysis which had been approved by the Toronto and Region Conservation Authority and the Town of Markham. The analysis consisted of three main components which are identified below:

- Public Health and Safety – type of public risk (e.g., road, sewer, watermain, structure, private property etc.)
- Erosion Index – factors that contribute to risk
  - Distance to public risk item
  - Stress exerted on erosion site (e.g., flow, age of development etc.)
  - Erodibility of erosion site materials (e.g., height, materials, angle etc.)
- Natural Resource – magnitude of risk, aquatic and terrestrial resources

Application of this prioritization methodology enabled identification of those sites which pose the greatest risk and those which would have greatest benefit of reducing risk to public health and safety from restoration. Of these sites, thirty erosion sites were selected for erosion restoration implementation (**Figure 10.1**).

Public Consultation

An integral component of a Class Environmental Assessment is the public consultation process in which the public is invited to actively participate in the study process. In this study, involvement of regulatory agencies was undertaken early on in the process to solicit input, especially with respect to identification and evaluation of erosion risks to public health and safety. Agreement was achieved with respect to the priority ranking scheme.

Through a Public Meeting, the public was invited to review the erosion site mapping, to comment on whether any erosion sites might have been missed, the priority ranking scheme, and preference with respect to erosion restoration works. Any sites that were identified by the public were revisited and reassessed by the study team. The public expressed preference for bioengineered restoration approaches rather than traditional hard treatments. Details with respect to the public consultation are presented in **Chapter 4** and **Appendix A**.,

Rehabilitation Alternatives

Rehabilitation of Markham's watercourses will benefit from action taken at the watershed, reach and site levels. Clear objectives for rehabilitating priority erosion sites are necessary to identify suitable approaches for mitigating risk to public health and safety from within the channel corridor. These objectives were defined and are presented in **Chapter 9**. Following a Class Environmental Assessment process, a long list of alternatives was developed that might be used to mitigate the effects of urbanization on watercourses at the watershed scale, reach, and site level. Incorporation of various source, conveyance, and end-of-pipe solutions into development plans will reduce the impact to public health and safety by limiting impact to equilibrium form and natural rates of channel change. In conjunction with identifying methods to restore eroded areas, consideration should be given to remove the risk (e.g., place manholes at further distance from watercourse), acquiring land or easements to create an appropriate channel corridor, and altering land use immediately adjacent to the affected area. Burial of protective works, which would enable channel processes to continue until an immediate risk occurs (e.g., to sanitary sewer) should be considered.

Through review of the restoration criteria and by insight gained with respect to channel conditions and processes occurring along each of the reaches along which the erosion sites are situated, a short list of restoration strategies was identified for each priority erosion sites. This short list was identified on conceptual restoration mapping of each site, which is presented within **Appendix E**. Toronto and Region Conservation will require detailed assessment and evaluation of restoration alternatives at the detailed design stage. The study follows the Municipal Class Environmental Assessment Process.

Implementation Plan

Creation of an implementation plan requires consideration of all action items that need to be undertaken to ensure that the restoration approaches and implementation thereof are well thought out. The erosion sites were grouped into time frames based on site conditions. Implementation of the restoration plan is subject to acquiring approvals, prioritizing of erosion sites, private landowner participation and funding.

Review of the implementation plan is recommended to occur on a 5 year rotation in conjunction with updates to the plan, as required under the Class EA process to ensure that recommendations are consistent with current policy. **Chapter 10** outlines all components of the restoration implementation plan including watercourses for future study, priority sites for restoration, further tasks that need to be completed, funding sources and estimated costs for the works.

Table 10.2 Recommended Implementation Plan. (Category A = public infrastructure, Category B = private damage, Category C = erosion not related to urbanization. For further explanation of information contained within this table, please see Chapter 10.4 of this report). [1] Note: Bolded/underlined numbers refer to priority erosion sites; adjacent, non-priority erosion sites were listed if their coincident restoration was considered feasible.

	PROJECT NO.[1]	REACH	LOCATION	ACTION	MEASURE	BENEFITS	HABITAT SENSITIVITY CLASS	SCHEDULE A, B, C	APPROVALS REQUIRED	COSTS ($) (Incl 15% contingency)	FIGURE (APPENDIX E)
Short Term – 1 to 4 years											
	R-ES-**<u>55</u>**, 56	R-8	Rouge River - upstream of Warden Avenue	-protect sanitary sewer from erosion -minimize damage to slope to protection -consider reconfiguration of parking area and establishment of buffer between edge of valley and tableland land uses	-regrade and vegetate valley wall slope -rock toe protection (buried if possible) -potential flow deflection	-reduce risk to parking lot -reduce risk to sanitary sewer	4	B	Markham TRCA	345,000	29
	GM-ES-01, **<u>02</u>**, 02b, 03, 04, 05, 06	GM-1	German Mills Creek -upstream of Steeles Avenue	-protect parking lot from erosion -stabilize channel banks	-slope toe protection adjacent to parking lot -revegetation of bank faces	-reduce risk to private property -reduce sediment loading -enhance terrestrial and aquatic habitat -stabilize channel form	1	B	DFO, TRCA, Markham	520,000	10
	EDT-ES-**<u>06a, 06b</u>**, 07, 08	ED-T	East Don River Tributary -downstream of Proctor Avenue	-protect private property -protect subsurface infrastructure -consider land acquisition or easements to create appropriate channel corridor -undertake public education	-move manholes away from/out of creek if possible -increase channel capacity where constricted -restore channel banks -replace crossing with channel spanning structure	-opportunity to address potential fish barrier -enhance channel function and form -reduce risk to subsurface infrastructure and manholes	3	B	Markham TRCA DFO Region	725,000	9
	R-ES-**<u>22</u>**, 23, 24	R -4	Rouge River -upstream and downstream of Markham Road	-protect private property -protect Markham Road footings -protect subsurface infrastructure	-protect bank toe by burial of rock toe protection and vegetation -fill slope, grade, and vegetate -move manhole if possible	-reduce hydration of slope toe materials -reduce risk to property	4	B	Markham TRCA	225,000	24
	GMTS-ES-**<u>24a</u>**, **<u>24b</u>** & 25	GMTS Side tributar y	German Mills Creek - upstream and downstream of Leslie Street	-protect manhole -remove/repair/replace existing geogrid and restore natural channel form and function -stabilize channel banks -remove garbage -repair stormwater outfall -remediate potential fish barrier under Leslie Street	*Upstream of Leslie St.:* -riparian enhancement -natural channel design -garbage removal *Downstream of Leslie St.* -regrade banks and vegetate -move manhole away from creek	-reduce potential for breakage of pipe -reduce potential for undermining Leslie Street -remove any fish barrier improve aquatic habitat -enhance channel function -reduce sediment loading	1	B	DFO, TRCA, Markham	175,000	11
	R-ES-**<u>40</u>**	R-8	Rouge River -upstream of Hwy 7	-protect private property -protect sanitary sewer	-bank toe protection -stabilization of bank face with vegetation	-reduce sediment loading to channel -reduced risk of public health and safety	4	B	Markham TRCA	190,000	26
	MJ-ES-**<u>10</u>**	MJ-4	Mount Joy Creek -downstream of Church St.	-protect subsurface infrastructure -stabilize banks -potential to undertake maintenance of nearby gabion bank protection	-remove/relocate manhole out of creek if possible -consider replacement of gabions with softer approach, if protection is required -stabilize banks through vegetative plantings and regrading as necessary	-adjustment of cross-sectional capacity -maintain bank protection but at increased benefit to aquatic and terrestrial habitat	4	B	Markham TRCA DFO Region	265,000	14

	PROJECT NO.[1]	REACH	LOCATION	ACTION	MEASURE	BENEFITS	HABITAT SENSITIVITY CLASS	SCHEDULE A, B, C	APPROVALS REQUIRED	COSTS ($) (incl 15% contingency)	FIGURE (APPENDIX E)
	R-ES-47a, 47b	R-8	Rouge River -upstream of Warden Ave, below Beaver/Rouge confluence	-remove undersized private crossing -protect subsurface infrastructure and manhole	-relocate manhole away from creek -remove concrete debris from channel -repair outfall structure -enhance riparian vegetation to stabilize banks	-remove flow constriction -reinstate natural channel form -protect private property -enhance terrestrial and aquatic habitat through riparian vegetation	4	B	Markham TRCA DFO Region	420,000	28
	MJ-ES-01, 02a, 02b	MJ-4	Mount Joy Creek -upstream and downstream of Tuclor Lane	-mitigate fish barrier -protect subsurface infrastructure -protect crossing -stabilize channel banks	-remove/relocate manhole from creek -assess potential fish barrier and mitigate to enable fish passage -modify crossing structure to reduce erosive shear on downstream channel banks and stormwater outlet pipe that is in wingwall -stabilize banks through use of bioengineering treatments -enhance riparian vegetation with trees and shrubs	-reduced risk to subsurface infrastructure -enhancement of riparian zone which benefits terrestrial and aquatic habitat	4	B	Region Markham TRCA DFO	300,000	13
	MJ-ES-11, 12	MJ-5	Mount Joy Creek -upstream of Church St.	-reduce risk to sanitary sewer and manhole	-remove/relocate manhole from creek -enhance riparian vegetation to stabilize banks -stabilize banks through planting on bank face and regrade only if necessary	-reduce risk to subsurface infrastructure -enhance terrestrial and aquatic habitat through riparian plantings	4	B	DFO Markham Region TRCA	195,000	15
	PM-ES-20,21	PM-7	Pomona Mills Creek -upstream of Kirk Dr.	-protect private property from erosion -protect subsurface infrastructure improve natural channel form	-create flooding relief for more frequent flows – e.g., two tier channel if possible through regarding -enhance riparian plantings to promote stability to bank face and bank top -slope toe protection should consider bioengineering (e.g., fascines), rock toe if necessary should be naturalized (e.g., vegetated rip-rap), -removal of weir should consider existing base level controls exerted by weir, and maintenance of natural channel form	-reduce risk to private property -improve aquatic habitat through removal of weir -re-instate natural channel form -enhancement of terrestrial and aquatic habitat through riparian plantings	1	B	DFO Markham TRCA	320,000	19

	PROJECT NO.[1]	REACH	LOCATION	ACTION	MEASURE	BENEFITS	HABITAT SENSITIVITY CLASS	SCHEDULE A, B, C	APPROVALS REQUIRED	COSTS ($) (incl 15% contingency)	FIGURE (APPENDIX E)
Intermediate Term – Years 4 to 7											
	R-ES-77	R-12	Rouge River -in Markham Golf Club, between Woodbine Avenue and Hwy 404	-stabilize channel banks -replace/modify existing bank protections (gabion, rip-rap)	-establish riparian zone along channel banks -plant bank faces -ensure all channel crossings have sufficient span -replace/enhance existing rip-rap protection with softer approach (e.g., use fascines or incorporate joint plantings)	-reduce sediment loading into watercourse -stabilize/naturalize channel form	4	B	Markham TRCA	1,900,000	30
	PM-ES-06	PM-4	Pomona Mills Creek -upstream of John St., northern limit of Ladies Golf Course	-remove obstruction to flow and aquatic habitat -protect subsurface infrastructure -restore natural channel form and function	-remove concrete fence post footings out of creek -move end of fence to a distance away from edge of bank -protection of subsurface infrastructure may require structure in creek to protect invert -consider mitigation of downstream fish barrier by modifying/removing weir, and replacement of low-level concrete crossing with bridge	-remove existing structures from creek that interfere with natural processes -protect subsurface infrastructure. -restore channel form	1	B	DFO, TRCA Markham	242,000	17
	ED-ES-05, 06, 07, 08, 09, 12	ED-1	East Don River -between Steeles Ave . and Bayview Ave	-examine potential fish barrier -protect private property from bank erosion -repair outfall and protect storm sewer -consider opportunity to acquire land or easements to establish an appropriate corridor.	-Remove/repair/replace existing bank toe protection -Set stormwater outfall back from channel -Remove bridge crossing (Site ES-06) and replace only if necessary with a sufficiently wide span -Stabilize slopes (regrade or fill banks; bioengineer slope toe, bury rock toe protection if needed.	-removal of concrete debris from channel -enhancement of riparian zone with benefit to terrestrial and aquatic habitat -remove flow constriction -enhancement of fish passage -reduce interference with natural channel form (i.e., storm sewer outfall)	3	B	Markham TRCA DFO	1,270,000	5
	ED – ES-18	ED-1	East Don River -downstream of CN track	-protect subsurface infrastructure -protect private property	-consider relocating manhole and sanitary sewer -stabilize valley wall toe by regarding/filling and grading/bury rock toe protection -repair existing bank toe protection only as necessary	-reduce risk to private property -reduce risk to sanitary sewer -enhance terrestrial habitat on slope	3	B	Markham TRCA DFO Region	240,000	7

	PROJECT NO.[1]	REACH	LOCATION	ACTION	MEASURE	BENEFITS	HABITAT SENSITIVITY CLASS	SCHEDULE A, B, C	APPROVALS REQUIRED	COSTS ($) (incl 15% contingency)	FIGURE (APPENDIX E)
	PM-ES-**22**	PM-7	Pomona Mills Creek -in Holy Cross Cemetery	-stabilize banks to protect graves -enhance corridor function -replace gabion with other structures	-Increase capacity of higher frequency flows through multi-stage channel if possible -regrade banks to a more stable configuration and vegetate if possible -bank toe protection of stone and vegetation -create variability in bed morphology Enhance riparian vegetation with shrubs and trees where possible	-enhance flow conveyance -improve aquatic habitat -enhance terrestrial habitat through riparian plantings protection of grave sites from erosion	1	B	Markham TRCA DFO	470,000	20
	ED-ES-14, **15**	ED-1	East Don River -upstream of Bayview Ave.	-repair stormwater outfall -protect sanitary sewer - relocate sanitary sewer and manhole away from river if possible -move outfall further back from creek	-stabilize banks where risk occurs by regrading slope, vegetation -bury rock toe protection if required	-reduce sediment loading to watercourse -reduce risk to manhole and sanitary sewer	3	B	Markham TRCA	220,000	6
	EDT-ES-**01**,02	EDT	East Don River Tributary -upstream of Bayview Ave.	-protect road -reduce erosion of private property -consider land acquisition or easements to establish an appropriate corridor	-remove gabion where not necessary -replace gabion treatment with softer approach -replace/reinforce bridge to protect from failure	-enhance naturalized appearance of treatments -replace hard structures with softer approaches	3	B	Region? Markham TRCA DFO	445,000	8
	BZ-ES-**09**, 10, 11	BZ-10	Berczy Creek -upstream and downstream of Warden Ave.	-protect road from channel erosion -reduce potential of valley wall failure -soften existing erosion protection works	-toe protection along valley wall – minimize hardening -potential realignment to be determined in conjunction with Warden Ave. widening -replace\modify existing erosion protection works	-reduce risk to road -protect trees on valley wall -protect private property -enhance natural appearance, restore natural channel form	5	B	Region Markham TRCA DFO	400,000	2
	PM-ES-**01**	PM-1	Pomona Mills Creek -upstream of confluence with East Don River	-repair/replace/modify bridge crossing and associated berm. -mitigate erosion concerns	-study should be completed to determine if crossing structure can be replaced by a channel spanning bridge -consideration of current base level control influence must be taken in any restoration plans -address downstream erosion with use of bioengineering approaches (fascines) -remove fish barrier -enhance downstream natural channel functions, perhaps through incorporation of channel bed features to stabilize creek	-removal of fish barrier -enhancement of natural channel functions -removal of flow constriction -protection of public health and safety	1	B	Markham TRCA DFO	195,000	16

	PROJECT NO.[1]	REACH	LOCATION	ACTION	MEASURE	BENEFITS	HABITAT SENSITIVITY CLASS	SCHEDULE A, B, C	APPROVALS REQUIRED	COSTS ($) (incl 15% contingency)	FIGURE (APPENDIX E)
	MO-ES-05	MO-1	Morningside Creek Tributary -upstream of Steeles Ave.	-protect Steeles Ave. from erosion	-repair erosion scar with filling and planting- bury rock toe protection where required -undertake minor realignment only if this reduces impact to Steeles Road	-reduce risk to road -stabilize watercourse -enhance riparian vegetation	5	B	Markham TRCA DFO	175,000	12
	BV-ES-03	BV-4	Beaver Creek -upstream of confluence with Rouge River, parallel to Hwy 407	-remove/replace pipe that projects out of bank -stabilize banks to protect stormwater outfall	-increase bank stability by slight modifications -minimize risk to stormwater structure -enhance riparian vegetation -consider moving outfall	-enhance bank stability and terrestrial habitat through riparian vegetation -reduce risk to stormwater outfall -reduce sediment loading to stream	4	B	Markham TRCA	175,000	1
	PM-ES-14	PM-6	Pomona Mills Creek -Baythorn-Brae Drive footpath	-remove channel constriction -protect public health and safety	-consider replacing existing crossing with channel spanning structure – identify implications for flow conveyance and base level control -provide for multi-tier channel to enhance 'floodplain' access during more frequent (e.g., < 5 yr flows) -bank protection/stabilization should be based on bioengineering approaches and incorporate vegetation wherever possible (fascines, vegetated rip-rap) -enhance riparian plantings	-enhance channel function -reduce erosive stress on banks through flood relief -reduce risk to public health and safety.	1	B	Markham TRCA DFO	460,000	18
Long Term – Years 7 to 10											
	R-ES-06	R-1	Rouge River -upstream of CN line	-protect slope from failure -consider land acquisition or easement to establish corridor -consider landowner education to minimize impact to affected area	-regrade slope to stable configuration and vegetate -incorporate buried rock near toe if necessary	-reduce risk to private property/golf course	4	B	Markham TRCA	395,000	21
	R-ES-07	R-1	Rouge River ` -upstream of CN rail, adjacent to Rouge River Drive	-stabilize slope to protect private property	-regrade or refill banks -bury rock toe protection where necessary	-enhance slope stability -enhance riparian vegetation which provides terrestrial and aquatic benefits.	4	B	Markham TRCA	345,000	22
	BZ-ES-14, 15,16, 18	BZ-9	Berczy Creek -downstream of Major Mackenzie Drive	-protect private property from erosion -restore channel connectivity and channel functions -consider opportunity to acquire land or easements to establish a corridor	-examine potential fish barrier -use bioengineering approaches to stabilize banks -move-pond offline if possible and repair erosion around dam	-reduce risk to private property -restore natural channel form -enhancement of riparian vegetation -enhance aquatic habitat	5	B	Markham TRCA DFO	645,000	3

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	R-ES-**44,** 43	R-8	Rouge River - upstream of Main St. Unionville in Unionville Fairways Golf Course	-protect golf course property from erosion by enhancing bank protection	-use bioengineering approaches where possible -protect slope toe enhance riparian vegetation	-reduces rate of erosion -enhances terrestrial and aquatic habitat	4	B	Markham TRCA	675,000	27
	R-ES-**25**,26	R-6	Rouge River -upstream of McCowan Road	-protect private property -minimize interference with natural channel processes -	-remove crossing if possible, if replacement is necessary then ensure that span is sufficiently wide to minimize interference with flows. -address large woody debris only if this poses a risk to aquatic habitat -where slope stabilization is required, consider regrading and bioengineering approaches -enhance riparian vegetation	-remove flow constriction -enhance aquatic and terrestrial habitat through riparian plantings. -stabilize channel	4	B	Markham TRCA DFO	175,000	25
	BRU-ES-13, **14**	BRU-3	Bruce Creek -downstream of Major Mackenzie Drive	-reduce risk to road -protect subsurface infrastructure -minimize interference with natural channel form and processes	-consider moving manholes away from the creek -move fence out of creek -address erosion only where it poses a risk -protect bank toe if necessary using soft approaches where feasible -consider instream works only where necessary -enhance riparian vegetation to promote bank stability	-stabilization of channel banks -enhance terrestrial and aquatic habitat through riparian plantings	5	B	Markham TRCA Region DFO	195,000	4
	R-ES-**09**	R-1	Rouge River -downstream of 14th Ave.	-mitigate nearby fish barrier if necessary -protect private property through slope stabilization -consider land acquisition or easements to create appropriate corridor -education opportunity for landowner to reduce impact on affected area	-stabilize slope (fill erosion scars, bank toe protection, bioengineer toe) -instream works only where necessary (e.g.,. flow deflection)	-enhance fish passage through mitigating/removing potential fish barrier -reduce risk to private property -enhance terrestrial and aquatic habitat through riparian vegetation	4	B	Markham TRCA DFO	465,000	23
									TOTAL Cost	**12,767,000**	

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1.0 INTRODUCTION

1.1 General

The Town of Markham is drained by nineteen watercourses, many of which are tributaries of the Rouge River (**Figure 1.1**). Watercourses situated within older areas of Markham (i.e., particularly west end) exhibit wide scale erosion and/or instability problems which are typical responses to the altered hydrologic regime that occurs as a result of urbanization. While erosion is a natural and necessary process that occurs in all watercourses, exacerbation of the erosion can lead to increased risks to public health and safety.

The Town of Markham through its Development Charges by-law imposed development charges against land to pay for increased capital costs required due to increased needs for services arising from development. Included in the Development Charges is the Allocation of Costs for the purpose of addressing stream conditions that would be exacerbated by development (i.e., primarily through change in hydrologic regime). Although the Town has been collecting development charges, a detailed plan for mitigating stream erosion and instability issues does not yet exist and is required to enable appropriate distribution of funds.

Aquafor Beech Limited was retained to undertake the Erosion Restoration Implementation Plan study in 2005. The objective of the study was to protect public health and safety by developing an implementation plan for erosion restoration. This was intended to be accomplished by identifying all erosion sites within Markham urban areas, to identify priority sites for restoration, and to develop a plan for monitoring the remaining sites. Toronto and Region Conservation will require detailed assessment and evaluation of restoration alternatives at the detailed design stage. The study follows the Municipal Class Environmental Assessment Process.

1.2 The Class Environmental Assessment Process

Class Environmental Assessments are a method of dealing with projects which display the following important characteristics in common (Municipal Engineers Association, 1993):

- recurring;
- usually similar in nature;
- usually limited in scale;
- have a predictable range of environmental effects; and
- responsive to mitigating measures.

Projects which do not display these characteristics would not be able to use the planning

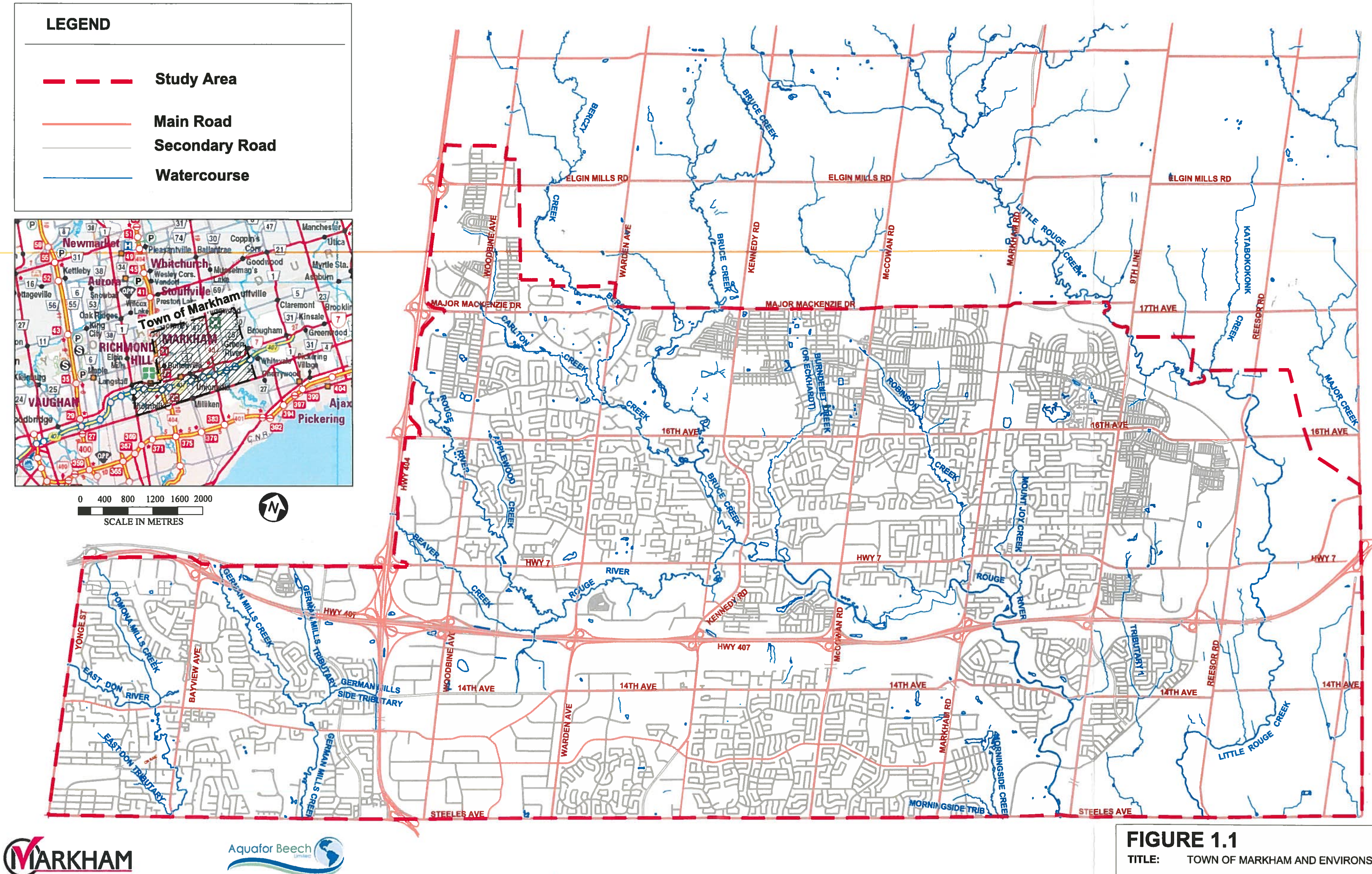
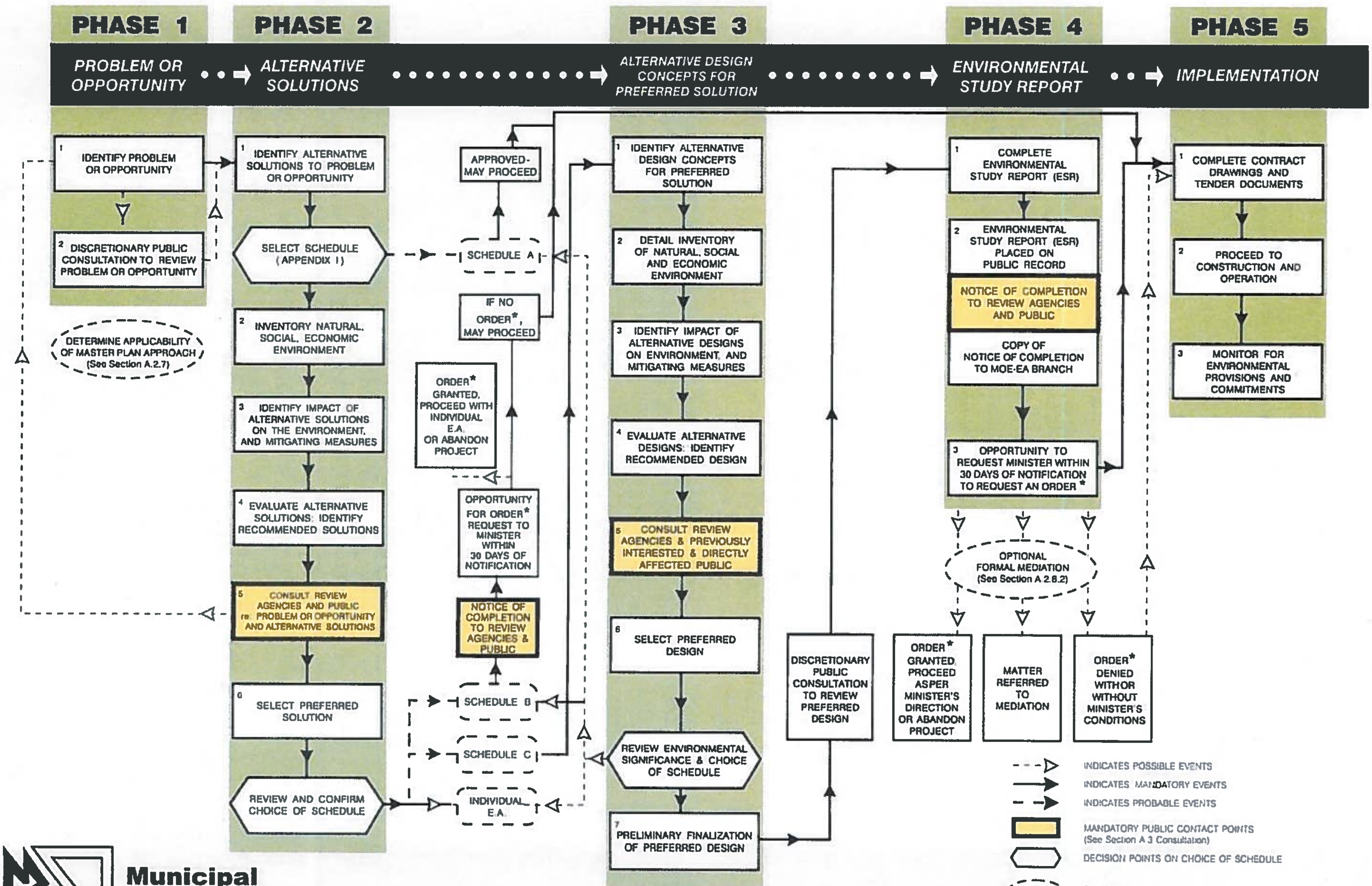


FIGURE 1.1
TITLE: TOWN OF MARKHAM AND ENVIRONS

Figure 1.2

MUNICIPAL CLASS EA PLANNING AND DESIGN PROCESS

NOTE: *This flow chart is to be read in conjunction with Part A of the Municipal Class EA*



Municipal Engineers Association

process set out in the document entitled "Class Environmental Assessment for Municipal Water and Wastewater Project", and must undergo an individual environmental assessment.

This study followed the Master Planning process within the Class Environmental Assessment for Municipal Water and Wastewater Projects process, and is subject to the requirements of the Environmental Assessment Act. This Class Environmental document therefore reflects the following five key principles of successful planning under the Environmental Assessment Act.

- Consultation with affected parties early on, such that the planning process is a cooperative venture.
- Consideration of a reasonable range of alternatives.
- Identification and consideration of the effects of each alternative on all aspects of the environment.
- Systematic evaluation of alternatives in terms of their advantages and disadvantages, to determine their net environmental effects.
- Provision of clear and complete documentation of the planning process followed, to allow "traceability" of decision-making with respect to the project.

The accompanying flow chart (**Figure 1.2**) illustrates the process followed in the planning and design of projects covered by this Class Environmental Assessment. The five phases, as defined in the flow chart, are summarized in the document as follows:

Phase 1: Identify the problem or deficiency.

Phase 2: Identify alternative solutions to the problem, by taking into consideration the existing environment, and establish the preferred solution taking into account public and agency review and input. At this point, identify approval requirements (e.g., OWRA, Lakes and Rivers Improvement Act, EPA) and determine the appropriate schedule for the project: proceed through the following phases for Schedule C projects.

Phase 3: Examine alternative methods of implementing the preferred solution, based upon the existing environment, public and government agency input, anticipated environmental effects and methods of minimizing negative effects and maximizing positive effects.

Phase 4: Document, in an Environmental Study Report, a summary of the rationale and the planning, design, and consultation process of the project as established throughout the above phases, and make such documentation available for scrutiny by review agencies and the public.

Phase 5: Complete contract drawings and documents, and proceed to construction and operation; monitor construction for adherence to environmental provisions and commitments. Where special conditions dictate, also monitor the operation of the completed facilities.

This document summarizes the steps taken to complete Phases 1 and 2 of the Class Environmental Assessment.

The above material addresses the planning and design process by which municipalities may plan sewage, stormwater management, and water works on a project by project basis. However, in many cases it is beneficial to begin the planning process by looking at all alternatives (or potential projects) that could be considered within the Town of Markham in an integrated manner. This is of particular importance when the study objectives (see Section 1.4) can only be met by implementing a series of projects that may be completed over a broad timescale.

This approach, which is referred to as the Master Planning Process, will be undertaken in this study. Further detail pertaining to this Municipal Class EA planning and design process is provided in Section 1.3.

1.3 Municipal Class EA Planning and Design Process

A Master Planning approach may be followed for studies where it is expected that a series of measures which are distributed geographically throughout the study area will be implemented over an extended period of time. This approach explicitly recognizes that there are real benefits in terms of better planning when long range holistic studies are undertaken over logical planning units, such as a subwatershed. This long range of planning approach enables the municipality to identify opportunities and to be proactive in addressing issues before they become a problem. It also allows the municipality to implement individual works which collectively become part of a larger management system.

The work undertaken in preparation of the Master Plan must recognize the Planning and Design Process of this Class EA, and should incorporate the five key principles of successful environmental planning as identified above. Documentation of the evaluation of alternatives should clearly state relevant assumptions and methods used in the analysis so that these can be verified by monitoring during the implementation phase. The Master Planning process should satisfy the first two phases in the Planning and Design Process of the Class EA.

When projects are undertaken which implement specific elements recommended in the Master Plan it will be necessary for the applicable Schedule to be determined. If the proponent so desires, the Master Planning process may be used to satisfy the requirements of Phases 1 and 2 of the Class EA process (Approach #2, **Appendix D** –

Municipal Class EA document). Schedule A and B requirements would therefore be met. Alternatively, subsequent efforts can be undertaken for Schedule B projects and a Project File would be filed once the individual projects are completed. Projects which fall under Schedule C need to fulfill the additional requirements of Phases 3, 4 and 5.

While the study, as a Master Plan provides an overview of methods that may be used to restore erosion sites, Toronto and Region Conservation Authority (TRCA) will require detailed site assessments, consultation with TRCA and an evaluation of alternatives approaches prior to selecting specific measures or practices. It should be noted that in-stream works will likely require DFO approval with TRCA recommendations that these works may be acceptable HADDS. Transport Canada will also likely conduct a review regarding navigation concerns.

1.4 Study Goals, Objectives and Primary Tasks

The study purpose has been defined as follows:

- To identify priority erosion restoration sites along Markham's watercourses which pose risk to public health and safety and to develop a restoration plan to address the erosion. The restoration plan is intended to protect the public while concurrently improving channel stability and the biological integrity of Markham watercourses within the physical, ecological, social and economic constraints associated with the urban settings of the creeks and rivers.

Secondary goals of the study may be defined as follows:

- To gain insight into the controls and modifying influences of Markham watercourses;
- To develop a long term plan for restoring the river in a cost effective (considering both capital and maintenance costs) manner.
- To define funding requirements.

The principle objectives of this project are:

- To identify all erosion, maintenance and potential fish barrier sites along Town of Markham watercourses.
- Characterize existing conditions of Markham watercourses on a watershed and reach scale.
- To develop an approach for selecting, screening and recommending alternatives to stabilize and/or restore Markham watercourses, and
- To develop an Adaptive Environmental Management Plan which costs, categorizes and prioritizes the preferred RESTORATION alternatives
- To identify project cost

The primary tasks which were undertaken as part of this study, and the associated chapters in which information is provided are summarized below.

Chapter 1 – Define study purpose;

Chapter 2 – Define problems associated with urbanization impacts on watercourses;

Chapter 3 – Define pertinent study area characteristics;

Chapter 4 – Review the public consultation process followed in this study;

Chapter 5 – Present geomorphic concepts of channel response to urbanization and modes of channel adjustment;

Chapter 6 – Define tasks undertaken to document erosion and extent of previous channel restoration works;

Chapter 7 – Summarize extent of erosion occurring along Markham watercourses and overall channel conditions;

Chapter 8 – Define components and sequence of analyses undertaken to define priority for observed erosion sites;

Chapter 9 – Establish a list of alternatives that may be used to alleviate and address erosion concerns.

Chapter 10 – Establish an implementation plan for the undertaking of priority erosion site restoration.

As was stated in Section 1.2, this study will follow the requirements of the Class Environmental Assessment Process for Municipal Water and Wastewater Projects, schedule B. For further detail regarding the Municipal EA process, see Section 1.3.

2.0 PROBLEM IDENTIFICATION

2.1 General

Urbanization alters the landscape of watersheds, changing the natural environment and modifying natural cycles occurring within them. It has been well documented that urbanization contributes to degradation of the environment through time. Degradation may occur at the onset, when lands are stripped of vegetation during the construction process which has commonly resulted in excessive sediment loadings being discharged to the receiving body of water. Degradation also occurs over a longer timeframe as alterations to the hydrologic pathways occur, resulting in a change to the hydrologic regime of a watercourse.

Excess sediment loading to receiving watercourses impact the environment in various ways. When the load is greater than the sediment transport capacity of a watercourse, then excess sediment accumulations occur within the channels. This reduces channel capacity, may contribute to a re-orientation of flows within the channel and result in destabilization of a section of channel either locally or for a significant distance downstream. Loading of fine sediment (clay, silt and sands) also adversely affect aquatic habitat by covering habitat which can smother eggs, decrease aeration in spawning beds, contribute to a loss of habitat for macro-invertebrates and/or decrease the suitability of substrate for various life stages of aquatic species. Contribution of sediment to a watercourse often also results in an increase in pollutant loadings, particularly for those pollutants that adhere to particles. The particulate (settle-able) and dissolved contaminants stress aquatic ecosystems by depleting oxygen, raising ambient water temperature, covering habitat or through the bioaccumulation or bio-concentration of contaminants in the tissues of various aquatic species.

Urban development within the lands draining to a watercourse also results in a transformation of the hydrologic characteristics within the subwatershed. Large amounts of previously permeable soils, which allowed rainwater to soak into the ground, are now covered with impervious materials such as concrete and asphalt. Rainfall events that previously contributed little or no runoff to the Creek now cause flow to occur in the channel. Consequently, the frequency of flow events, and the volume of water draining to the Creek has increased significantly.

Commensurate with the increase in runoff volume is a decrease in the time it takes for drainage water to reach the channel. Storm sewers were constructed to rapidly convey the rainwater to the Creek resulting in higher flow rates in the channel. While stormwater management processes have been effective at mitigating some of these effects, the hydrologic regime is nevertheless impacted.

2.2 Identification of Problems and Opportunities

The response of watercourses to urbanization within their drainage areas is well documented and understood. Since the physical form of a watercourse becomes adjusted to the flow regime that is conveyed through it, an alteration in flow regime (flow volume, shape of hydrograph, frequency of flows, peak flows etc. all of which are in response to urbanization) often requires the channel to respond by enlarging its cross-sectional capacity and planform configuration. The channel response is not typically immediate but may take several decades to complete. These adjustments usually result in channel enlargement, and accelerated movement as planform adjustments take place which can create a risk to public health and safety.

In addition to the alteration in hydrologic regime that occurs as a result of urbanization, there are various other impacts resulting from human modification of the landscape. These specifically refer to modifying influences of channel form such as riparian vegetation, floodplain materials and direct alteration of watercourses. Further discussion of the modifying and controlling influences of channel form and function is provided in **Chapters 3 and 5** of this report.

Problems that have been identified along Markham watercourses can be classified as: Physical Impact, Hydrological Impact, Water Quality, and Biological Impact. These impacts may be directly or indirectly a result of urbanization and human modification of the landscape include:

- widening of creek, causing outflanking and overtopping of erosion restoration structures (e.g., hardened channel lining),
- manholes situated in creek,
- erosion of private property (property lines, parking lots),
- destabilization of valley walls adjacent to private property,
- movement of watercourse in proximity to subsurface infrastructure,
- planform development in areas of previous straightening,
- exacerbated erosion rates in areas where erosion naturally occurs,
- systemic instability along watercourse,
- water quality impairment which results in visual degradation and may be a limiting factor to the restoration of aquatic habitat,
- creation of barriers to fish migration,
- undercutting and undermining of bridge abutments,
- undercutting and undermining of bank restoration materials,
- loss of baseflow
- increase in temperature
- loss of fish habitat (bed, benthic and food source),
- loss of floodplain access during more frequent flows.

Although erosion within a watercourse is a natural process, exacerbation of erosion rates occurs due to changes in hydrologic regime and sediment loading attributable to urbanization. Left unchecked, substantial degradation of Markham's watercourses could occur, which would compromise not only aquatic habitat and channel stability, but also create a risk to public health and safety. Risks include erosion in private property, damage to structures and potential breakage of subsurface infrastructure which would result in further environmental degradation (e.g., water quality, aquatic habitat, odours etc.).

In summary then, the primary problems within the context of this study include:

- risk to public health and safety
- degradation of channel form and stability
- degradation of aquatic habitat

The opportunities include:

- identification of restoration alternatives to protect public health and safety
- restoration of watercourses and aquatic habitat

3.0 STUDY AREA

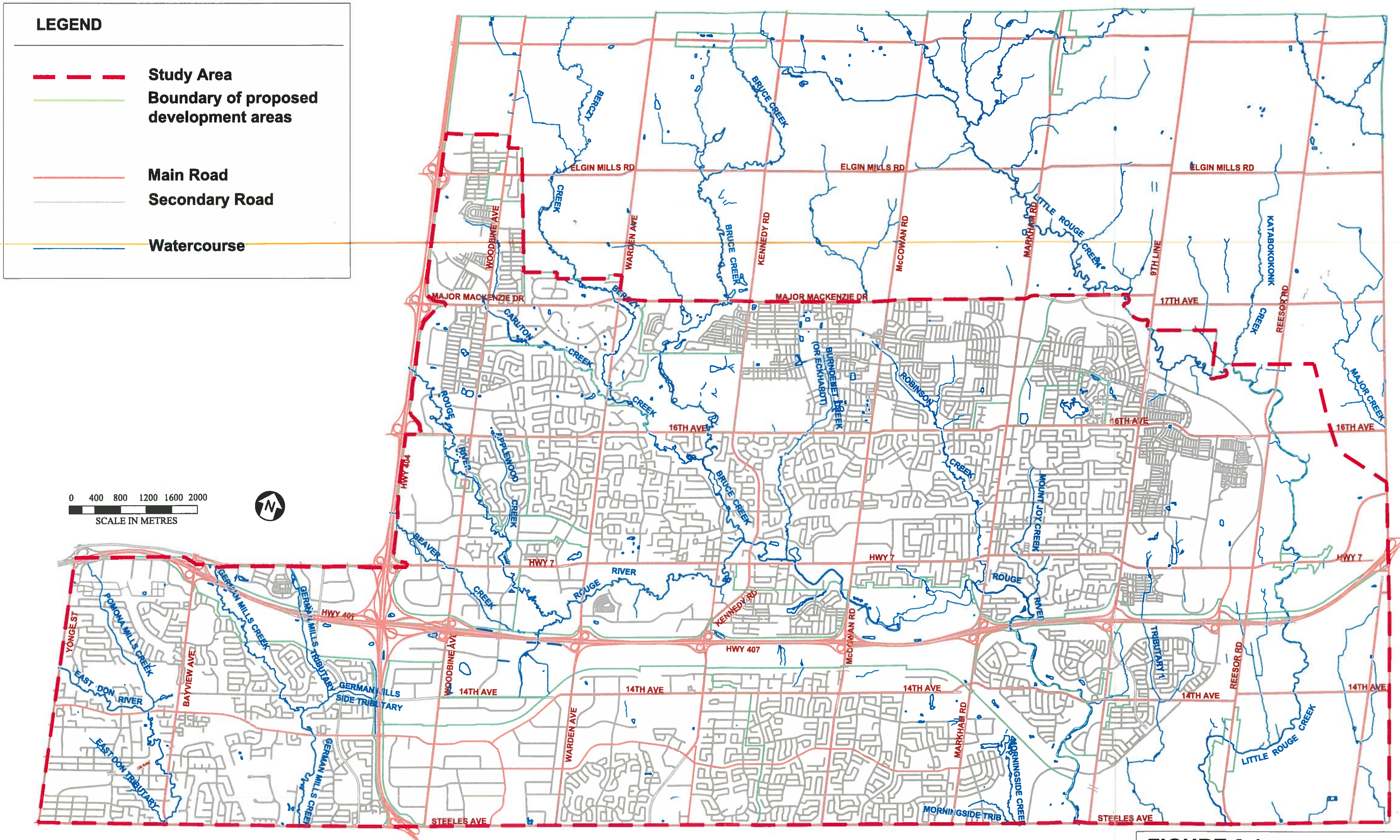
The intent of this study was to identify areas of erosion along watercourses that are situated within urban or urbanizing watersheds throughout the Town of Markham. The study area was therefore a function of existing development limits and development limits as defined by Markham's official plan (see **Figure 3.1**). This area is drained by tributaries of the Don and Rouge Rivers such that there are 19 watercourses within the study area. The character and condition of the stream channels and their watersheds will influence the occurrence and rate of erosion sites observed along Markham's watercourses.

The form of each stream channel is the product of its local environment and the flows of water and sediment that are conveyed through it. The processes occurring within each stream channel are influenced by the spatial variability and changes to factors which control and modify its form. These factors, which may occur naturally or be influenced by human actions, include channel boundary material, channel slope, surrounding vegetation, flow regime, and human activity. The general nature of these controlling and modifying factors within the study area will be discussed further in the following sections.

3.1 Geology

The surficial geology of Markham consists of two generalized geological units: glacial till and lake deposits (Sharpe and Barnett, 1997). The spatial distribution of these materials is important for understanding the character of boundary materials along each individual watercourse (**Table 3.1**). Newmarket Till is the most common unit, which is a dense and pebbly mixture of sand and silt. A localized occurrence of the older Thorncliffe Formation (till), which consists of sandy layered silt and clay, is located along German Mills Creek between Steeles Avenue and John Street. The remainder of the region is dominated by glacial lake deposits. The areas with lake deposits are more commonly characterized by finer materials such as silt and clay; however; sandy deposits are also present, particularly along the East Don River immediately north of Steeles Ave and along the Rouge River (Highway 7) from Woodbine Avenue to past Kennedy Road. A map showing the surficial geology associated with Markham watercourses is shown in **Figure 3.2.**

Larger channels (e.g. Rouge River, East Don River) have reworked the materials described above, giving rise to Holocene alluvial deposits with compositions ranging from clay to gravel. All geological units tend to be relatively thick and no outcroppings of bedrock were reported by Sharpe and Barnett, (1997).

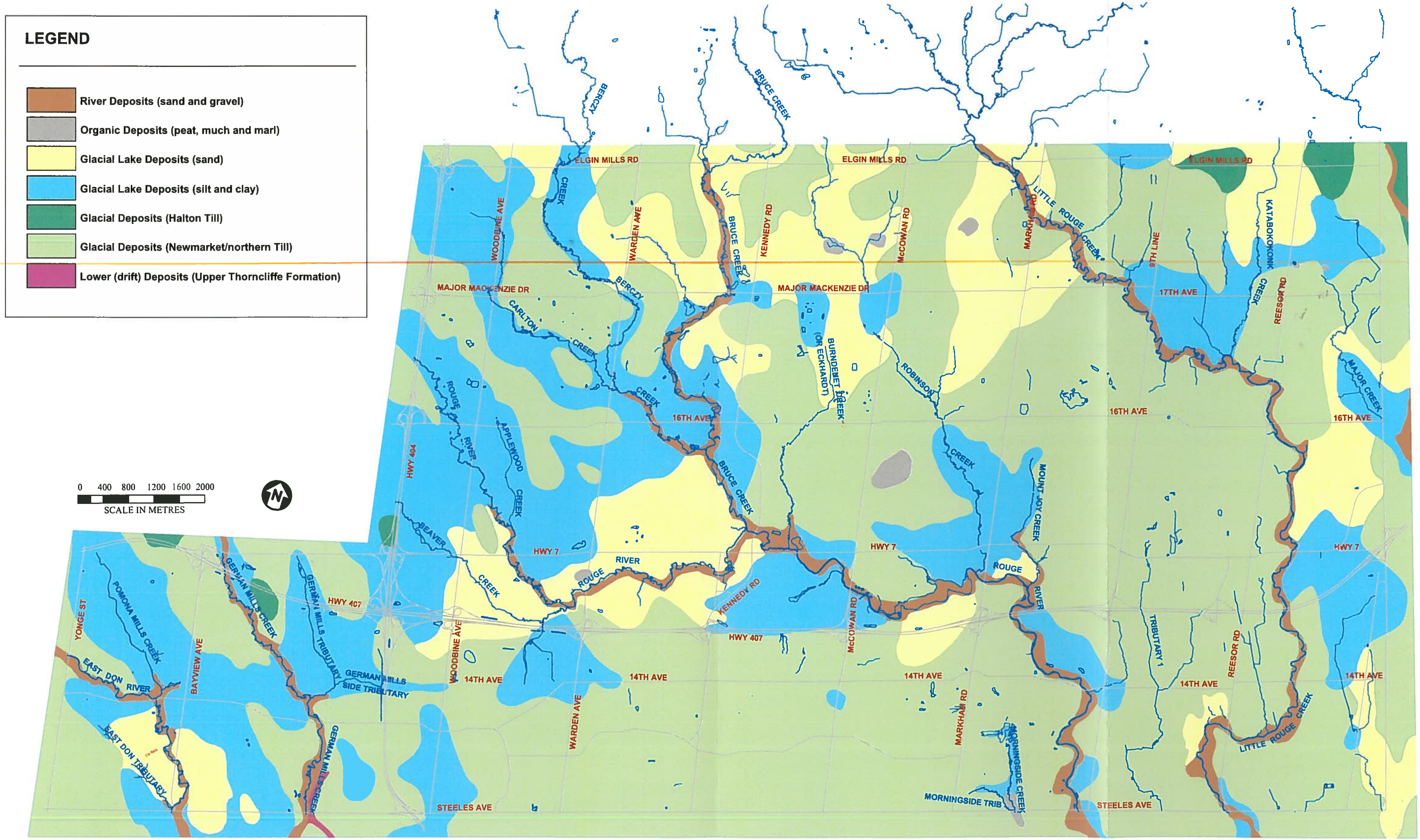


MARKHAM

Aquafor Beech Limited

FIGURE 3.1

TITLE: STUDY AREA AND DEVELOPMENT LIMITS



Source: Sharpe, D.R., and Barnett. P.J., 1997; Surficial Geology of the Markham Area, NTS 30M/14, southern Ontario; Geological Survey of Canada, Open File 3300.

FIGURE 3.2

TITLE: TOWN OF MARKHAM SURFICIAL GEOLOGY

Table 3.1: Dominant surficial geology units for each watercourse in Markham.

Watercourse	Dominant Geological Units*	Occurrence** (%)
Applewood Creek	Glacial Lake Deposits (silt and clay)	100
Beaver Creek	Glacial Lake Deposits (sand and silty sand)	100
Berczy Creek	Glacial Lake Deposits (silt and clay)	100
Bruce Creek	Glacial Lake Deposits (silt and clay) Glacial Lake Deposits (sand and silty sand)	75.5 24.5
Burndenet/Eckardt Creek	Glacial Till (sandy silt to sand)	100
Carlton Creek	Glacial Lake Deposits (silt and clay)	100
East Don River	Glacial Lake Deposits (silt and clay) Glacial Lake Deposits (sand and silty sand)	60 40
East Don River Tributary	Glacial Lake Deposits (sand and silty sand)	100
German Mills Creek	Glacial Till (sandy silt to sand) Glacial Lake Deposits (silt and clay)	73.2 26.8
German Mills Tributaries	Glacial Lake Deposits (silt and clay)	100
Little Rouge Creek	Glacial Till (sandy silt to sand)	100
Milne Creek	Glacial Till (sandy silt to sand)	100
Morningside Creek	Glacial Lake Deposits (silt and clay)	100
Pomona Mills Creek	Glacial Lake Deposits (silt and clay) Glacial Deposits (clayey silt to silt)	97 3
Robinson Creek	Glacial Lake Deposits (silt and clay) Glacial Till (sandy silt to sand)	50.6 49.4
Rouge River	Glacial Lake Deposits (silt and clay) Glacial Lake Deposits (sand and silty sand) Glacial Till (sandy silt to sand)	36.9 33.7 29.4
Tributary 1	Glacial Till (sandy silt to sand)	100
Mount Joy Creek	Glacial Till (sandy silt to sand)	100

*Dominant geological units are those which are largest in geographical extent and in direct contact with the watercourse boundary (i.e. watercourse mapped within unit or unit bounds alluvial valley).
**Occurrence as percent of total watercourse length within Markham study area

3.2 Land-Use/Cover

As noted, the form of a watercourse is a result of the interaction among numerous variables including hydrology. The landuse and land cover of a watershed can modify the hydrologic regime, requiring a channel response. Since the response requires time, review of the urbanization development pattern within the Town of Markham provides insight into watercourses that are likely to exhibit instability today (2006) and which watercourses may yet be expected to exhibit instability in the future. Knowledge of both the landuse history and watershed geology can be used to provide insight into how far along a watercourse is in terms of its response (i.e., only just begun, halfway through, nearly complete). **Figure 3.3** illustrates the development history of Markham. This

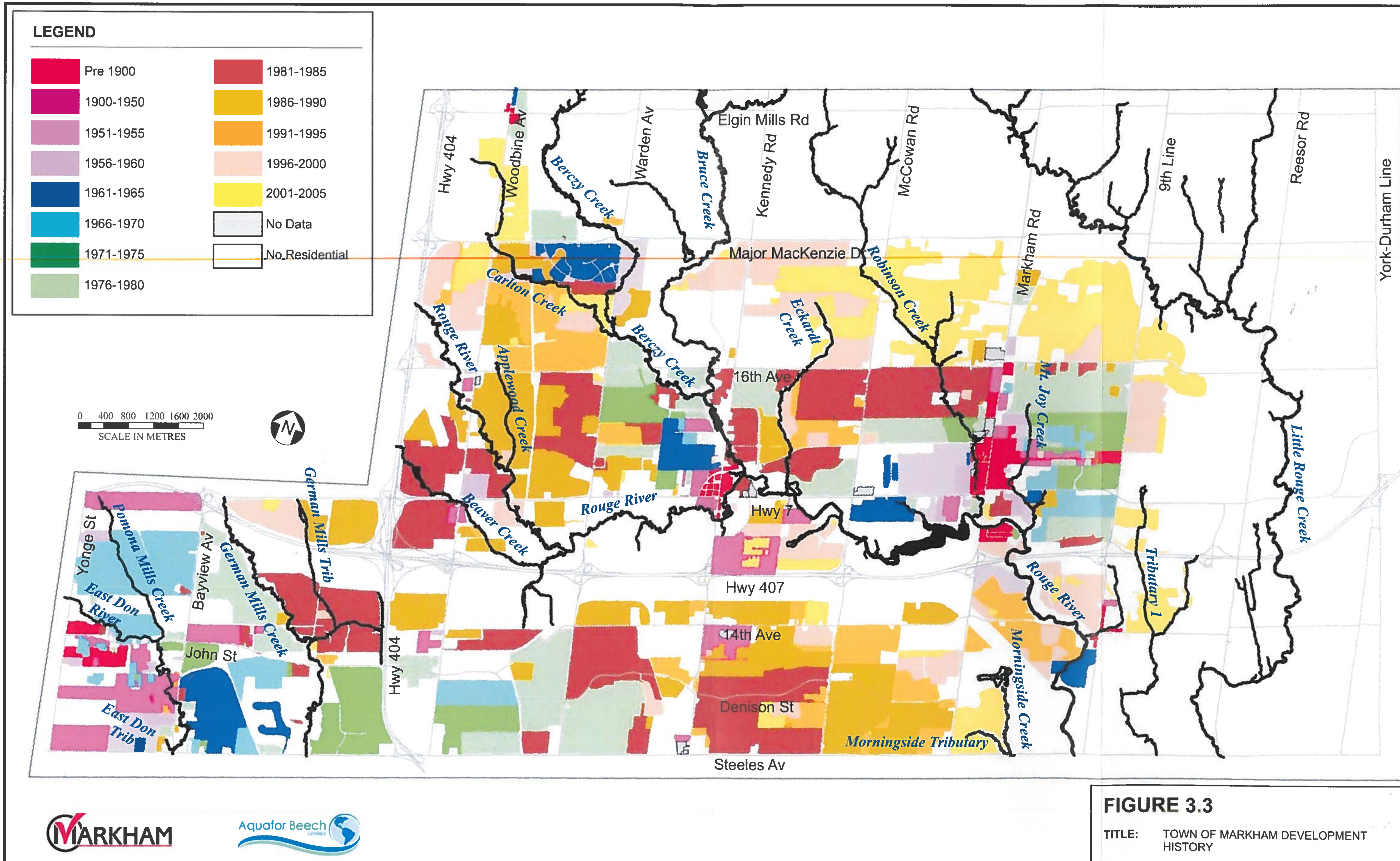


FIGURE 3.3

TITLE: TOWN OF MARKHAM DEVELOPMENT HISTORY information was used in GIS to quantify landuse characteristics on a subwatershed basis (see **Table 3.2**), which was used in subsequent analyses (**Chapters 5, 6, and 7**).

Table 3.2. Overview of landuse characteristics in Markham watersheds (from west to east) based on development history mapping provided by the Town of Markham.

Watercourse	Average age of development in Markham (yrs)	% Impervi ous-ness	Development Status (2005) within Markham
East Don River ▶Θ	54	57	Fully Developed
Pomona Creek [1] (tributary of East Don River) ▶Θ	(54)	(57)	Fully Developed
German Mills Creek ▶Θ	27	52	Fully Developed
Markham Creek [2] (tributary of German Mills Creek) ▶Θ	(27)	(52)	Fully Developed
Upper Rouge River ▶Θ	25	58	Fully Developed
Beaver Creek[3] ▶Θ	(25)	(58)	Fully Developed
Applewood Creek[3]	(25)	(58)	Fully Developed
Middle Rouge River ▶Θ	23	39	Partially Undeveloped (East of Warden Ave.)
Milne Creek[4]	(23)	(39)	Fully Developed
Carlton/Berczy Creek	23	32	Partially Undeveloped (Upstream of Major MacKenzie Dr)
Bruce Creek	11	12	Partially Undeveloped (Upstream of Major MacKenzie Dr)
Eckardt Creek (previously Burndenet Creek)	23	29	Fully Developed
Robinson Creek	24	29	Development Nearly Complete
Mount Joy Creek	29	55	Fully Developed
Unnamed tributary (tributary of Little Rouge River)	3	37	Partially Undeveloped
Morningside Creek	14	57	Fully Developed
Lower Rouge River ▶Θ Θ▶	24	40	Fully Developed (Significant areas are golf course)
Little Rouge River Θ▶	2	7	Mostly Undeveloped (Except for new development near 16th Ave and 9th Line)

( ) = Watercourse included in larger subwatershed for calculation of average values.
▶Θ Watercourse receives substantial water from other upstream jurisdictions.
Θ ▶ Watercourse contributes substantial water to other downstream jurisdictions.

Pomona Creek [1] = Age and Imperviousness are well represented in East Don Values
Markham Creek [2] = Age and Imperviousness are well represented in the German Mills Values; however, age of development may be slightly younger (20 to 27 years)
Applewood – Beaver Creek [3] = Age is well represented in Upper Rouge Values; For Imperviousness Applewood is nearly all residential (~60%); Beaver is very high in Industrial/Commercial (60 – 80%).
Milne Creek[4] = Age and Imperviousness are not well represented by Middle Rouge Values; Average age is ~45 years and landuse is mixed residential, commercial, industrial (60 – 80 %).

Residential development in Markham has expanded throughout the last century, and typically consists of suburban communities of varying ages. A number of spatial trends have been identified in the development history of Markham:

- Clusters of older developments (pre-1900) are scattered throughout the watershed (e.g. Thornhill, Unionville, and Old Markham Village), with the highest concentration of old development in the west end of Markham (west of Hwy 400)
- Development appears to radiate outward from older urban centres, and has typically progressed in a northerly direction in each watershed
- Older developments tend to have small or non-existent setbacks from the watercourse, with many private properties extending through the watercourse and adjacent floodplain.
- Some watersheds are associated with significant development upstream within other jurisdictions that influence stream flow patterns in Markham (e.g. East Don River receives water from Vaughan)
- Current development in Markham (post 2000) is concentrated in the area north of 16th Avenue and between immediately west of Kennedy Road and 9th Line

In addition to the residential areas of Markham, other general spatial characteristics of landuse are apparent:

- *Agricultural and rural land* uses still dominant areas east of Reesor Road and north of Major MacKenzie Drive (e.g. Little Rouge River, Tributary 1).
- Major *road right-of-ways* through Markham include Hwy 7, Hwy 404, and Hwy 407. Commercial and industrial areas are concentrated in areas surrounding Hwy 7, specifically areas south of Hwy 7 between Hwy 404 and Warden Avenue, and areas along the east side of Hwy 404 (Upper Rouge River and Beaver Creek).
- Significant *parklands* include Rouge Park North Corridor (Upper Little Rouge River) and Milne Park associated with the Milne Lake reservoir (Middle Rouge River).
- Many *golf courses* are dispersed throughout Markham, particularly on lands adjacent to the Rouge River, Bruce Creek, and Pomona Creek.

3.3 Aquatic Resources

The Toronto and Region Conservation Authority have a record of fish surveys completed along Markham watercourses which provide insight into the type of fisheries that exist in the study area. The Rouge River Fisheries Management Plan and the Don River Fisheries Management Plan contain valuable information pertaining to aquatic habitat conditions which were referenced within this study and which should be considered when undertaking any restoration works along Markham watercourses.

Review of the materials and with input from TRCA, it was determined that there are both cold and warm water aquatic communities within Markham's watercourses. For the purpose of this study, aquatic habitat conditions were grouped into 5 categories (see **Table 3.3** for a listing of aquatic habitat by watercourse (note however that since the Updated Rouge River Fisheries Management Plan has not been completed to date, the classification has not been confirmed by TRCA but will be required to be confirmed at the detailed design stage):

5 - *intolerant coldwater fish community*: Aquatic habitats are characterized by cold water temperatures; high dissolved oxygen levels; stable, moderate gradient streams; groundwater dominated flows; cobble/gravel/sand substrates; well developed pool:riffle morphology. Fish communities are very sensitive to disturbance. While not strictly a coldwater species, fish habitats supporting redside dace would also fall in this category.

4 - *tolerant coldwater fish community*: Aquatic habitats similar to the above, but generally characterized by larger order streams, coarser substrates, larger pools to support adults. Stream temperatures may be warmer, and streams generally only support salmonids during their juvenile life stages, with adults migrating to the lake.

3 - *diverse warmwater fish community*: Aquatic habitats very diverse ranging from moderate to large river habitats similar to 4 above to low gradient rivers with aquatic macrophytes as a significant habitat element. These are generally runoff dominated streams that are more nutrient rich, but are generally stable.

2 - *moderately tolerant warmwater fish community*: Aquatic habitats are generally moderately degraded in terms of natural hydrology, stream stability and water quality. Generally these systems supported fish communities typical of 3 – 5 above, however loss of groundwater discharge; shift from pool:riffle to flat:run morphology; habitat instability from "flashy" hydrology; and water quality degradation eliminate sensitive species from the fish community

1 - *tolerant/highly tolerant warmwater fish community*: Similar to 2 above, however, instream habitats are degraded to the point where only the most tolerant species can survive

Table 3.3: Aquatic habitat classification by watercourse from west to east across the Town of Markham. Note: classification will need to be confirmed at the detailed design stage since the Updated Rouge River Fisheries Management Plan has not been completed to date.

Habitat Sensitivity	Class
East Don River and tributaries	3
Pomona Mills Creek	1
German Mills Creek and tributaries	1
Beaver Creek	4
Carlton Creek	4
Bruce Creek	5
Berczy Creek	5
Burndenet/Eckart Creek	4
Applewood Creek	1
Rouge River	4
Little Rouge River	5
Tributary 1	2
Mount Joy Creek	4
Robinson Creek	4
Morningside Creek	5

3.4 Terrestrial Resources

Vegetation exerts an important modifying influence on watershed processes. The presence of large wooded or scrubland areas provides for significant terrestrial habitat and also moderates the hydrologic cycle. There are several large naturalized areas that exist within the study area:

- East Don River – Pomona Mills Park
- German Mills River – German Mills Settlers Park
- Bruce-Berczy confluence – Toogood Pond Park
- Robinson Creek – Springdale and Cedar Valley Parks
- Rouge River – Milne Park
- Little Rouge River – Rouge Park North Corridor

A stream corridor is a linear landscape feature which tends to contain the flow and lateral adjustments of the watercourse, with an associated vegetation community. All of Markham's watercourses are situated within a stream corridor that consists of natural or modified vegetation. The width of the stream corridors vary and appears to be largely a function of watercourse size (i.e., width) and development history (older urbanized areas tend to have narrower corridors, with some properties landscaped to the channel bank). Vegetation is not only important for riparian habitat, but also plays a key role in channel form and process by modifying bank stability and redirecting local flows (e.g. in-channel woody debris). Vegetation that is characterized by deep and dense root networks are very effective at enhancing the shear strength of bank materials, especially for banks that are ~ < 0.75 m high. The coarse and woody root networks of trees and shrubs are particularly effective on higher banks. The shade provided by vegetation is an important factor in moderating stream temperatures and providing aquatic habitat.

The vegetation along Markham's watercourses is dominated by deciduous shrubs and grasses. Wooded areas are situated primarily around undeveloped and well-defined valleys and around some online ponds and reservoirs.

Review of TRCA files indicated that there are no PSWs, ESA, or ANSIs within the Don River Tributaries study area. Within the Rouge River tributaries study area however, there are a few PSW's and ESA's located within the Town of Markham. These include Robinson Swamp Provincially Significant Wetland Complex; the Unionville Marsh PSW (which is also ESA (#89) and the Milne Woods ESA (# 139).

Information with respect to species at risk within the study area was determined in reference to the MNR website (**http://nhic.mnr.gov.on.ca/MNR/nhic/species.cfm**). Although a few species at risk were identified within Markham (e.g. Handsome Sedge), review of species locations did not reveal any terrestrial species at risk due to watercourse erosion and degradation.

4.0 PUBLIC CONSULTATION PROCESS

This study followed the Master Planning process within the Class Environmental Assessment for the Municipal Water and Wastewater Projects process, and is subject to the requirements of the Environmental Assessment Act. As such, this Class Environmental document therefore reflects the five key principles of successful planning under the Environmental Assessment Act as outlined in **Chapter 1.2**. One of these principles includes consultation with affected parties early on during the process to ensure that the planning process is a cooperative venture. For this study, consultation was undertaken with regulatory agencies at the outset of this study and later with public involvement. Results of the consultation process that were undertaken are discussed within this chapter. Presentation materials and correspondence pertaining to the public consultation are presented in **Appendix A.**

4.1 Regulatory Agency Involvement

At the outset of the study, the Toronto and Region Conservation Authority (TRCA) was invited to participate and provide input into the direction of the study. A subsequent meeting was held with various environmental representatives of the TRCA to provide specific input with respect to methodologies. For this second meeting, the Department of Fisheries and Oceans (DFO) and Ministry of Natural Resources (MNR) were also invited. The DFO representative determined that TRCA could act on their behalf and therefore would not need to be directly involved in the study. The MNR representative for the study area did not reply and did not attend any meetings. Thus, only representatives from TRCA became involved in the study.

Two meetings were held with representatives from the TRCA, the Town, and Study team. Meeting content and outcomes are summarized below. Materials presented and discussed at the meetings are presented in **Appendix A.**

<u>*Meeting 1: December 15, 2005*</u>

Location: Town of Markham

Purpose: to provide background of the study to TRCA and to solicit input with respect to direction and concerns about the study

Summary: TRCA was in overall support of the study and expressed interest in continued involvement with respect to the various environmental disciplines that are incorporated into the study. TRCA expressed that an opportunity exists to tie this study into the Rouge River Watershed Plan. An overview of the priority ranking approach was provided to TRCA, who were asked to provide comment on the approach. This was subsequently provided by TRCA.

Meeting 2: February 9, 2005

Location: Town of Markham

Purpose: to solicit input from TRCA regarding the erosion prioritization approach, relevant information pertaining to the study area and Markham watercourses, and restoration approaches

Summary: the meeting was held as a round table discussion to address input provided by TRCA in response to Meeting No. 1. Each component of the priority ranking scheme was examined and agreement was attained as to the items to be included in each category and the relative scoring of each component within the categories. Information pertaining to aquatic habitat scoring would be provided by TRCA subsequent to the meeting. This was received by Aquafor at a later date. **Chapter 8** of this report represents the erosion prioritization approach that was developed with, and agreed upon by, TRCA.

Appendix A contains a summary of all meeting agendas, minutes and correspondence.

4.2 Public Meeting

One public meeting was held during the study to inform public residents of the study and to solicit input with respect to priority restoration sites and erosion restoration alternatives. Prior to any meeting taking place, information was presented first to Town Council to obtain approval to proceed. A public relations consultant was retained to moderate the public meeting.

The Public Meeting was held at the Town of Markham, (Canada Room) on 18 May 2006. A newspaper ad was placed in both the Markham Economist & Sun and the Thornhill Liberal. Notice of the meeting was also sent to numerous interest groups and residents who would be directly affected by restoration works at the priority erosion site locations.

The objective of the meeting was to:

- Provide an overview of the erosion risks in Markham;
- Introduce the Watercourse Erosion Implementation Plan;
- Gather input on the Evaluation Approach used, the erosion sites and the remedial options to be used to restore watercourses.

Participants were invited to review poster boards and to determine whether any erosion sites, that they were aware of, had been omitted. A half hour formal presentation was then given to provide an overview of the study. The presentation included a discussion of the Class EA process, an explanation of erosion concepts, a history of action taken by the

Town with respect to identifying and remediating erosion sites, and an overview of the type of erosion sites found within Markham with associated potential risks to public, structures, and fisheries. The presentation was followed by a question and answer period and then followed by roundtable discussions amongst participants which were facilitated by members of the study team and the external public relations consultant (all materials presented at the public meeting are in Appendix A). In summary, the public meeting included:

- A series of posters which defined:
    - Goals and objectives of study
    - Study area
    - Location of erosion sites
    - Photographs of 30 erosion sites considered to pose a potential risk to public, structures or fisheries
- Presentation:
- A workbook questionnaire that was used to promote discussion and solicit input (see attached)

Twenty-one residents attended the public meeting, many of whom participated in round table discussions and provided responses and comments to the workbook questionnaire. The workbook questionnaire was designed to obtain responses from the public with respect to whether or not the study team had missed any erosion sites and the types of works that the public would prefer to be used to address any erosion concerns. The responses are summarized below:

Question 1: Do you have any concerns about the Evaluation Approach used? (If so, please specify what they are).

1. When considering erosion evaluation, must also consider storm sewers.
2. How will town solve (pay for repairs) of erosion problems on our property with taxes already so high
3. Excellent approach. Fix small erosion sites now before they worsen, regardless of funding availability
4. Natural resource should be ranked higher
5. Excellent approach. Some [erosion] problems can be corrected without major expenditure

Question 2: Have we missed any erosion sites? (If so, please specify where they are).

- We could not see in details
- German Mills Creek at Brandgate Ct (N of John St, W of Leslie) Top of bank failure occurred on Aug 19, 2005 although not sure if any actual creek erosion occurred.
- Milne Creek south of Drakefield (footbridge)

- EDT ES-06 is a high priority site for 5 reasons: 1) 400 ft long, 2) 2 storm sewers, which overflow, 3) Town has easement on my property, 4) large willows have fallen or at risk of falling, 5) repaired damages to landscaping, pond and [swimming?] pool but recent flooding has destroyed again

Question 3: Are there any priority erosion sites missing? (If so, please specify where they are).

- Private property sites south of CNN (ibid.) Rail.
- Erosion site on Rouge River in Unionville (at 5 Second Street), should be classed as high priority. Incipient cutoff (gooseneck) would cause severe problems
- Correct small erosion sites (e.g. upstream of priority sites) to reduce downstream erosion. Apply small streams and watercourses policy ASAP.
- Pomona Mills Creek between Kirk Dr and Thorny Brae at bottom end – flooding and erosion are issues
- Pomona Mills Creek immediately south of Holy Cross Cemetery. Weir has collapsed.

Question 4: Are there any remedial options you think should not be used. What are they and why?

- We prefer the use of soft approaches (vegetation) and preservation of trees.
- Gabions are the least desirable. They can be pushed over by frost heave, washed out and are unattractive. They do not lend themselves to re-vegetation.
- Prefer softer, vegetated and natural approach
- Minimize hard treatments where possible and maximize natural treatments. Try to implement more "at source" controls or "conveyance" controls to reduce downstream erosion
- Use best method, as directed by erosion committee. Widening the dam (weir on Pomona Mills Creek?) between the cemetery (Holy Cross) will stop the erosion in this area.

Any other comments?

- From residents of Fairfield Place:
- erosion damage to private property should be considered and repaired
- damage to "these" private properties should be addressed and paid for by Town of Markham. Fix now before problems worsens
- Huge amount of large woody debris needs addressing.
- Resident 38 years along Pomona Mills Creek. Creek a constant concern. Several band-aid solutions but no intelligent solution. Approx. $15,000 property damage caused by August 19, 2005 storm. Town will not assume any responsibility. Suggest a bridge be built at the site of the walk through between Baythorn and Thorny Brae so the creek can flow more freely. Suggestions:

- Clean up watercourse (remove fallen trees and overturned abutments)
- Maintain cleanups
- Replace existing crossing (three CSPs) with a larger bridge structure
- There needs to be more communication with public. No information on Town of Markham website.

In response to the public comments that were received, the study team completed follow-up field inspections to erosion sites that may have been missed and which were identified by the public. These sites were then included with the sites identified during the initial field walks and subsequently included in analyses.

Follow Up By Study Team

In response to the public comments that were received, the study team completed follow-up investigations for each of the locations identified, including:

- 5 Second Street – Rouge River – Field Site Revisited
- Drakefield Road – Milne Creek – Field Site Revisited
- Circle Court – German Mills – Field Site Revisited
- Fairfield Place – East Don River –Ranked in Top 30
- 7 Victoria Ave – Bruce Creek – Field Mapping and Photographs Reviewed
- Thorny Brae – Pomona Mills Creek - Field Observations and Photographs Reviewed

At each of these locations, the presence of erosion was evaluated using the methods described in Chapter 6 which were applied during the field program for this study. No new erosion sites were found at the follow-up field sites. Summaries of each follow-up site are provided below.

Rouge River (5 Second Street)

- This site had already been included in the erosion site inventory (**Site R-ES-31)** and was not identified as a priority site within the screening analysis outlined in Section 8.1. The site was re-evaluated to ensure it had been given appropriate consideration in the erosion prioritization (**Appendix B-5, Appendix C**).
- While some evidence of lateral migration was apparent, the erosion risk did not appear to be immediate, and was largely associated with the future cut-off of a meander loop (process could take from years to decades to occur).

Milne Creek (Drakefield Road)

- Notable evidence of channel instability was identified along the lower reaches of Milne Creek (**Appendix B-7**). Evidence of enlargement, widening and increased sediment supply was apparent along the watercourse in response to urbanization; however, noted erosion was not considered to pose public risk.

- Milne Creek upstream of the Drakefield Road crossing was also investigated. The channel appeared stable between Drakefield Road and Bakerdale Road, however, much of the channel was fenced within private property, inhibiting a thorough investigation.

German Mills Creek (Circle Court)

- The valley wall of German Mills Creek near Circle Court was investigated for stability.
- Evidence of some past slope instability was apparent along a couple of properties; however, since the channel was more than 20 m from the slope, and lined with gabion that was in fair condition, the instability is unrelated to river processes (i.e., it is a geotechnical issue). As the watercourse is not a direct contributor to the slope instability, it is does not satisfy the criteria for inclusion in this study.

East Don River (Fairfield Place)

- This follow-up site contained an number of erosion sites included in the priority ranking (**Sites ED-ES-05 to ES-08, Figure 7.2**) and have collectively been included within the Top 30 erosion sites (**Figure 10.1, Table 10.2**).

Bruce Creek (7 Victoria Ave)

- Field information (mapping and photographs) were used to re-evaluate erosion along the lower reach of Bruce Creek near the CN railway crossing. Two sites within the erosion site inventory (**BRU-ES01 and ES02**) were not identified as priority sites within the screening analysis outlined in Section 8.1. No new erosion sites were identified, and noted erosion was not considered to pose public risk.

Pomona Mills Creek (Thorny Brae)

- This site had already been included within the Top 30 erosion sites (**Site PM-ES-14, Figure 7.2**). Issues relating erosion and flooding were confirmed to be associated with CSP culverts under a local footpath crossing (**Figure 10.1, Table 10.2**)

5.0 GEOMORPHIC SYSTEMS UNDERSTANDING

In a study such as this, it is important to gain an understanding and appreciation of Markham channel conditions and processes, to provide a context for observed erosion sites and as background material for development of restoration plans. As such, this chapter is intended to provide an overview of basic channel adjustment and erosion concepts and to relate these to Markham watercourses. Insight gained into channel conditions and processes through field reconnaissance and background information review are compiled here to provide more specific insight into Markham watercourses which informs the selection of restoration alternatives and implementation plan of subsequent chapters in this report.

5.1 Controls and Modifiers of Channel Form

The configuration of a watercourse, in cross-section, profile and planform is a result of the interaction amongst numerous variables that define channel form. These variables are typically defined as either controlling factors (i.e., geology, climate, physiography), or modifying influences (e.g., vegetation, human activity). Modifying influences of channel form are those factors that modify the influence of geology and climate and affect channel shape.

The boundary materials of a channel (i.e. bed and banks) are influenced by local geology and contributions of sediment from upstream. The size of boundary materials affects the configuration of the watercourse and whether or not features within it are well-developed. The relative resistance of boundary materials will also determine the predominant mode of channel adjustment (i.e., channel response to change tends to occur along those boundary materials that are weaker which can lead to predominant widening, migration or deepening tendencies). Characteristics of boundary materials also have implications for aquatic habitat types and quality. **Figure 3.2** in **Chapter 3** portrays the geology along Markham watercourses

Stream flow influences channel form primarily by the magnitude of flows conveyed through it, which is generally controlled by its upstream drainage area and climate. The amount of rainfall, and rate at which it enters the watercourse, may be modified by human activities (i.e. land-use and increased imperviousness). In comparison to a non-urbanized drainage area, more rainfall within an urban catchment tends to be directed to the stream channels (and at a faster rate), and less water tends to be slowly infiltrated into the groundwater systems.

The channel slope is generally controlled by the historical evolution of the stream system within its geologic context (profiles have been created for each watercourse and are presented in Chapter 7 and Appendix). The grade of a channel contributes to flow energy. The profile of a watercourse is typically concave shaped with the steepest areas in headwaters or below base level control points. Local gradients may be modified by biotic (e.g., roots in channel), geologic (resistant outcrops of materials), and human factors (e.g., weirs).

Vegetation is not only important for riparian habitat, but also plays a key role in channel form and process by modifying bank stability and redirecting local flows (e.g. in-channel woody debris). The type of vegetation that exists on channel banks influences channel cross-sectional shape through characteristics of its rooting network. For example, when riparian vegetation consists of trees, then channels tend to be wide and shallow. When bankside vegetation consists of deep and dense rooting grasses and herbaceous plants, then cross-sections tend to be deep and narrow (Millar, 2000; Trimble, 2004).

Human activity may also directly change the characteristics of channel form and material through realignment and by installation of bank protection or instream structures weirs, culverts, and dams.

Land use and land cover within the watershed significantly influence the rate and method of water and sediment routing to a watercourse. Clearing of land during European settlement in the Markham area, as in much of southern Ontario, resulted in increased soil erosion which has caused sediment loading to the river corridors. Deforestation also altered the rate and pathways of water delivery to receiving watercourses. In response, the equilibrium form of the watercourses was affected and adjustments occurred. More recent land use changes within the Town of Markham are associated with urbanization and drainage network modifications. Both of these factors have increased the rate and volume of overland flow that is delivered to receiving watercourses.

When the modifying and controlling variables remain relatively constant, then the channel becomes adjusted or 'balanced' to them to create a stable configuration. A balanced channel is referred to as being in quasi-equilibrium. The concept of an equilibrium channel form is often represented pictorially by a balance (see **Figure 5.1**). In this balance, when sediment load or size are disrupted or a change in flow occurs, then the balance is offset and the imbalance may result in aggradation or degradation problems. For example, if flow increases, but the slope of the channel remains the same, then the size of material and/or quantity of material that can be moved will increase, and must increase, to enable a balance to be regained. As such, erosion and deposition are necessary and natural processes that occur in all watercourses.

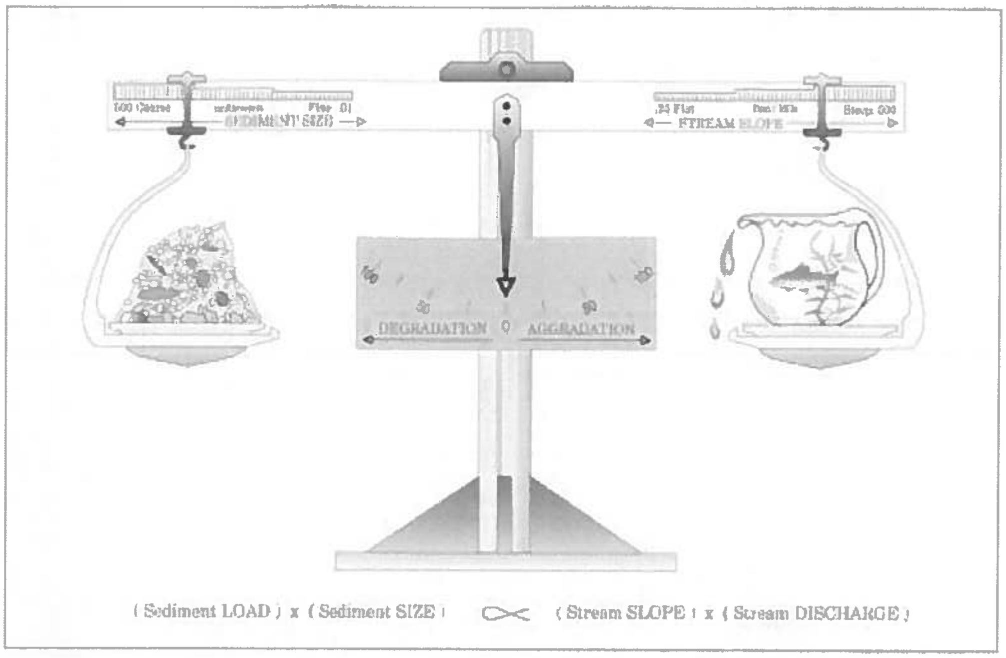


Figure 5.1. Lane's balance concept for channel equilibrium form (from Rosgen, 1996)

5.2 Urban Impact

The land cover within a watershed is an important factor in determining hydrologic pathways and rates of water routing to the receiving watercourse(s). Review of the scientific literature clearly documents that an increase in drainage basin imperviousness alters the frequency and magnitude of flows. Bledsoe (2002) found that the greatest increase in erosion potential from urbanization was associated with minor flow events or sub-bankfull flows having depths of < 0.7 Dbf (where Dbf is the depth of the dominant discharge in the pre-disturbance channel). Booth (1991) suggested that the threshold for channel stability occurs when the impervious cover within a watershed is 10%. Further research has demonstrated that a notable decrease in quality of aquatic habitat occurs when watersheds are 10 – 15 % impervious (Booth and Reinhelt, 1993; Galli, 1994, and Shaver et al., 1995). Beyond this threshold, aquatic habitat quality in streams was typically found to be poor.

An increase in flow volume and frequency will elicit a channel response at the micro, meso and macro scales of channel morphology, all of which are interlinked. Changes at the micro level occur most quickly and directly affect aquatic habitat (i.e., mobility of substrate materials and characteristics of the substrate grain size distribution). At the same time that micro level changes occur, changes in meso – scale channel form (cross-section geometry) are in motion. Each of these adjustments contribute to changes in channel stability and, over time, can place human health and safety at risk.

The rate and extent of land use change within a watershed will, in conjunction with local factors such as riparian vegetation and geology, determine how a channel responds to changes in its hydrograph. The pre-existing channel stability which is, in part a result of previous watershed changes such as land clearing at the onset of European settlement in the late 1700s/early 1800s are also important precursors.

The development history of Markham was presented in **Chapter 3** as **Figure 3.3**. Review of the mapping demonstrated that while some areas of Markham predate the 1960s, large areas of development have occurred since the early 1980s. As noted in **Chapter 3**, the older areas of development are typically along the East Don River and German Mills Creek and near the confluence areas of tributaries to the Rouge River. Newer developments occur in the middle and headwater areas of most watercourses. Little Rouge Creek is the least impacted by urbanization of all watercourses within Markham.

The extent of stormwater management that has been implemented within southern Ontario varies temporally with most work being undertaken post 1980. As such, older development areas are expected to have a greater impact on receiving watercourses than newer development. Stormwater management has become more progressive through time but does not yet fully restore the hydrologic regime to pre-urban conditions. In general, there is agreement that current stormwater management practices still result in channel impacts and, while these may not be to the same extent as occurs under uncontrolled stormwater runoff conditions, continue to result in degradation of Markham's watercourses.

The response of a channel to urbanization has been documented and is depicted graphically in **Figure 5.2.** In general, there is a lag time between onset of change and initiation of channel response. The amount of time required for the channel to adjust to the change in flow regime is a function of boundary materials and other factors that are discussed further in **Section 5.3.3**. As a generalization, channels situated within sandy materials may take up to 25 years to adjust to watershed urbanization; whereas channels with cohesive clay boundaries may take 50 years to adjust to watershed urbanization.

5.3 Modes of Channel Change

Natural watercourses gradually migrate across their floodplain through the processes of erosion and deposition. Adjustments to channel form (e.g., cross-section) occur spatially along watercourses due to increases in flows (in the downstream direction as a result of increasing drainage area) and to local variations in floodplain materials and riparian vegetation (e.g., rooting depth, density etc.). When the natural rate of change is exacerbated, such that erosion begins to occur in proximity to structures and private land, then intervention may be warranted if this poses a risk to public health and safety.

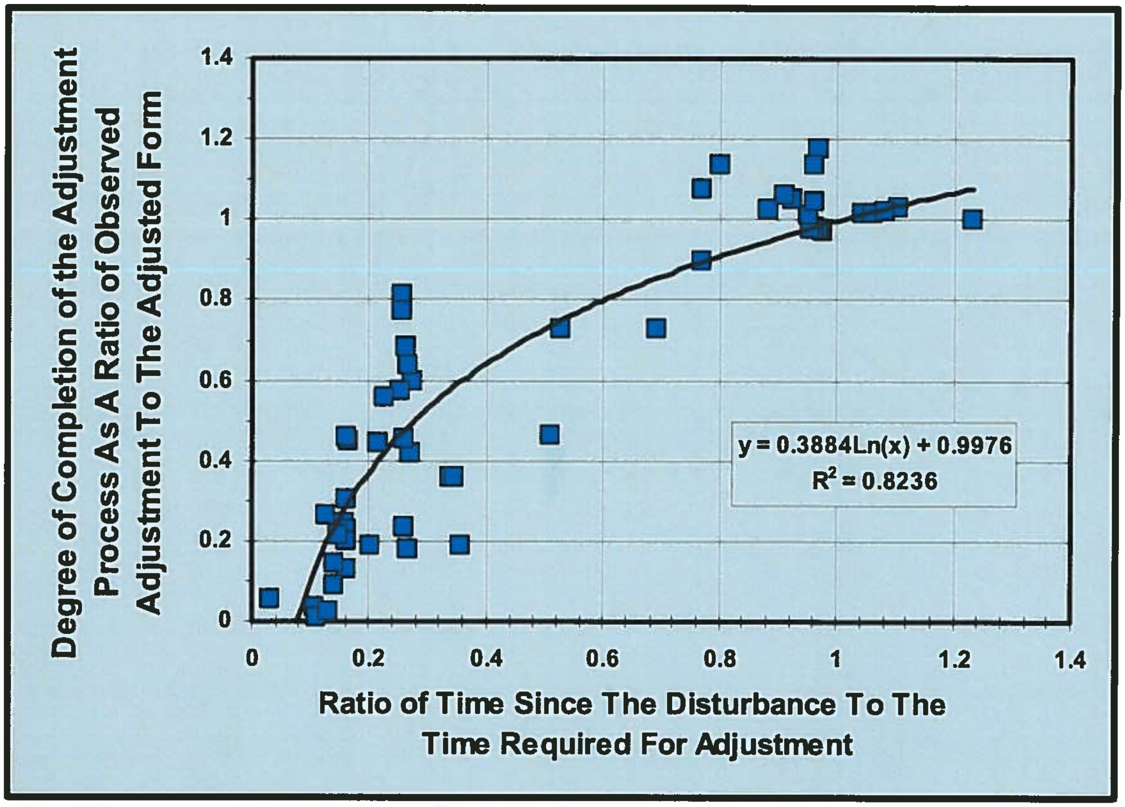


Figure 5.2 Channel enlargement vs. time.

5.3.1 Scales of Channel Change

The response of a channel to a change in flow regime requires adjustments to the micro-, meso-, and macro- scales of channel form. The micro-scale includes sedimentary bars and grain size distribution on the channel bed. Meso-scale features refer to bed morphology such as pools and riffles, and cross-sectional form. Macro-scale features include planform configuration. As may be expected, micro scale adjustments occur most quickly following a change in flow regime whereas changes in macro form may require several decades to complete. Although seemingly inconsequential, changes in micro-scale can affect the quality of fish habitat and initiate changes at the meso-scale which, in turn, affect macro-scale changes.

5.3.2 Typical response to urbanization

In response to urbanization, the typical response of a channel is to enlarge its cross-sectional area so that it can accommodate the increased volume of flow. Enlargement typically occurs through channel widening and, to a lesser degree, incision **(Figure 5.3).** The increased duration of flows in a channel, higher peak flows, and increased frequency of higher flow events that occur in response to urbanization will also cause an increase in channel migration rates and planform adjustment (i.e., which result due to changes in channel width). As channel enlargement occurs, the volume of sediment that is generated through erosion typically results in localized, or reach-scale aggradation in downstream sections of the watercourse. All of these modes of channel change have consequences not only to channel morphology, but also for aquatic and terrestrial species (i.e., disturbance or loss of habitat).

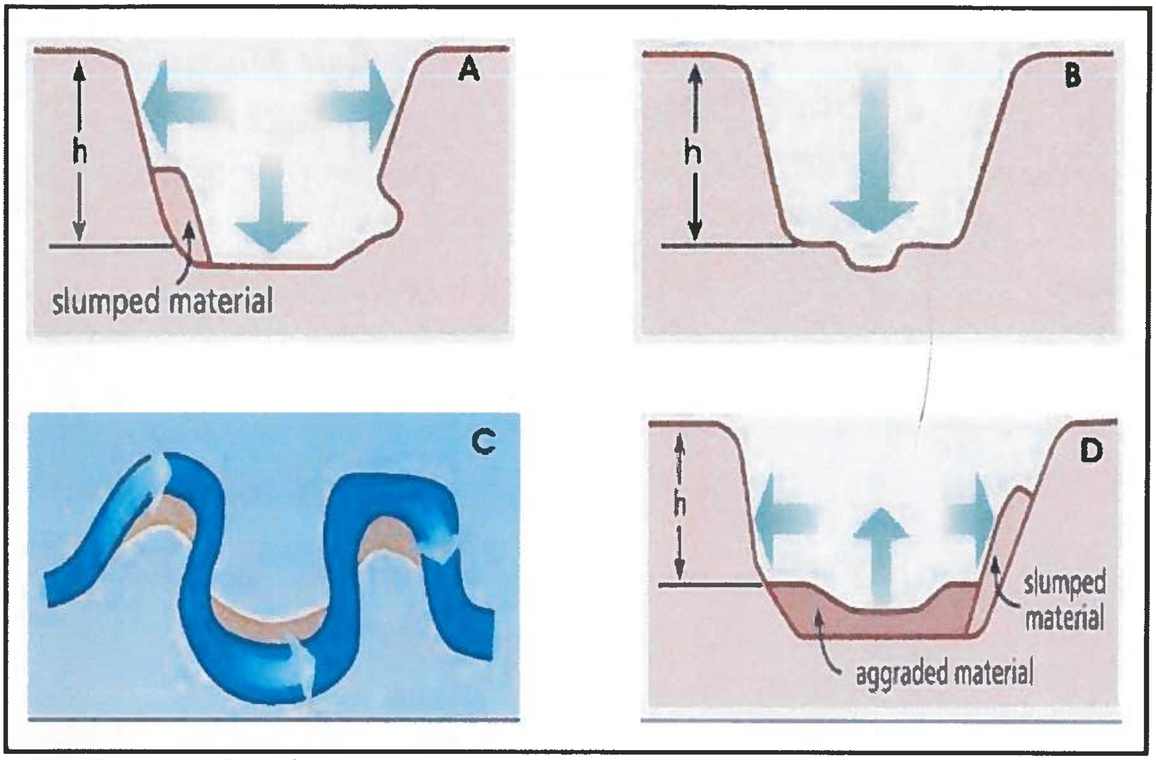


Figure 5.3 Modes of channel change through which a watercourse adjusts its channel form in response to changes in flow regime (from: USDA, 1998)

5.3.3 Bank Erosion

Bank erosion typically occurs along the outside of meander bends due to the concentration of velocity and shear forces in this location; deposition typically occurs along the inside of the bend. Outside meander bend erosion is a primary mode of channel migration across its floodplain. Bank erosion along straighter sections of channel is typically associated with channel widening and undercutting of banks

Rates of bank erosion vary naturally and are influenced by factors such as (Knighton, 1998, Lawler et al., 1997):

- bank material composition (e.g., number of stratigraphic units, resistance of bank materials – cohesive materials erode in clumps whereas non-cohesive materials erode grain by grain),
- channel geometry,
- rooting characteristics of riparian vegetation,
- bank height,
- animal influences (e.g., livestock trampling, burrowing of animals),
- flow properties (e.g., magnitude and distribution of velocity and shear stress, stream power),
- Bank weakening factors such as wetting-drying and freeze-thaw processes,

Exacerbation of natural erosion rates typically occurs when there is a change in the sediment of flow regimes that are conveyed through a watercourse. Erosion rates may also be exacerbated due to local factors (e.g., spatial change in boundary materials) or change in riparian vegetation either as a function of human activity or natural changes.

A change in flow regime can occur as a result of climatic change (e.g., precipitation patterns) or changes in surface water patterns (e.g., through urbanization). Of these, it has been well established that changes in flow regime that are due to urbanization tend to cause channels to enlarge and adjust. Indeed, over the last 100 years, there has been a noted increase in bank erosion rates (Hooke, 1980). The time required for a channel to adjust to changes in flow regime varies, and is dependent on the type of geologic materials in which the channel is situated.

5.3.4 Rates of Change

The rate by which a channel responds to adjustments to its controlling and modifying influences varies and is dependent on numerous factors, several of which are identified below:

Pre-existing channel stability – if the pre-existing channel is stable, then it will have a greater ability to absorb change than if it is unstable. Similarly, the more stable the channel, the slower the rate of change would be.

Magnitude of change – if the changes in flow or sediment delivery to the watercourse is small, then the channel may be able to absorb the change without significant adjustments, or the adjustments may occur at a micro-scale. If the magnitude of change is large, then the channel is likely to respond more quickly and more extensively.

Rate of change – if the change in flow or sediment regime occurs gradually through time, the channel may be able to accommodate the change more readily than if the change occurs rapidly.

Resistance of boundary materials – the composition and consistency of boundary materials (e.g., banks or bed) will determine the modes of erosion that are most effect in eroding them. When boundary materials are erodible (e.g., banks with higher proportions of sand), then erosion occurs more rapidly. Banks containing high clay and silt components will erode more gradually. When channel bed materials are less erodible than bank materials, then the channels will typically widen more than degrade. The opposite occurs when bank materials are more resistant to erosion than the channel bed.

Vegetation influence – the rooting network and density of bankside vegetation exerts an important modifying influence on the erodibility of bank materials. That is, dense and deep rooting networks are especially effective at increasing the shear strength of banks that are less than 0.70 m in height. Along higher banks, the deep and dense rooting networks of grasses and herbaceous plants will increase the shear strength of the upper bank, but are not as effective at protecting the lower bank from erosion. Here, the deep and coarse rooting network of trees are especially effective in stabilizing banks.

Human Intervention – structures that have been placed within or along watercourses can exert both a modifying and controlling influence on channel form. These included stormwater management ponds which modify the hydrologic regime of a watercourse, and weirs and dams that influence profile development and can create base level controls to which the channel is adjusting. Structures in the channel also have the potential to create barriers to fish passage.

6.0 EROSION INVENTORY

A detailed field assessment of all watercourses within the study area was completed to ensure that all potential erosion sites would be identified. This involved walking along each watercourse identified within the study area limits (**Figure 6.1**). During this walk, the following were mapped, inventoried, and photographed to provide an overview of the conditions along each watercourse, and to be used in subsequent analysis within this study:

- Channel type (e.g., alluvial, clay, structural etc.)
- Extent of hardened channel treatments (e.g., rip-rap, gabion, terrafix etc.)
- Reach breaks along watercourse
- Erosion sites which may pose a risk to public health and safety (including measures of site length, height, relevant observations regarding bank materials, item at risk, flow characteristics, and site conditions).
- Naturally occurring erosion sites (i.e., those that are unlikely to pose a risk),
- Potential fish barriers,
- Location of substantial large woody debris accumulations,
- Areas of required maintenance (e.g., rotted gabions, displaced rip-rap)

Details regarding each of these observations are presented in subsections of this chapter.

6.1 Channel Type and Channel Treatments

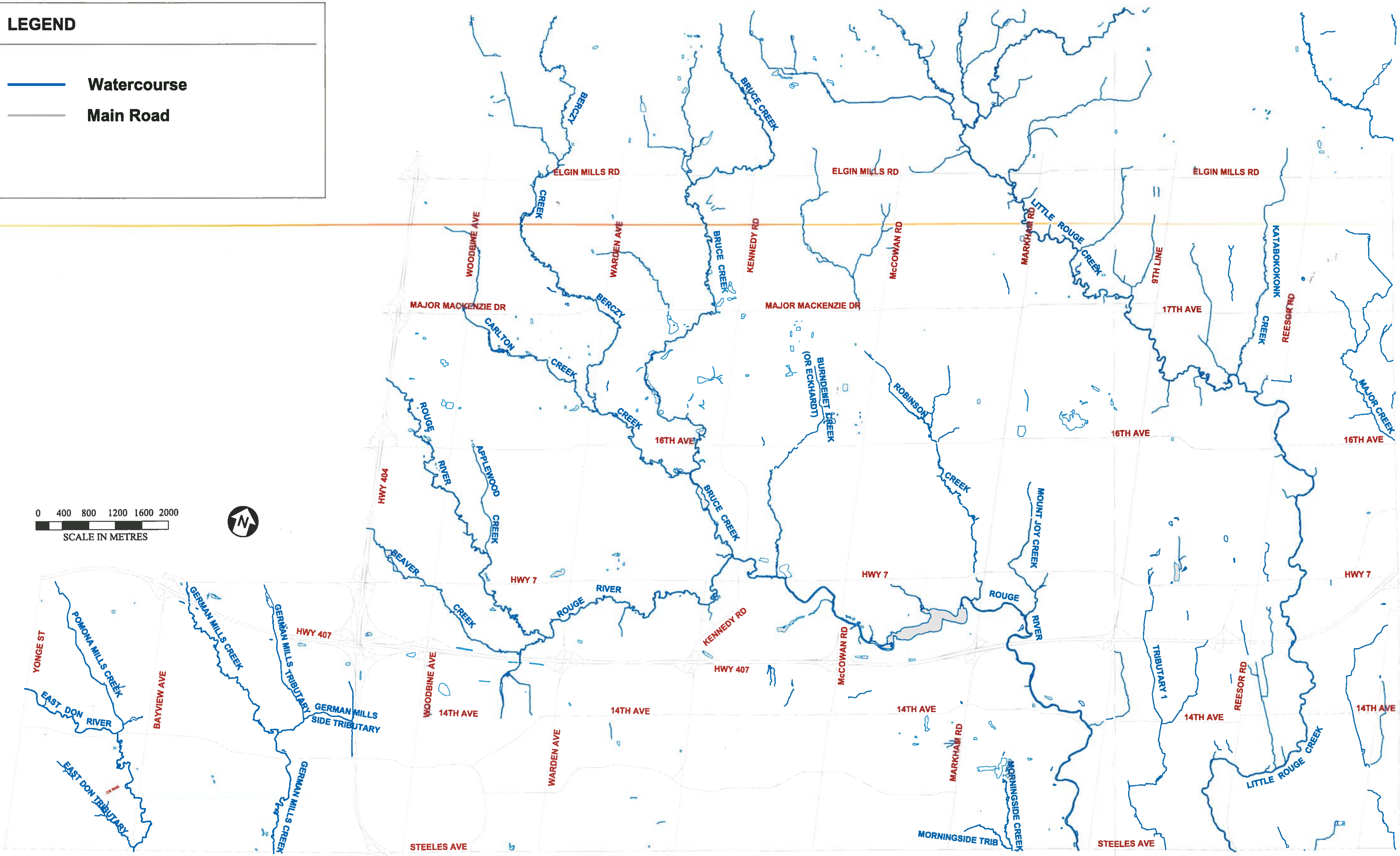
In addition to verifying the boundaries of 'like' reaches and identifying areas of erosion concern and potential fish barriers, observations made during the field walk enable classification of stream type and of channel conditions that are not evident on background mapping or aerial photography. For example, units on a geologic map represent a summary of overall conditions and therefore do not represent the spatial variability that can occur at a finer resolution. While this generalization may be appropriate for many purposes, spatial variability within a geologic unit can account for, or provide insight into, the processes that are at work within a reach or within the broader context of the drainage network.

During the field walk, detailed observations of channel characteristics were made to enable classification of Stream Type. That is, each 'like' reach was classified as one of the following channel types:

- Alluvial Channel (AL) – bed and bank materials are composed of alluvium or unconsolidated overburden;
- Rock Bed Channel (RB) – the bed is composed of bedrock while one or both banks are composed of alluvium or unconsolidated overburden;

LEGEND

- Watercourse
- Main Road



MARKHAM

Aquafor Beech Limited

FIGURE 6.1

TITLE: MARKHAM WATERCOURSES

- Rock Controlled Channel (RC) – the bed and both banks are composed of bedrock;
- Structural Channel (SC) – the bed and banks are hard lined with concrete, rip-rap, armour stone or gabions.
- Clay Bed Channel (CB) – the bed is composed of clay while one or both banks are composed of alluvium or unconsolidated overburden;
- Clay Controlled Channel (CCC) - the bed and both banks are composed of clay;
- Semi – Alluvial Clay (SAC) – bed and bank materials are composed of alluvium or unconsolidated overburden with exposures of clay common on the channel bed throughout the reach;
- Semi-Alluvial Structure (SAS – bed or bank is hard lined with concrete, rip-rap, armour stone or gabions;
- Ditch (D) – the channel has been artificially straightened and modified.

Information pertaining to channel type provided background information for each reach that was defined along Markham watercourses and will be further discussed in **Chapter 7**.

In areas of previously identified erosion or instability, previous works have been undertaken to mitigate erosion and/or to protect structures and private property. As such, significant lengths of channel within the study area are lined with gabion baskets, rip-rap, or armour stone. Since areas of previous erosion mitigation works may require maintenance/replacement in the future, the extent of all channel treatments was mapped (see **Figure 6.2** for an example and **Appendix B** for all digital field maps).

6.2 Rapid Geomorphic Assessment of Each 'Like' Reach

When a study is undertaken of an extensive length of channel, then the watercourse is typically divided into reaches to separate units. Each reach unit represents a different combination of controlling and modifying factors that result in different channel forms from adjacent reaches. Due to the relative consistency in controlling and modifying factors within a reach, there is relatively homogeneity in channel form, function and process. Channel response to any change will vary by reach with respect to extent of response and timing of response.

As part of the 2004 Markham Development Charges Update Study, each reach along Markham's watercourses had been assessed with respect to channel stability. At that time, during the stream walk, detailed observations of channel characteristics and geomorphic conditions were made and a photographic inventory of general and specific site conditions was compiled. Typical conditions throughout the reach were considered and evaluated by completing a Rapid Geomorphic Assessment (RGA; MOE, 1999) and Rapid Stream Assessment (RSAT; Galli, 1994). Results from the RGA and RSAT were compiled to determine which reaches were considered to be stable, moderately stable, or unstable. During the 2005 field season for this study, the 2004 RGA scoring charts were revisited and, if necessary, adjusted to better reflect the reach channel conditions. Some changes to the stability scoring had been anticipated since the 2005 field walks encompassed the entire reach length, while the 2004 walks did not always encompass the entire reach length.

The RGA is a semi-quantitative assessment of physical evidence of channel stability which also enables identification of the probable mode-of-adjustment (See Section 6.0 in the *Technical Procedures Manual* for additional detail). The presence or absence of channel features shown in each of four geomorphic processes were assessed during the stream walk:

- Aggradation (AI) – excess deposition of sediment
- Degradation (DI) – lowering of the channel bed invert
- Widening (WI) – increase cross-sectional area through widening
- Planimetric form adjustment (PI) – change in the meandering pattern

Each of these processes is represented by 7 to 10 indices. The RGA is applied over a channel segment of at least two meander wavelengths or 20 bankfull widths and is ideally applied over the entire reach. Identification of the active processes that are operative on a reach basis is useful for guiding the selection of appropriate restoration methodologies. That is, selection of appropriate restoration approaches should be based on an understanding of the interaction/impact of existing processes on the restoration approaches that are being considered. Further, restoration approaches should, wherever possible, minimize interference with natural channel processes.

Information pertaining to channel stability within each reach defined along Markham watercourses provides relevant background information when determining appropriate restoration solutions. **Chapter 7** reviews background information and places it in the context of this study.

6.3 Erosion and Maintenance Sites

During the reconnaissance walk, any erosion sites that appeared to be in proximity to any structures or private property were identified on 1:5,000 scale mapping. These sites were assigned an identifying number which would facilitate subsequent erosion priority ranking (see **Chapter 8**). Significant erosion sites that did not appear to be in proximity to structures or property were also documented to record occurrence. These sites were not assigned an identifying number as they would not be included in the erosion restoration ranking procedure to determine priority sites for restoration.

The field walk along each of Markham's watercourses provided an opportunity to document the location and type of previous restoration works that had been placed along channel banks and valley walls. Where these occurred, the different treatments (e.g., gabions or rip-rap) were examined to determine whether they were in disrepair and/or in need of maintenance (e.g., rotted gabions, outflanked rip-rap). Details regarding the nature and extent of problems were recorded, and their location was clearly identified on 1:5,000 field maps. (See **Appendix B** for digitized field maps)

For each erosion site, a table was completed to document characteristics of the erosion sites which included the following information:

Watercourse and reach – each site was assigned a unique identifier
Erosion site number – numbered sequentially from downstream to upstream
Photograph numbers – pertaining to photos of erosion sites
Type of erosion – valley wall, bank, bridge, etc.
Length – field measure of extent of erosion scar
Height of bank or valley wall – measured from toe of slope to top of slope
Condition of site – bare, vegetated, overhanging etc.
Rate – active, gradual, old based on field indicators
Risk 1 and 2 – what items are at risk (e.g., private property, sewer pipe)
Rank – Low, Medium, High based on field observations as to severity of rate and risk
Observations – any items that may influence, or be affected by, the erosion site both upstream or downstream

Details pertaining to each erosion and maintenance site as recorded in the field have been tabulated and are presented in **Appendix C**

A photographic inventory was compiled of all erosion sites, maintenance sites, potential fish barriers, crossing structures and any other points of interest. Each photo was referenced to 1:5,000 scale mapping and recorded on the erosion and maintenance site. The photographic inventory is presented on CD in **Appendix C**.

6.4 Potential Fish Barriers and Large Woody Debris

The reconnaissance level field walk along all Markham watercourses provided a unique opportunity to document any in-stream structures that could, potentially, result in a barrier to fish passage. As such, any in-stream structures which created a noticeable drop in water level was mapped, photographed, and documented. Further investigation would need to be undertaken to determine if the potential fish barriers actually do interfere with fish passage during various flow events and pertinent life stages.

When significant large woody debris accumulations were observed, these were examined and mapped for the purpose of documenting occurrence. Since large woody debris can interfere with flow hydraulics and exacerbate or create erosion concerns. Further investigation as to whether the large woody debris accumulations do, in fact, pose a concern would be required before their removal would be recommended. That is, since large woody debris within a channel provides aquatic habitat function and occurs naturally within wooded areas, they are not considered to be a deleterious substance.

Digital field maps that show the locations of fish barriers and large woody debris accumulations are provided in **Appendix B**. Details with respect to fish barriers (e.g., height of drop, nature of barrier) are provided in **Appendix C**.

7.0 MARKHAM WATERCOURSE CONDITIONS

7.1 General

During the course of this study, background information was reviewed and compiled to gain an understanding of modifying and controlling influences on channel form. This information, which has already been presented in previous chapters (e.g., **Chapters 3** and **5**) provides a context for observations made during the field inventory (**Chapter 4**). Given the spatial and temporal component of this type of assessment, profiles for each watercourse have been constructed that provide an overview of many pertinent channel characteristics and their controlling and modifying influences for the purpose of understanding channel processes and conditions within individual reaches (See **Figure 7.1** for an example and **Appendix D** for all profiles).

This chapter is intended to present results from the field inventory and to discuss overall conditions of Markham's watercourses. While detailed field investigations and analyses were beyond the scope of this study, general insight into causative factors could be insight into the observed watercourse conditions within the study area. This has included a review of local geology and development history – both of which influence the rate and extent of channel change that may be expected along a watercourse. The type of restoration works that could be implemented when erosion poses a risk to public health and safety should consider the mode of adjustment that is occurring along the watercourse, the relative amount of channel change that has, and may yet be expected to occur, and the time frame for completion of the adjustment process.

7.2 Results of Erosion Inventory

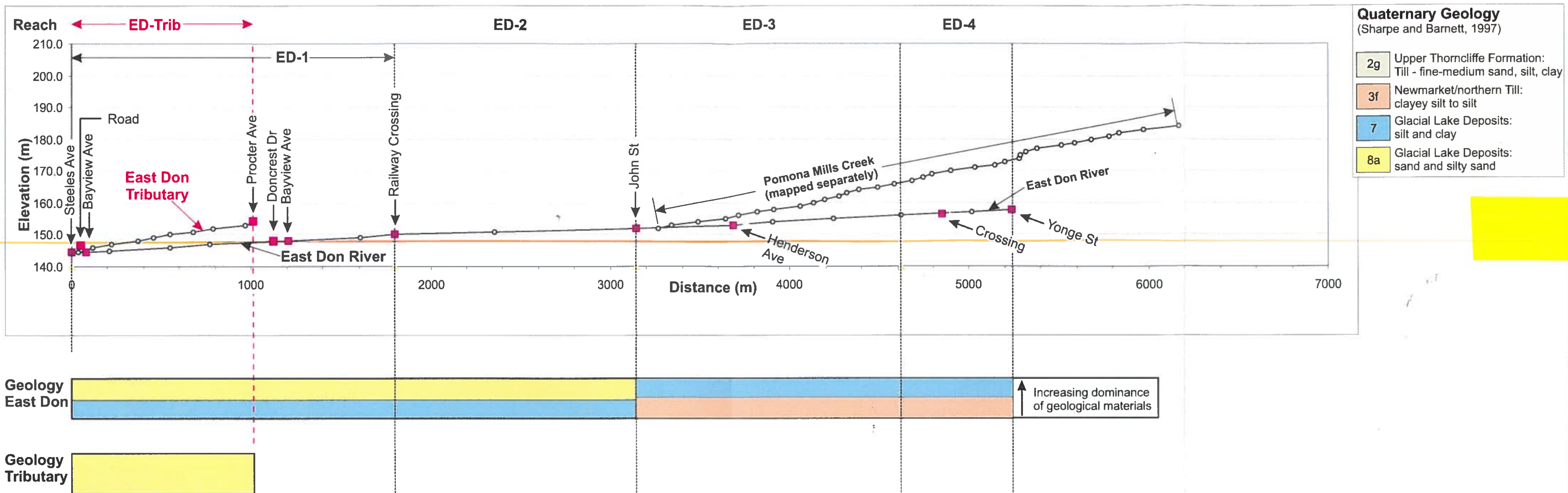
The erosion inventory that was completed for 19 watercourses in Markham included approximately 105 km of channel. During the field walk, the following were recorded on field maps:

- location and extent of erosion sites,
- location and extent of sites requiring maintenance,
- location of potential fish barriers,
- location of large woody debris accumulations
- extent of bank treatments (gabion, rip-rap, armourstone)

These field maps were transcribed into digital form to produce comprehensive mapping (see **Figure 7.2** for example and remainder of maps in **Appendix C**).

Results of the inventory are as follows:

- 308 erosion sites
- 63 fish barriers
- 27 areas identified as requiring maintenance



	ED-Trib	ED-1	ED-2	ED-3	ED-4
Development History	Before 1970; 1986-1990; (Tributary) 1950-1960	Before 1950	1900-1975	1966-1976	Before 1900
Channel Type	SAS	SAC-SC	AL	AL-SC	AL-SCm
Channel Stability	MS	MS	MS	MS	MS
Dominant Process	D	W	A	W	W
Number of Fish Barriers	3	2	0	0	1
Number of Erosion Sites	8	19	8	11	2
Number of Maintenance sites	2	0	0	0	0
Reach		ED-1	ED-2	ED-3	ED-4
Tributary Reach	ED-Trib				

KEY TO TERMS

AL Alluvial
SAC Semi-alluvial clay
SC Structural channel
SAS Semi-alluvial structure
Suffix "m" denotes minor occurrence

S Stable
MS Moderately stable
U Unstable

A Aggradation
D Degradation
P Planform adjustment
W Widening

Figure 7.1

Profile of East Don River and East Don Tributary with results from stream inventory.

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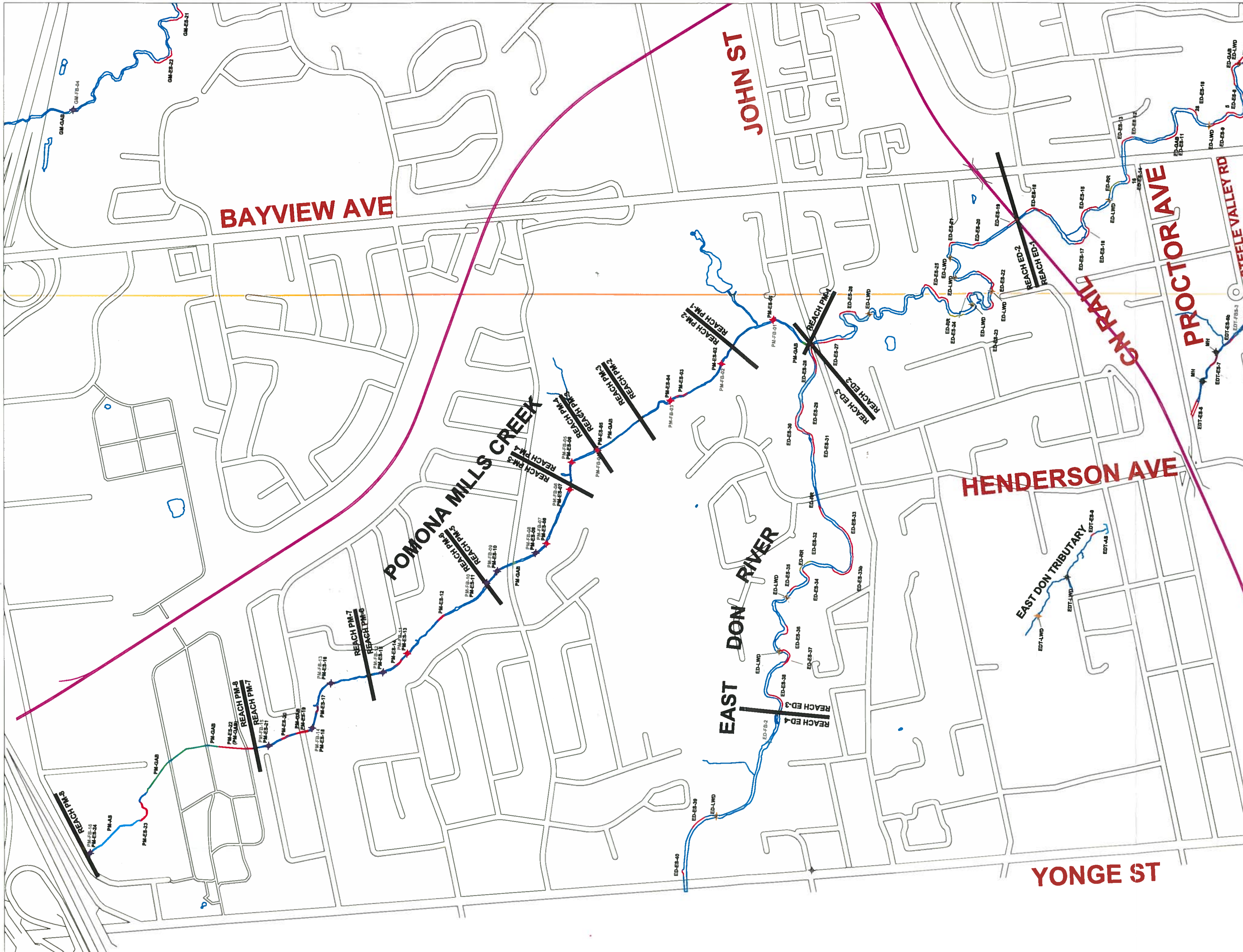

PROJECT: TOWN OF MARKHAM EROSION RESTORATION IMPLEMENTATION PLAN

MARKHAM

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WATERCOURSE: EAST DON RIVER
REACH: ED1–ED4 FIGURE: 7.2
AQUAFOR PROJECT NO.: 64550

LOCATION: STEELES AVENUE TO YONGE STREET

LEGEND SCALE 1:10,000

- Erosion Site (ES)
- Maintenance Site (M)
- Fish Barrier (FB)
- Minor Erosion (E)

MH: Manhole RR: Rip–Rap
GAB: Gabion AS: Armour Stone

7.2.1 Erosion Sites

A break down of sites per watercourse is provided in **Table 7.1.** Review of the Table clearly demonstrates that most erosion sites occur along watercourses situated in older development areas (i.e., East Don River, German Mills Creek) and which receive flow from upstream of Markham. It is important to reiterate that although 308 erosion sites have been identified, not all are considered to be priority for restoration. Review of the field inventory results however, do demonstrate that there are numerous sites of sediment loading into the watercourse. **Figure 7.3** provides a graphical example of the frequency of erosion sites by watercourse.

Table 7.1: Results of field walks documenting the number of crossings and erosion problems for each watercourse.

Creek/River	ID	Profile Length (m)	# of Crossings	# of FB¹	# of ES²	# of M³	Total # of Problems	Problem Frequency (Number of Problems per km)
East Don	ED	5238	7	2	40	0	42	8.0
- Pomona Mills	PM	3022	11	15	24	0	39	12.9
- East Don Trib	EDT	1430	3	3	9	2	14	9.8
German Mills	GM	6533	7	4	23	5	32	4.9
- Trib Markham	GMTM	2895	5	6	7	3	16	5.5
- Trib Side	GMTS	927	2	1	3	3	7	7.6
Beaver	BV	4423	10	0	11	0	11	2.5
Applewood	A	1813	3	3	0	0	3	1.7
Carleton	C	5236	6	2	5	2	9	1.7
Berczy	BZ	6115	7	1	20	0	21	3.4
Bruce	BRU	6804	7	1	14	0	15	2.2
Burndenet/Eckardt	ECK	3935	6	0	11	2	13	3.3
Milne	MLN	730	2	0	0	0	0	0.0
Robinson	ROB	6640	12	7	18	2	28	4.2
Mount Joy Creek	MJ	2591	7	6	17	3	25	9.6
Morningside	MO	851	3	0	5	0	5	5.9
Tributary 1	T1	7077	11	1	0	0	1	0.1
Rouge River	R	25473	20	11	84	3	98	3.8
Little Rouge	LR	15738	11	0	16	2	18	1.1
Totals		**107470**	**140**	**63**	**307**	**27**		

FB¹ = fish barrier, ES² = erosion site, M³ = maintenance site

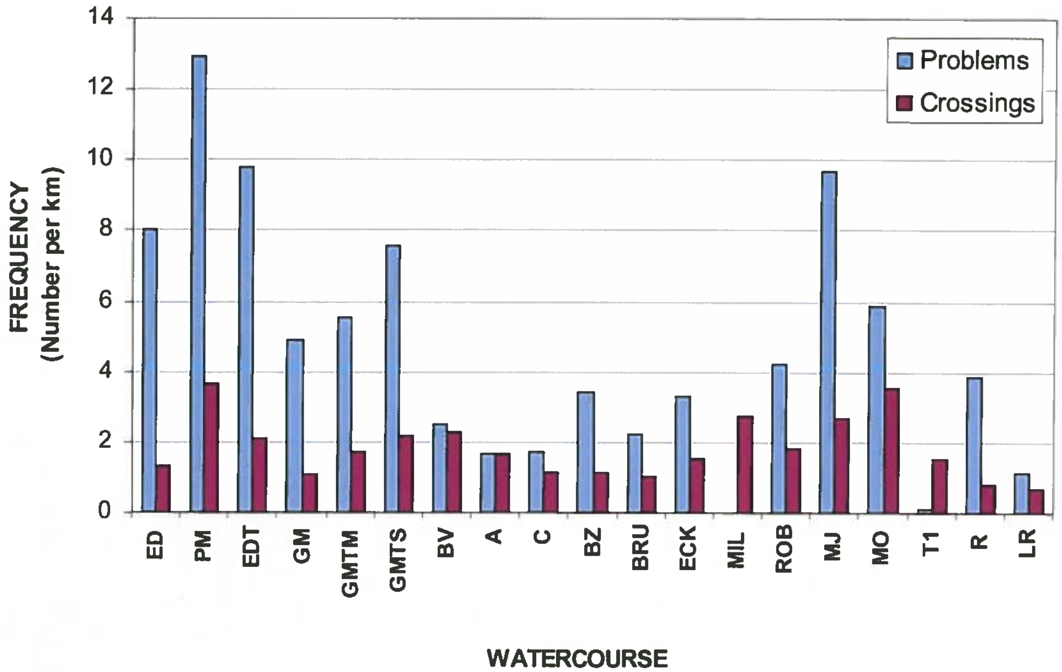


Figure 7.3: The frequency of erosion problems by watercourse within the Town of Markham. (see **Table 7.1** for watercourse abbreviations)

7.2.2 Fish Barriers

Review of **Table 7.1** and the mapping presented in **Appendix C** demonstrates that there are numerous crossings over Markham's watercourses; there are 137 crossings within the study area. **Figure 7.3** provides a graphical display of the number of crossings.

The implications of watercourse crossings on fish passage and fish habitat have been well document both in the published and unpublished literature. Understanding the potential impact of culverts on fish passage requires an understanding of the role that culverts play in the life cycle of fish. Upstream migration, which may required passage through a culvert occurs for various reasons including (Katopodis, 1992, Manitoba Natural Resources, 1996, Robison, Mirati and Allen, 1999, Savoie and Haché, 2002):

- spawning,
- rearing,
- feeding,
- finding suitable (overwintering and summer) refuge and habitat,
- seeking refuge from predators or harmful environmental conditions (e.g., water quality or low flows).

Upstream fish migration can only occur when the water is sufficiently deep and flow velocities are within the range that the fish species can tolerate. Several of Markham's culverts contained little water depth.

Physical barriers created by culverts, some of which were observed in Markham include (Robison, Mirati, and Allen, 1999; Savoie and Haché, 2002; Alberta Infrastructure, 1999):

- High velocities at culvert inlet, outlet or barrel;
- Excessive height of culvert intlet and outlet inverts (e.g., perched condition);
- Shallow water depth at inlet, outlet, or downstream channel;
- Lack of resting pools at culvert inlet, outlet or barrel.

If the combination of culvert length and velocity in a culvert is too high to enable fish migration during a critical life stage then this could affect fish health and spawning activity.

7.2.3 Channel Hardening

The location and extent of different bank treatments was mapped during the field walk and transcribed into digital format (see **Figure 7.2** and **Appendix C** for mapping). The extent and type of bank stabilization/erosion treatments that occur along Markham's watercourses was tabulated and is presented in **Table 7.2**. Approximately 7.5 km of channel banks are lined with a hard treatment; this represents 3.5 % of total bank length within the Town (i.e., 210 km when accounting for two banks along creek).

The most common bank treatment used along Markham's watercourses is *rip-rap*; most of this material is placed along Beaver Creek and the Rouge River. This material is typically placed along banks and occasionally within the channel as well. Vegetation is rarely incorporated into the rock material. Opportunities exist to enhance the function of rip-rap through plantings. This would provide a benefit to both terrestrial and aquatic habitats and improve aesthetic appearance. Failure of rip-rap was noted in several locations. This failure may be due to the fact that placement did not consider future channel enlargement

Gabions that were noted during the field investigation were often in a state of disrepair, with corroding wire and loss of rock content. As a result, some gabions were sagging and quantities of rip-rap had entered the channel. Gabions were typically used as a bank treatment several decades ago and thus are towards the end of their lifespan. When maintenance of these gabions is undertaken, an opportunity exists to replace gabions with softer approaches that reduce the amount of hardened materials, enhance terrestrial and aquatic benefits while improving aesthetic value.

Armourstone was seldom observed as a bank treatment along Markham's watercourses. Along the East Don Tributary, outflanking and failure of the armourstone wall could be attributed, in part to the undersized cross-section that was created by placing armourstone along both banks. That is, by fixing a cross-section at one point in time, without accounting for future changes to the flow regime within the channel, an increased channel capacity that would be required to accommodate the increased flows does not exist.

Hence, where untreated channel cross-sections would enlarge, armourstone lined banks would be overtopped, scoured and outflanked.

Table 7.2: Occurrence and length of channel hardening in each watercourse.

Creek/River	# of Riprap sections	Riprap Length (m)	# of Armourstone sections	Armourstone Length (m)	# of Gabion sections	Gabion Length (m)
East Don	41	161.8	0	0	6	216
- Pomona Mills	0	0	2	354	9	450.8
- East Don Trib	1	24.2	2	302.4	0	0
German Mills	7	292.36	0	0	5	244.7
- Trib Markham	2	44.1	0	0	2	72.2
- Trib Side	2	255.8	0	0	1	34.6
Beaver	12	1036.44	0	0	2	24
Applewood	0	0	0	0	0	0
Carleton	0	0	0	0	0	0
Berczy	13	135.9	0	0	5	261
Bruce	6	202.7	0	0	0	0
Burndenet/Eckardt	4	140.1	0	0	2	16.7
Milne	1	88.8	2	21.4	0	0
Robinson	1	17.1	2	24.8	5	86.3
Mount Joy Creek	4	247.6	0	0	4	134.4
Morningside	3	95.9	0	0	0	0
Tributary 1	0	0	0	0	0	0
Rouge River	44	1926.8	0	0	19	546.5
Little Rouge	3	131	0	0	0	0
Totals	**143**	**4800.6**	**6**	**702.6**	**60**	**2087.2**

7.3 Typical Problems

From the numerous erosion sites documented, a number of typical problem types were identified. Types of problems were generally grouped based on public risk type, erosion type, and relevance to fish habitat. While similar erosion processes were occurring at many erosion sites, the nature of the problem was typically based on the proximity of the risk and the type of risk (i.e. erosion processes in close proximity to property and infrastructure were identified as problems when posing a risk to public health and safety). A selection of photographs illustrating typical problems observed along Markham watercourses is provided in **Figures 7.4a – c** and is summarized below:

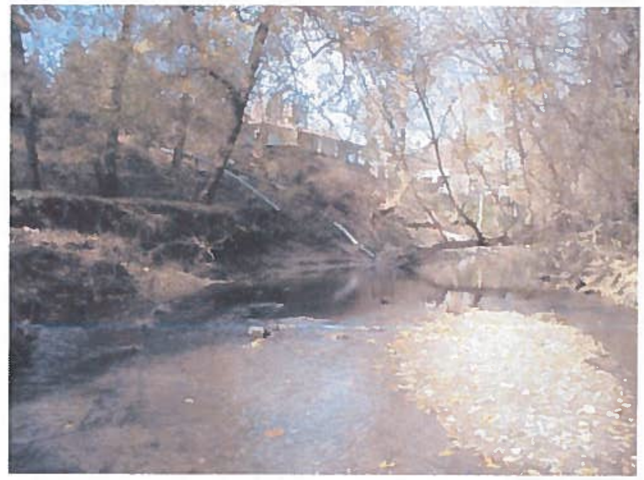
Risk to Public

- Bank erosion into landscaped yards
- Large trees fallen in yards and channels due to bank erosion
- Damage to private crossings and bridges
- Failing valley walls due to toe erosion and slope stability issues
- Failure and outflanking of bank structures (i.e. gabion, rip-rap, armourstone)

Figure 7.4a

Typical Erosion Problems - Risk to Public (Private property)

Fallen trees - East Don Tributary



Erosion in private yards - East Don River

Erosion in private yards - Rouge River

Valley wall erosion - East Don River

Bridge failure - East Don River Tributary

Private bridges/crossings - Berczy Creek

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Figure 7.4b

Typical Erosion Problems - Risk to Public and Structures

Parking lot - German Mills Creek

Roads - Warden Ave - Berczy Ck

Upheaval of existing bed protection - German Mills Creek Tributary

Walkway crossing - Pomona Mills Creek

Exposed Manhole - Mt. Joy Creek

Bridge pier undercutting - East Don River Tributary

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Figure 7.4c

Typical Erosion Problems - Risk to Public and Fisheries

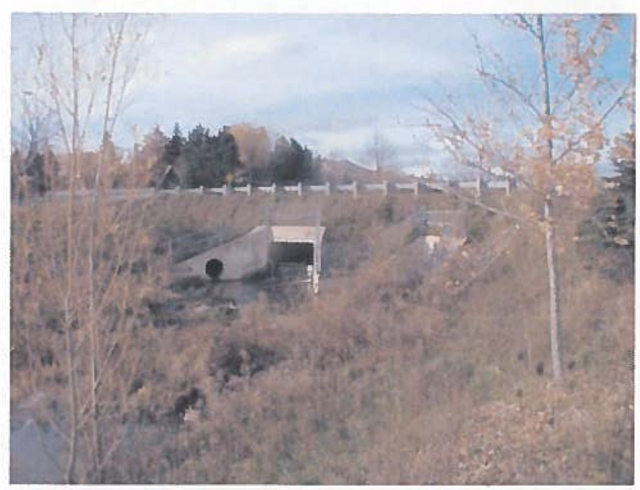
Weir - Pomona Mills Creek

Shallow water - Bruce Creek

Shallow water - Pomona Mills Creek

Fine sediment in channel - East Don River

Weirs/barriers - Berczy Creek



Culvert barrier - Applewood Creek

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- Rotting and outflanked old concrete structures from historic crossings/structures

Risk to Public and Infrastructure

- Parking lots or roadways adjacent to eroding banks or slopes
- Outflanked outfalls and manholes
- Failing valley walls due to toe erosion and slope stability issues
- Failing and outflanked bank structures (i.e. gabion, rip-rap, armourstone)
- Rotting and outflanked old concrete structures from historic crossings/structures
- Bridge and culvert abutments rotting, undercut, or eroded
- Overtopped and/or outflanked crossings and weirs
- Displaced bed protection (i.e. placed stone or geogrid)

Risk to Aquatic Habitat

- Significant drops or knickpoints in channel due to weirs and culverts
- Shallow water under bridges and through culverts
- Significant sediment accumulations from bank and structure erosion
- Displaced bed protection (i.e. placed stone or geogrid) creating loss of natural bed habitat

Table 7.3 provides further detail regarding the negative implications of the problem categories outlined above. Of specific concern is the potential cascading effects of channel instability. In other words, erosion and adjustments in channel form can result in further feedbacks which accentuate future problems within the channel. For example, previous channel restoration activities can inadvertently deflect energy (and consequently erosion) downstream to other areas and many past works have not taken into account the effects of channel enlargement caused by changes in flow regime. For instance, failure and outflanking of old bank protection (i.e. gabions, rip-rap, etc.) can result in failed structure material within the channel, which in turn deflects flow energy causing local bank erosion. Thus, the effectiveness of the bank protection may be reduced and the failed material in the channel may further exacerbate instability while also affecting the quality of aquatic habitat. Indirect effects of channel enlargement may also promote bank instability by increasing contributions of large woody debris from the banks, further encouraging flow disruption and local bank erosion. Erosion problems can be the result of a complex combination of factors, which requires an integrated understanding of the causes to develop effective solutions.

Table 7.3: Erosion problem categories and implications.

Problem Category	Implications of Problems
Risk to Private Property	• Existing or future private property loss • Existing or future property damage • Risk to public health due to physical hazards and the potential negative effects of damage to public infrastructure • Other feedback effects of channel instability accentuating future problems
Risk to Public and Infrastructure	• Existing or future public property loss • Existing or future damage to roads, crossings, parking lots, or sewer lines • Existing or future damage to hardened channel structures and bank protection • Other feedback effects of channel instability accentuating future problems
Risk to Aquatic Habitat	• Barriers to fish passage – isolation of ecological communities • Increased fine sediment in stream negatively altering habitat • Overall decreases in species abundance and diversity

The spatial trends associated with the typical problems listed in **Table 7.3** appeared to be correlated with the age of development in Markham (i.e., older development areas were characterized by more erosion risks than younger development areas). This pattern is due to a number of interrelated factors including:

- Older developments tend to have private properties which extend through the watercourse corridor or are in proximity to the watercourse while newer communities incorporate set backs as prescribed by regulatory agencies ;
- Watercourses within older developments tend to have older structures, bank protection, weirs, and culverts may be failing or rotting due to age;
- Trunk sewers and manholes are often within valleys and adjacent to, or under, watercourses. Particularly in older development areas; natural migration of the watercourse has caused it to become in proximity to subsurface infrastructure.

It appears that age of development and age of infrastructure are important indicators of areas likely to exhibit erosion problems. This may be particularly true as older infrastructure and channel works had likely not accounted for future changes in flow regime as watershed development progressed. These observations are also important for issue of degraded aquatic habitat. Scour downstream of older culverts and weirs is often associated with barriers to upstream fish migration due to perched culverts or knickpoints in the channel profile. Increases in sediment loading to the watercourse due to channel enlargement in older communities may contribute to degradation of aquatic habitat.

A few other spatial patterns should also be noted:

- Slope stability problems along valley walls tend to occur on larger watercourses (e.g., Rouge River, East Don River, and Little Rouge River.
- Localized erosion concerns tended to be associated with failed structures or local channel adjustments. Thus, the occurrence of erosion is a function of structure location and local channel alignment.
- Widespread erosion problems are likely dominated by the impact of flow regime change (particularly on smaller watercourses).

7.4 Human Environment and Impacts

Human activity influences channel processes both directly and indirectly. The types of human impact that may compromise channel stability can generally be summarized as stream flow magnitude (*volume and timing*), channel realignment, drainage network modification, vegetation treatment (*i.e., removal, landscaping*), grade control modification (*i.e. dams, weirs, online ponds*), and boundary hardening (*i.e. concrete, gabion, armourstone, rip-rap*). Changes in landuse and land-cover modify runoff patterns to the receiving watercourses, which can exacerbate erosion hazards and contributes to environmental degradation (e.g., water quality). Direct modification of a watercourse typically alters channel form and function, which can require channel adjustments if the form is not in keeping with a suitable natural configuration for the setting. Alteration of the drainage network alters the hydrologic regime of watercourses. The Town of Markham has recognized this problem and subsequently initiated the small streams study which is intended to protect small features by recognizing them as integral components of the drainage network.

It should be noted that channel adjustments occur in all natural watercourses and is considered to be an important natural process through which the channel achieves a stable configuration. All channel adjustments may be perceived as a risk when this occurs in close proximity human landuses (e.g., structures, infrastructure etc.). As such, human activity and land use that is in proximity to the watercourse becomes problematic if insufficient setbacks exist that allow for some level of channel adjustment and flooding which can be expected along both natural and modified stream environments.

All of the human impacts noted above are apparent on watercourses in Markham. Indeed in many cases, the channels are responding to multiple types of human impact that may span multiple time frames (e.g., European settlement, older development and recent urbanization) within individual channel reaches (i.e. particular impacts may be confounded). Through this study it became apparent that some watercourses exhibited widespread degradation, erosion, and instability, whereas other watercourses were characterized by the occurrence of localized impacts. Prominent observations for some watercourses are presented in **Table 7.4**.

Table 7.4. Notable problems associated with human environment and impacts

Watercourse(s)	Typical Problems	Human Environment and Impacts*
East Don River	Channel erosion into private property and failure of hardened channel banks	• Flow regime • Vegetation treatment • Boundary hardening • Proximity
Pomona Mills Creek	Localized erosion around weirs and downstream scouring of the bed and banks. Bank failure particularly in hardened and realigned reaches upstream.	• Flow regime • Vegetation treatment • Boundary hardening • Grade control - weirs • Channel realignment • Proximity
Berczy Creek	Localized erosion around old weir, downstream scouring of the bed and banks into private property. Erosion risk near roadway.	• Vegetation treatment • Grade control - weir • Proximity
Rouge River	Local erosion problems around structures, channel bends, and valley walls. Widespread erosion particularly associated with golf courses.	• Vegetation treatment • Boundary hardening and structures • Proximity
Mount Joy Creek, German Mills Creek, and the East Don Tributary.	Erosion risk around infrastructure (e.g. roads, parking lots, and sewer lines).	• Flow regime • Boundary hardening and structures • Vegetation treatment • Proximity
Rouge River, Bruce Creek, and Carlton Creek	Habitat and terrestrial resources modified by dams and online ponds	• Grade control • Fish barriers
Rouge River and East Don River	Slope stability problems along local sections of valley wall accentuated by slope-toe erosion	• Flow regime • Proximity

*See discussion above for explanation of Human Environment and Impact types.

7.5 Dominant Influences on Markham Watercourses

As introduced in **Chapter 3**, a number of controlling and modifying factors influence the form of a watercourse and its response to human activities within its watershed. These factors include the channel boundary materials, the channel slope, the surrounding vegetation, and the flow regime. Historical changes in land use and modifications a channel's form will influence present day processes.

Boundary materials

The nature of the boundary materials in a watercourse is generally related to the local geologic environment. In other words, the texture and range of sediment sizes available to be reworked by a channel will depend on the nature of the parent materials within the watershed. The spatial distribution of surficial materials will also play a role as a channel will transport sediments to downstream reaches, and continually deposit and rework alluvial sediments within the corridor.

Although much of Markham's surficial geology is characterized by glacial tills, glacial lake deposits are also very common in areas surrounding the watercourses; these areas likely represent the relatively low lying areas following deglaciation. While the glacial till and glacial lake parent materials can range from clay to boulders, reworking of the materials within the alluvial corridor tends to be associated with finer materials within the floodplain and coarser materials along the bed and lower banks. This pattern of sediment distribution is due to the selective transport of mainly fine material onto the floodplain.

Evidence of undisturbed glacial materials within Markham watercourses is apparent along channel beds and at valley wall contacts. Older tills may also be exposed along the toe of deeper valleys (*e.g. Rouge River, East Don River, and German Mills Creek*). Glacial materials tend to be dense and cohesive, indicating that dominant modes of erosion are likely hydration of clay and other physical forms of weathering. The coarse sediments that contribute to riffle forms originate from glacio-fluvial lenses and the larger sediment clasts within the till matrices.

The general influence of boundary material on channel stability is largely dependent on the relative proportion of intermediate sediment sizes (i.e., silt, sand, and fine gravel tend to be more mobile) and the relative difference in erodibility between channel bed and bank materials. Higher clay content tends to help stabilize banks, while coarser bed material (cobble and boulder) can help to stabilize the bed. Although the distribution of material types is quite varied throughout Markham, the abundance of intermediate sediment sizes (silt to fine gravel) within the Rouge and Don River watersheds enables channels to adjust their form by eroding and reworking the boundary. Erodable materials may act as important sediment supplies to the watercourse, however, excessive sediment loading to the watercourse can have negative impacts on channel form, process, and habitat.

Channel boundaries may also be modified by direct human modifications to the watercourse. Typically, placement of large materials (armourstone, gabion, and rip-rap) is used to reinforce and stabilize bed and banks, thereby restricting channel adjustments and frequently leading to outflanking and/or overtopping of the large materials. Channel stability may also be compromised by previous channel works: armourstone can restrict channel capacity; failed rip-rap or gabion can redirect flows against channel banks; and concrete culverts can cause blow-out of downstream banks.

Channel slope

The slope or gradient of a channel controls the amount of energy present as water flows through the channel. Thus, variations in channel slope are important when assessing erosion along watercourses within Markham. Channel slope will vary at a number of different scales, including the watershed, reach and site scales.

Variations in slope at the watershed scale are generally controlled by the region's geologic context. In other words, the regional patterns of topography are largely the product of receding glaciers during deglaciation. The shape of the present day channel profile may be concave, convex, or linear. A concave profile indicates that channel slopes are greatest in the upstream reaches (e.g. *Burndenet Creek and Bruce Creek*). A convex profile indicates that the channel slopes are greatest in the downstream reaches (e.g. *Little Rouge River and Robinson Creek*). A linear profile indicates that channel slope is relatively consistent throughout the watercourse. Areas which exhibit greater slopes may be more susceptible to erosion problems due to the relative increases in stream energy and long term profile adjustment processes.

Reach scale variations in channel slope maybe be controlled by geology, however, large grade control structures such as dams (*e.g. Rouge River*), online ponds (*e.g. Carlton Creek*), and undersized crossings (*e.g. Beaver Creek*) may impose modifications to the watercourse gradient. Generally, these grade controls result in a decreased slope upstream (promoting aggradation), and an increased slope downstream (promoting degradation). Similar, grade controls and impacts are imposed at the channel scale by in-stream structures (weirs, dams) and crossings (there are ~137 crossings in the Markham study area). These channel scale grade controls can also cause localized scour of bed and banks, often creating significant knickpoints in the channel (resulting in barriers to fish).

Vegetation

Vegetation exerts an important influence on channel form and on watershed hydrology. Alteration to watershed level vegetation was initially due to European settlement and agricultural activity. Today, human activity in proximity to watercourses affect the type and extent of vegetation that exists on channel banks. In Markham, as elsewhere, removal of vegetation and landscaping along banks alter the riparian zone vegetation community. Cut branches from backyard tree and shrub pruning often are thrown into watercourses and the valleys that abut private properties. Removal of vegetation can have a destabilizing effect on the bank due to loss of root binding. Landscaping (mowing to edge of channel, vegetation dumping into valley) can also influence bank stability by removing deep rooting vegetation thereby reducing flow resistance along the banks and floodplain in addition to decreasing structural stability due to lawn mowing activity. Occurrence of large woody debris may be increased by accelerated erosion processes or channel enlargement due to the urban flow regime as well as to pruning activity on private property. Large woody debris within the channel accentuates bank instability by locally redirecting flows against the banks and by causing constriction of flows.

Flow regime

Changes to the flow regime influences channel form and the processes that occur along a watercourse. Historic landuse change (e.g., European settlement) likely contributed to initial channel incision within the floodplains and the creation of terraces (*e.g. Burndenet/Eckardt Creek*). This has contributed to pre-existing channel conditions which, in turn, influence contemporary processes. Continued expansion of development within the watersheds has resulted in the destabilizing processes which will be discussed further in Section 7.6. Although urbanization has modified watercourse flow regimes in Markham, contributing to instability and degradation of channel quality, stormwater management practices have improved over time. Even so, existing stormwater management efforts may not be fully effective at minimizing impact, as SWM practices must also further address issue of increased runoff volume (i.e., volume control).

7.6 Dominant Channel Processes along Markham Watercourses

Concepts relating to the processes of channel adjustment are discussed in **Chapter 5**. The four general channel processes that occur along a watercourse are widening, degradation, aggradation, and planform adjustments. Channel enlargement occurs in urbanizing watersheds and is an increase in cross-sectional channel capacity which can include both elements of channel widening and degradation.

Evidence of channel enlargement was observed on many watercourses in Markham. Changes to the stream flow regime (i.e. increased flows) are the dominant cause of enlargement processes. Enlargement has been occurring on some channels for quite some time (due to the earlier changes in flow regime as a result of urban development) and may yet be expected to occur along watercourses which have experienced more recent development and subsequent alterations to flow. Based on geology, the process of enlargement and response to an urban flow regime is likely to take several decades (up to 50 years), particularly in areas where the channel has exposed glacial materials. Streams in west end of Markham (*i.e., East Don River and German Mills Creek*) are further along in their adjustment process due to the older development history. In areas where glacial materials are exposed at the bed, enlargement occurs predominantly through widening since relative erodibility of banks is less than the bed. Channel widening is a dominant process on many channels in Markham, particularly within the downstream reaches of each watercourse.

Evidence of degradation was noted on watercourses in Markham and particularly in reaches with increased channel gradient as evident on the longitudinal profiles (*e.g. Robinson, Burndenet, and Little Rouge*). Degradation, or lower of the bed, has included both historic and contemporary processes resulting in terracing within the floodplain, and exposure of clay materials on the channel bed. Localized degradation was also observed at some crossings and weirs which may be due to the hydraulic scouring effects imposed by the structures as well as reach level channel bed lowering. The presence of grade control structures along watercourses interferes with large scale channel bed lowering, which, in some cases, has likely prevented significant downcutting.

Processes of channel enlargement and degradation in some reaches can contribute significant supplies of sediment to the channel, resulting in aggradation of downstream areas. Evidence of aggradation was common on Markham watercourses, particularly upstream of where channel slopes are modified by significant grade controls (e.g. dams) and crossings (grade control and/or width constriction). Contributions of sediment supply from enlargement and widening processes were observed on some watercourses resulting in channel bars and contributing to floodplain deposition (*e.g. East Don Tributary, Milne Creek, Morningside Tributary*). The abundance of sediment that was supplied to some watercourses (*e.g., Rouge River*) was highly influenced by landuse practices which have reduced bank stability (e.g., lack of native plant riparian zone and corresponding deep and dense rooting network of the plants).

Planform adjustments are less common on Markham watercourses. The adjustment of a channel from one planform type to another is the result of a complex interaction between sediment supplies and stream energy, and is also influenced by changes in the channel cross-section (see paragraph below). Evidence of planform adjustments were seen on some Markham watercourses due to significant increases in local sediment supplies and thalweg wandering in previously straightened reaches (*e.g., German Mills Side tributary, Mount Joy Creek*). Planform migration (i.e. meander bend movement) was observed on many watercourses, with some reaches exhibiting particularly active meander processes (*e.g. Beaver Creek, Rouge River, Burndenet Creek, and Little Rouge River*).

It should also be noted that changes in meso-scale form (cross-section) require changes in macro-scale form (planform). In other words, channel enlargement and widening will influence the form and processes occurring in channel bends (i.e. meandering). Thus, the classification of channel processes discussed above requires further integration of the many elements of channel adjustment through time. An overview of channel processes on a watercourse basis is provided in **Table 7.5**, which is defined in further detail in the watercourse profiles (**Appendix D**).

Table 7.5: Summary of dominant problems for each Markham watercourse. (W = width, A= aggradation, D = degradation, P = planform adjustment)

ID	Watercourse	*Overall Condition	Dominant Problem	Dominant Process(es)	Controlling Factors	General Opportunities
ED	East Don	Unstable	-channel enlargement, bank erosion, and bank protection failure resulting in loss and damage of private property (i.e. landscaped yards)	W	Flow regime Hardened banks compromised Lack of riparian buffer	remove concrete, rock, and wood debris associated with failed trees and bank protection remove old concrete structures (old crossings) enhance riparian vegetation and re-form stable banks maintenance or removal of existing bank protection source control of storm water (e.g., disconnect downspouts)
EDT	ED Tributary - East Don Trib	Unstable	-failure of bank protection and trees resulting in loss and damage of private property (i.e. landscaped yards). -damage to infrastructure a problem.	W	Flow regime Hardened banks compromised Lack of riparian buffer	remove concrete and rock debris associate with failed bed and bank protection enhance riparian vegetation re-instate natural channel form maintenance or removal of existing bank protection source control of storm water (e.g., disconnect downspouts)
PM	ED Tributary - Pomona Mills	Unstable	-bank erosion and bank protection failure largely associated with weirs and grade control structures -over-topping of an undersized culvert crossing and realignment also a problem in upstream reaches	W, D	Flow regime Local grade controls Hardened banks compromised Lack of riparian buffer Response to realignment	remove concrete and rock debris associate with failed bed and bank protection removal of sheet piling weirs replace undersized culverts with bridge crossings enhance riparian vegetation re-instate natural channel form maintenance or removal of existing bank protection Pomona Creek Erosion Restoration and Habitat Enhancement Study source control of storm water (e.g., disconnect downspouts)
GM	German Mills	Moderately Stable	-channel situated in private property or in proximity to infrastructure -channel adjustments and migration causing risk to public health and safety -failure of previously placed bank protection -existing erosion control materials (e.g., gabions) are failing and requiring maintenance	W, P	Flow regime Hardened banks Boundary materials (including clay)	re-form bank and enhance riparian vegetation in local erosion areas (e.g. parking lot) enhance riparian vegetation with planting of trees and shrubs, through private and public property (e.g. parklands) source control of storm water (e.g., disconnect downspouts)
GMTM	GM Tributary - Trib Markham	Moderately Stable	-some bank erosion (enlargement) in downstream reaches. -upstream erosion less common, proximity an issue.	W	Flow regime	remove urban debris from watercourse enhance riparian vegetation with shrubs and trees in upstream reaches source control of storm water (e.g., disconnect downspouts)
GMTS	GM Tributary - Trib Side	Moderately Stable	-bed protection failure (i.e., terrafix) -channel working to develop meandering form in response to previous realignment -channel incised downstream of highway -highway drainage contributing high flows and garbage to watercourse	W	Flow regime Hardened channel bed materials	remove urban debris from watercourse (including refrigerator) – upstream of Leslie Street; other garage is downstream of Leslie Street enhance riparian vegetation with shrubs and trees re-instate natural channel form source control of storm water (e.g., disconnect downspouts)
BV	Beaver	Moderately Stable	-erosion associated with meander bend migration in downstream reaches. -realignment and numerous crossings in upstream reaches. -excess sediment load in channel -online ponds -proximity of private property to watercourse	A (W)	Flow regime Hardened banks compromised Channel modification Grade controls at crossings	soften hardened banks through incorporating vegetation replace hardened bank treatment with softer approach during maintenance establish non-manicured buffer adjacent to watercourse in private property enhance riparian vegetation with shrubs and trees
C	Carleton	Moderately Stable	-urbanizing watershed -channel situated in private property -several on-line ponds (reach C2-pond) -landscaped to top of bank	A (W,P)	Vegetation, woody debris Grade controls at crossings Hardened bank treatments Human modifications	establish non-manicured buffer adjacent to watercourse in private property enhance riparian vegetation with shrubs and trees enhance plantings around ponds

ID	Watercourse	*Overall Condition	Dominant Problem	Dominant Process(es)	Controlling Factors	General Opportunities
			-large woody debris accumulations in downstream reaches. -online ponds (realignment) in upstream reaches.			stormwater source control
A	Applewood	Stable	-channel is on-line stormwater management pond downstream of Apple Creek Boulevard. -multiple fish barriers exist along the watercourse (including immediately upstream of confluence with Rouge River) -channel corridor is generally well vegetated		Grade controls at crossings and SWM facilities Corridor vegetation	mitigate fish barrier impact enhance riparian vegetation (especially trees)
BRU	Bruce	Stable	-proximity to private property -modification of corridor by golf course -various potential fish barriers -channel flows through golf course -some sediment loading to watercourse	W (A)	Grade control – major dam Vegetation, landscaped golf courses - Clay boundary materials	establish non-manicured buffer adjacent to watercourse in private property (e.g. Reach 1, 2) enhance riparian vegetation remove concrete from channel establish wider riparian zone (raeach 3) mitigate fish barriers incorporate vegetation in existing bank treatments replace hard bank treatments with bioengineered approach
BZ	Berczy	Moderately Stable	-risks to private crossings and a weir. -bank erosion adjacent to road. -some erosion within private property and yards -existing gabions require maintenance – currently rotting (Reach 10, 13 -proximity of road and private property to watercourse -various potential fish barriers -landscaping to bank edge.	A (W)	Grade controls at crossings and weir Vegetation, landscaping, woody debris Clay boundary materials -Flow regime	enhance riparian buffer with planting of shrubs and trees adjacent to watercourse establish non-manicured buffer adjacent to watercourse in private property (e.g. Reach 1) replace gabions with softer bioengineering treatments mitigate potential fish barriers to enable upstream fish passage source control of storm water (e.g., disconnect downspouts)
ECK	Eckardt (formerly Burndenet Creek)	Moderately Stable	-channel corridor shows evidence of downcutting and migration across floodplain (e.g., terraces, relic meander cut-offs) downstream of 16th Ave. -active processes of planform development upstream of Highway 7 -proximity of private property to watercourse -local erosion associated with woody debris, channel bends -degradation of aquatic habitat -maintenance of gabion baskets required	US: D DS: W	Grade controls at crossings Vegetation, landscaping, woody debris Channel confinement Large woody debris Clay boundary materials	enhance channel stability and restore aquatic habitat through channel restoration at a reach scale enhance vegetative plantings along banks with species that will stabilize the banks (upstream of Hwy 7) soften existing bank treatments (e.g., rip-rap) with vegetative plantings replace existing gabions with softer approaches. source control of storm water (e.g., disconnect downspouts, ponds)
ROB	Robinson	Stable	-potential barriers to upstream fish migration -local erosion sites. -on-line ponds with dams (some being outflanked), creating barrier to fish migration -gabions failing and requiring maintenance (Reach 5) -watercourse flows through private property	US: P MW: A DS: D,W	Clay boundary materials Human modifications Flow regime Hardening of channel boundaries Riparian vegetation	removal of concrete blocks in channel (e.g., Reach 6) establish unmaintained riparian buffer within private property enhance riparian vegetation with trees and shrubs remove fish barriers (Reach 7) replace gabions with softer bioengineering approach if feasible
T1	Tributary 1	Stable	-channel situated in agricultural fields with livestock access to watercourse -degradation of natural channel form and function - though this may be a natural consequence of local controls and hydrologic regime	A, W	Corridor vegetation Channel grade Road and rail crossings	eliminate livestock access to watercourse establish well-vegetated terrestrial corridor (shrub, trees etc.) enhance wetland function
MJ	Mount Joy Creek	Moderately Stable	-headwater of channel piped underground and emerges into geogrid lined channel -loss of natural channel form due to previous straightening and lining with geogrid and rip-rap -subsurface infrastructure is in proximity to creek – manholes now in creek or in banks -local erosion associated with crossings and sewer manholes -extensive lining of channel with rip-rap, geogrid, and gabion	US: A (D) DS: W	Grade controls at crossings and weir Channel bed and bank protection (gabions rip-rap etc.) Vegetation, landscaping	provide buffer along creek with respect to lawn-mowing on private property replace manicured grass along channel banks with unmaintained grasses, shrubs and/or trees. replace rip-rap and gabions with bioengineered bank protection (if protection is necessary)

ID	Watercourse	*Overall Condition	Dominant Problem	Dominant Process(es)	Controlling Factors	General Opportunities
			-gabion baskets require maintenance			restore natural channel form in rip-rap lined channel (bed morphology if banks must remain protected from erosion) potential groundwater seepage observed – important to maintain sources
MO	Morningside	Moderately Stable	-woody debris accumulation. -tributary erosion problems due to enlargement from upstream stormwater management pond.	Main: A Trib: W	Flow regime Vegetation, woody debris	remove excessive large woody debris from channel (Tributary) enhance channel stability and restore aquatic habitat through channel restoration at a reach scale (Tributary) source control of storm water (e.g., disconnect downspouts)
R	Rouge River	Moderately Stable	-erosion problems associated with channel bends, slope toe erosion, failed bank protection, proximity of private land, and bank modification by golf courses. -large woody debris a problem in a few localized areas.	A (W,D)	Flow regime Grade controls at crossings, major dam Hardened banks compromised Vegetation, landscaping	stabilize channel banks within the Markham Golf and Country Club through establishing riparian buffers and revegetation of bank faces. source control of storm water (e.g., disconnect downspouts)
LR	Little Rouge	Stable	-local erosion associated with bend migration and old crossings.	US: A DS: D	Grade controls at crossings	monitor stability at old crossings

*Based on average of all reaches as published in Markham DC Study and adapted for erosion site prioritization.

7.7 General Opportunities for Restoration and Further Study

Through completion of the field inventory and field mapping (**Appendix B**), it became apparent that there are general opportunities for erosion restoration and enhancement that could occur during regular maintenance activities along Markham's watercourses (see **Table 7.6**). Incorporating vegetation in and around previously placed hardened bank protection can also be undertaken by landowner and volunteer groups to promote stability of the banks and to enhance terrestrial and aquatic habitat.

Table 7.6. General action that can be undertaken to enhance channel stability

Issue	Opportunity
Rip-Rap	Few sections of rock lining have incorporated any vegetation. Placement of live stakes or plugs within the rip-rap could contribute to stabilization of bank materials while enhancing terrestrial and aquatic habitat and increasing aesthetic appeal. See **Chapter 9** for a range of restoration options.
Gabions	Many gabions are towards the end of their life span, as evidenced by extensive corrosion of the wire baskets and loss of rock content. During routine maintenance, consideration should be given for replacing the gabions with softer, but equally effective solutions that promote stability, enhance terrestrial and aquatic habitat, and increase aesthetic value. See **Chapter 9** for a range of restoration options.
Armourstone	Where armourstone was previously placed, modification to cross-sections may be necessary to ensure that cross-sectional capacity is sufficient for the existing and anticipated future flow regime that is to be conveyed through the watercourse.
Landscaping	Many sections of Markham's watercourses flowed directly through, or adjacent to, private property. Landscaping of the properties resulted in a loss of riparian vegetation or decreased quality with respect to benefits to banks.
Riparian Vegetation	Vegetation exerts a substantial influence on channel form and stability as well as contributing to aquatic habitat, terrestrial habitat and other environmental benefits. Enhancement of vegetation along the drainage network is considered to be beneficial (including backyard swales)
Stormwater management	Source control to reduce the volume of water that enters the stormwater drainage network is desirable and can be achieved through landowner co-operation. See **Chapter 9** for further details.

Through completion of the detailed field inventory, it became apparent that erosion along some watercourses was systemic and a result of watershed level processes rather than a response to local perturbations or controlling/modifying factors. Similarly, some watercourses were identified which showed notable signs of response to previous perturbations in the watershed (e.g., historic landuse change) and are now responding to further change as a result of urbanization. The watercourses that would benefit from further study and from action at a watershed level are identified in several categories below:

Modification of flow regime

Initiation of programs across the city that encourage site-level stormwater retrofits (e.g., disconnect downspouts, biofilters) and swale drainage will be beneficial in reducing the volume and rate of urban runoff delivery to the watercourse. Action taken across the city, and especially in older developed neighbourhoods of watercourses which currently exhibited erosion sites with risk to public health and safety will provide immediate benefit. Watercourses that would benefit from watershed scale stormwater reduction include:

East Don River
Pomona Mills Creek (note: study is currently underway)
German Mills Creek
German Mills Creek Tributary
Robinson Creek
Mount Joy Creek

The East Don River, German Mills Creek and their tributaries receive significant drainage from upstream municipalities (e.g., Town of Richmond Hill, City of Vaughan). Mitigation of the flow regime of these watercourses through the Town of Markham will require action on the part of the neighbouring municipalities.

Sensitive watercourses

During the course of the field inventory, several watercourses were identified as sensitive to change, both from historic landuse changes (e.g., European settlement) and more recent urbanization. Degradation of aquatic habitat has occurred in these channels:

Burndenet Creek/Eckhardt Creek – substantial evidence of floodplain migration and incision, resulting in terraced downstream of 16th Avenue; very active meander migration processes upstream of Hwy 7 (this watercourse has been the subject of detailed investigation)

Morningside Creek Tributary – significant enlargement, sediment loading, and large woody debris problems below stormwater management pond.

Carlton Creek – substantial evidence of channel adjustments, resulting in chutes on floodplain and meander cutoffs, large woody debris accumulations are in creek

Highly altered/modified watercourses

Several watercourses have, historically, been significantly impacted by human activity. Channel works completed at the time are now in a state of failure and compromise aquatic habitat. Wide scale study and restoration would benefit the following watercourses:

Pomona Mills Creek – multiple weirs, significant alteration of channel form, significant introduction of rip-rap materials into creek (this watercourse is the subject of a current investigation)
Mount Joy Creek – loss of natural channel form and function due to presence of geogrid bed protection; piping of headwater section of creek underground, many manholes are at risk and subsurface infrastructure is in proximity to the creek.
Tributary 1 (see Figure 6.1 for location) – agricultural land use has previously enabled cattle access to watercourse. Recent landuse change (Boxgrove Developments) in this area now precludes cattle access; the watercourse, however, remains impacted.
Milne Creek – modified within private property; downstream actively eroding within wooded area.

<u>Actively migrating channels</u>
A few watercourses were identified as migrating actively across their floodplains within the watercourse corridor. While these adjustments do not pose an immediate risk to public health and safety, suitable lateral migration zones should be considered given any future development in or around the corridor. Appropriate setbacks for infrastructure and property should be determined to avoid future erosion risks. Active lateral migration was noted on the following watercourses:

Beaver Creek – downstream reaches adjacent to Hwy 407
Rouge River – particularly between Hwy 7 and Kennedy Road
Burndenet Creek – upstream of Hwy 7
Little Rouge Creek – upstream of Reesor Road

8.0 EROSION PRIORITY RANKING

Compilation of the field inventory revealed a substantial number of erosion sites, fish barriers and areas of previous protection that required maintenance. Along the ~ 105 km of channels that were walked, results of the field inventory were as follows:

- 27 areas requiring maintenance
- 61 potential fish barriers
- 308 erosion sites

Overall, 334 sites were identified as representing erosion and/or areas of maintenance concern. It is important to note that although identified, many of these sites are a result of natural and necessary channel processes and were identified only because of their potential risk to public/private property, public health and safety, and infrastructure (sewers, bridges, roads etc.). It is unlikely that all sites merit intervention and, for this reason, a screening level analysis will be undertaken to remove from the list those sites that do not pose a risk and, as such, should remain untouched to enable natural processes to continue unimpeded.

8.1 Screening Level Analyses

Completion of the screening level analyses require assumptions to be made about those sites that are unlikely to pose a risk to the public. For the purpose of this study, several criteria were used to identify those sites that would not be included in a more detailed evaluation of potential erosion concerns. The analytical capabilities of GIS were used to apply each criterion. A manual review of the results was undertaken at each step to ensure that field observations of any structures that were not evident on mapping, were recognized and used to refine the results. The screening level criteria that were established for this study are as follows:

- Sites that are **not** in proximity to infrastructure, property lines, roads etc. are unlikely to pose a risk:
    - > 25 m from resource,
    - Valley wall contacts > 15 m + stable slope line from resource (outside of stable top of bank according to generic regulation mapping),
- Sites that were ranked as a 'low risk' and 'gradual rate of erosion/old scar' during the field are unlikely to pose a short-term risk to the public (photos and notes were reviewed to ensure that nothing is missed)

8.2 Erosion Priority Ranking

Identification of those erosion sites that warrant intervention so that risk to public health and safety may be reduced requires careful consideration of the factors that contribute to the risk. For this purpose, an erosion priority ranking methodology was developed based on previous schemes presented in consulting reports (TSH, 1997; ABL, 2005) and consultation with the Town of Markham and Toronto and Region Conservation. The erosion ranking method used in this study combines three weighted indices including

Component	**Potential Weighting**
Public Health and Safety – type of public risk	40
Erosion Index – factors that contribute to risk	38
Natural Resource – magnitude of risk, aquatic and terrestrial resources	22

Details with respect to the sub-components for each component identified above are provided in the subsequent sections. For each component, the sub-components are rated and then pro-rated to correspond to the weighting scheme identified above.

1) Public Health and Safety (Weighting = 40 % of total score)
This index is intended to identify and rank relative risk with respect to public health and safety. An eroding bank adjacent to an open space would rate lower than an eroding bank in proximity to a road.

Hamilton

Type of Public Risk	**Rating/40**
Public trails	12
Private crossings	20
Public footbridges	24
Road bridges	32
Public parking lots	28
Roads	24
Buildings	40
Major dams	40
Minor dams/weirs	20
Private Property (structure/ parking lot, yards) – in active use	36
property line (not in active use)	30
Public Property/Open space/Parkland	8
Sewer pipe	28
Manhole	32
Watermain	28
Outfall	12

2) Erosion Index (Weighting = 38 % of total score)

Assessing the risk of erosion is accomplished by identifying, and rating, those parameters that contribute to this risk. Each parameter is assigned a relative weighting of the total erosion risk score. The cumulative score from each parameter is weighted as outlined above to represent % of the total erosion ranking score.

Parameter	Definition	Component Score
Distance	Distance from top of bank to resource type (e.g, property boundary, manhole, road etc.)	18
Stress	Position of flow in planform and cross-section; flow regime and age of development	10
Erodibility	Physical characteristics of bank materials	10
Risk of Erosion Total Score		**38**

Distance – a determination of how far the erosion site is from a component identified under health and safety (e.g., building, subsurface infrastructure, manhole, road etc.).

Distance	Rating/18
In channel	18
0 – 5 m	16
5 – 10 m	8
10 – 20 m	4
> 20 m	2

Stress – the hydraulic stress of flow at each site will influence, in part, the erosion rate and hence influences the erosion risk. Stress is accounted for by considering the position of flow in the planform and cross-sectional configurations as follows:

Flow Position	Rating/4
evenly distributed in cross-section – straight section	1
bank piping/seepage	2
at drop (e.g., weir)	3
overtop flow – outflanking of structures	4
flow at bank – thalweg alignment or meander bend	4

Flow Regime/ Imperviousness cover	Rating/2
< 10 %	2
11 – 29	1.5
30 – 59	1
> 60	0.5

Average Age of Development	Rating/2
0 – 10	2
11- 20	1.5
21 – 30	1
31 - 50	0.5

Existing Channel Condition	Rating/2
Unstable	2
Moderately Stable	1
Stable	0

Erodibility – the rate of erosion at any site is a function of the physical characteristics of the site. Seven parameters have been identified each of which contribute to the overall assessment of site erodibility.

Erodibility Component	Rating /10
Stratification 1 unit = 0.5 2 units = 1.0 3 units = 1.5	1.5
Particle size Protection – in-tact = 0.5 Protected – moderately compromised = 1.0 Protected – severely compromised = 1.5 Boulder = 0.5 Clay = 1.0 Shale = 1.0 Gravel = 1.0 Sand = 2.0	2
Exposure of bank face (ascertains level of vegetative control) >49% exposed= 1.5 25- 49% exposed= 1.0 < 25% exposed= 0.5	1.5
Bank height to bankfull depth >2 = 1.5 1.3-2 = 1.0 <1.3 = 0.5	1.5
Bank angle < 1.5 = 1.5 1.5 – 3 = 1.0 > 3 = 0.5	1.5
Bank Height Valley wall > 2 m = 2 Bank < 2 m = 1	2

3) Significance of Erosion (Weighting = 22 % of Total Score)

The significance of erosion examines each site in terms of the implications with respect to public safety and environmental impact. The key components that have been identified include:

Component	Component Score
Extent of Erosion	14
Aquatic Habitat	8
Terrestrial Species[1]	0

[1] (none found during analysis and therefore removed as a component score – see further details in text below)

Extent of Erosion and Damage - is defined as the spatial area that is encompassed by the erosion site. The larger the site, the higher the ranking (note, rating will be pro-rated to component weighting):

Extent	Rating/14
0 – 100 m^2	3.5
101 – 200 m^2	7.0
201 – 300 m^2	10.5
> 301 m^2	14

Determination of the area incorporates an evaluation of stable slopes for the materials which are defined as follows:

Limestone/bedrock	1.5:1 (hor:vert)
Clay till	2.0:1 (hor:vert)
Sand & gravel	2.5:1 (hor:vert)

Aquatic Habitat – While public health and safety are a predominant concern, the value of the natural resource is an important factor in determining the priority for restoration. Five general fish community types were defined which are as follows:

Class 5 – *intolerant coldwater fish community*: Aquatic habitats are characterized by cold water temperatures; high dissolved oxygen levels; stable, moderate gradient streams; groundwater dominated flows; cobble/gravel/sand substrates; well developed pool:riffle morphology. Fish communities are very sensitive to disturbance. While not strictly a coldwater species, fish habitats supporting redside dace would also fall in this category.

Class 4 – *tolerant coldwater fish community*: Aquatic habitats similar to the above, but generally characterized by larger order streams, coarser substrates, larger pools to support adults. Stream temperatures may be warmer, and streams generally only support salmonids during their juvenile life stages, with adults migrating to the lake.

Class 3 – *diverse warmwater fish community*: Aquatic habitats very diverse ranging from moderate to large river habitats similar to 4 above to low gradient rivers with aquatic macrophytes as a significant habitat element. These are generally runoff dominated streams that are more nutrient rich, but are generally stable.

Class 2 – *moderately tolerant warmwater fish community*: Aquatic habitats are generally moderately degraded in terms of natural hydrology, stream stability and water quality. Generally these systems supported fish communities typical of 3 – 5 above, however loss of groundwater discharge; shift from pool:riffle to flat:run morphology; habitat instability from "flashy" hydrology; and water quality degradation eliminate sensitive species from the fish community

Class 1 – *tolerant/highly tolerant warmwater fish community*: Similar to 2 above, however, instream habitats are degraded to the point where only the most tolerant species can survive

The habitat sensitivities for watercourses within Markham are identified below:

Habitat Sensitivity	**Class**	**Rating/8**
East Don River	**3**	4.8
Pomona Mills Creek	**1**	1.6
German Mills Creek	**1**	1.6
Beaver Creek	**4**	6.4
Carlton Creek	**4**	6.4
Bruce Creek	**5**	8
Berczy Creek	**5**	8
Burndenet/Eckart Creek	**4**	6.4
Applewood Creek	**1**	1.6
Rouge River	**4**	6.4
Little Rouge River	**5**	8
Tributary 1	**2**	3.2
Mount Joy Creek	**4**	6.4
Robinson Creek	**4**	6.4
Morningside Creek	**5**	8

Terrestrial Species - The presence or absence of significant vegetative species in proximity to the erosion sites was determined in reference to the Ministry of Natural Resources Natural Heritage Information Centre (http://nhic.mnr.gov.on.ca/MNR/nhic/species.cfm). The Information Centre data was reviewed to identify endangered species observations and aerial groupings such as ESA, ANSI, and PSW. While natural erosion patterns will cause undermining and toppling of vegetation along a watercourse, this process may be exacerbated by changes in flow regime caused by urbanization. When the processes are exacerbated, then this constitutes a risk to the terrestrial resources. Review of the Ministry of Natural Resource data did not reveal any terrestrial resources that might be at risk in proximity to any of the identified erosion sites. As such, this item was removed from the scoring since it would not assist in further defining priority of erosion sites.

8.3 Summary of Ranking

As noted, 307 erosion sites were identified during the course of this study and, to enable identification of sites for priority restoration, a ranking procedure was developed. The following provides a quick overview of how the long list was reduced to form a priority list for restoration.

Step 1. Public risk sites that were found to be > 25 m away from the erosion site were considered to be too far away from the creek to be at risk within an approximate 100 year timeframe. Nevertheless, photographs of each of these sites were reviewed to ensure that any sites that were actively eroding would remain in the reduced list. This process enabled *74 sites to be removed* from the long list.

Step 2. The Toronto and Region Conservation Authority has been in the process of developing updated natural hazard mapping which is based on current technical standards and information. Erosion sites that were less than 25 m away from the watercourse, but were outside of the natural hazard Regulation Line, and had a 'LOW' field risk assessment were identified. These sites were reviewed and *7 sites* were subsequently removed from the long list.

Step 3. Sites that were less than 25 m away from the watercourse and had a low risk rating based on the field documentation were identified. These sites were reviewed to assess relative risk. Sites that appeared not to pose a risk (i.e., distance away from channel, indicators of erosion activity). As a result, an *additional 106 sites* were removed from the long list.

Step 4. Upon completion of Steps 1 to 3, the long list had been reduced to 121 erosion sites. Each of these sites was subsequently assessed using the Priority Ranking scheme outlined in **Chapter 8.2** of this report.

9.0 RESTORATION ALTERNATIVES

9.1 General

From the completed background analyses and field investigations, a general understanding of drainage network, subwatershed and reach level processes was gained. Other studies (e.g., Markham Development Charges Update (Aquafor, 2004), Burndenet Creek Erosion Control Optimization Study (Aquafor, 2004), Rouge River Wet Weather Flow Study (Aquafor, 2003), Rouge River Fish Management Plan (TRCA)) provide additional insight into conditions of the creeks and rivers that flow through the Town of Markham.

Understanding of river channel dynamics, disturbance causes and the likely evolutionary path of the river are necessary for, and form the basis of identifying opportunities and constraints for addressing channel specific erosion concerns along any watercourse. This emphasis ensures that mitigation options are selected which promote stability in the river and that eliminate or minimize disturbances to key parameters within the watercourse.

The objectives of this chapter are to:

- present general considerations for watershed level mitigation options;
- identify alternative approaches to address erosion risks of private property and structures;
- present a range of potential solutions (options) to address erosion risk sites and to restore Markham watercourses;
- summarize the objectives of the Markham erosion restoration implementation plan;
- select preferred options which optimize these objectives;
- prioritize options on a site by site basis to ensure that a phasing schedule is developed which promotes the most effective mitigation strategy in terms of cost and time efficiency; and,
- provide unit cost estimates for preferred alternatives.

The range of solutions considered is provided in Section 9.2. These solutions provide protection on a watershed scale (Section 9.2.2) and at a reach scale (Section 9.2.3). The Markham erosion restoration goals and objectives are presented in Section 9.3. Evaluation of the restoration options in light of specific goals and objectives in conjunction with observations of the reach characteristics is completed using an evaluation matrix (Section 9.4). The alternative(s) which fulfilled the most criteria and met appropriate restoration objectives was selected for recommendation in this study. Finally, the rationale for costing the preferred works and unit costs are provided in Chapter 10.

9.2 Erosion Restoration Approaches

9.2.1 General

The intent of this study has been to undertake an erosion inventory for the purpose of identifying sites for restoration.. Through the field walks, it became apparent that some erosion sites required immediate restoration due to the imminent risk to public health and safety. Similarly, it became apparent that along some watercourses, the observed erosion was systemic and would benefit more from subwatershed and reach scale restoration efforts rather than 'patchwork', particularly when no immediate risk to public health and safety could be discerned. Restoration options have therefore been grouped into Watershed level options and Reach level options, based on the scale at which they are effective.

Traditionally, when addressing local erosion concerns, the restoration team focuses on short sections of channel rather than on a broader spatial perspective along the watercourse and within its drainage network. As such, restoration solutions are often designed without a sound understanding of the river's larger spatial and temporal context, especially in light of geomorphologic setting and controls (Kondolf and Downs, 1996). This approach often leads to the failure of restoration works which may also adversely affect downstream or upstream channel conditions or processes.

The background information and insight provided in Chapter 5 provide an overview of geomorphic channel conditions and processes that are operative in general, and specifically along Markham watercourses. This insight has been used to select restoration approaches that are effective at watershed scales, and at the site level. The watershed and reach level options are presented in Sections 9.2.2 and 9.2.3, respectively.

9.2.2 Watershed Level Options

At the watershed scale, it is important to identify and understand the controlling and modifying influences of channel form and the processes that occur along the drainage network. Ideally, the impact of any changes within the watershed on the flow and sediment regimes of the receiving watercourse is identified from both historic and future perspectives as this will influence contemporary and future channel conditions and processes. A detailed study of these processes and channel responses was beyond the scope of this study. Nevertheless, background information presented in Chapter 5 and generally known channel responses to changes in sediment and flow regime can be used for the purpose of identifying effective watershed level restoration options.

Watershed scale options affect downstream channel stability and are applied to the entire watershed or key components thereof. The concurrent and ongoing Rouge River Watershed Management Plan being undertaken by the Toronto and Region Conservation Authority provides a watershed scale perspective and evaluation of various future potential land use and land cover scenarios. Overall, the objective of watershed scale channel restoration efforts, is to minimize change primarily to the hydrologic flow regime. Watershed level options will be presented in general form only within this report as an evaluation of specific benefits for the various approaches is beyond the scope of this study.

Ideally, river restoration begins in the headwaters and progresses downstream. Since many of the watercourses have drainage areas that are largely within the Town of Markham, watershed level options will be particularly effective at reducing urbanizing impacts on the receiving watercourses. Key findings that influence the selection of watershed level restoration options are presented in **Table 9.1**. It is not the intent of this document to provide a comprehensive list of watershed level restoration options since this would require further study that spans various disciplines.

Watershed level solutions which eliminate or reduce downstream impacts by controlling sediment and hydrologic inputs tend to be preferred over instream channel modifications. By attacking disturbances at the source, broad scale channel degradation or exacerbation of existing processes can be avoided.

Stormwater Management within New Developments - This case assumes that new developments will meet MOE stormwater management guidelines. Reduction in stormwater volume in addition to reducing peak flows is beneficial in mitigating the effect of an altered flow regime due to urbanization. Incorporation of progressive source, conveyance, and end-of-pipe stormwater management techniques will be beneficial both for reducing flow volumes and peak flows. Benefits of increased infiltration also contribute to groundwater recharge, baseflow and water quality. The effectiveness of many techniques will vary spatially depending on local geology.

Stormwater Management within Infill Development – parking lot controls, biofilters, rooftop storage, promotion of infiltration trenches, soak away pits, oil-grit separators for water quality can all be considered as stormwater management techniques in infill developments.

Stormwater Retrofits – Retrofitting of existing storm water management facilities and modifying existing stormwater management practices (source, conveyance, and end-of-pipe) should be considered. Particularly effective measures include infiltration/exfiltration systems and pervious pipe systems. Many simple actions can be taken by individual landowners (e.g., disconnect downspouts) that effectively contribute to a reduction in the flow volume that is discharged to a watercourse.

Restoration of Degraded Tributaries –Restoration of particularly degraded watercourses through implementing stormwater management controls and bank stabilization will have a positive impact on the Don and Rouge Rivers. Bank stabilization through enhanced bank vegetation and riparian zone plantings would help to reduce sediment loading into the watercourses.

Table 9.1. Watershed scale processes that influence Markham Watercourses

Factor	Implication for the Markham Watercourses
Historic land use change (sediment and hydrology impacts)	Excess sediment resulting from the forest to agriculture land use change has likely impacted Markham watercourses resulting in pulses of sediment moving through the drainage network.
Contemporary urbanization (hydrology impacts)	Substantial amounts of urbanization have occurred within the last few decades and, as such, many of the watercourses have not yet fully adjusted to the impacts of changes in flow and sediment regimes. Adjustments are expected to continue into the future.
Future land use change	Future changes in land use are expected to alter characteristics of the drainage network and to result in further channel adjustments. Impacts are expected to increase in the upstream direction as the ability of the watercourse to assimilate changes in flow and sediment regime decreases proportionally.
Main branch of Rouge River	Restoration of the tributaries and reducing impact of watershed changes on them will, in turn, reduce impacts on the main branch of the Rouge River .
Sediment sources	Sediment supplied through erosion of channel banks and valley walls are important for the purpose of maintaining natural channel functions. As such, sediment supply should be maintained, particularly where sources contain coarser materials.
Proximity of private property and structures to erosion prone areas	Many of the identified erosion areas are a result of natural channel processes, some of which have been exacerbated by watershed level activities. The proximity of private property to the top of eroding bluffs and migrating channel bends raises the risk of what are otherwise normal natural processes that may be left unmitigated. Ensuring that suitable set backs are implemented in any land development plans is imperative to maintain natural sediment supplies and to enable the contemporary and future channel to adjust its form as necessary
Channel spanning structures (e.g., dam, weirs)	Abandoned dams and other structures that cross the channel, accumulate sediment and act as base level controls to which the channel profiles become adjusted over a period of time. The age of many structures suggest that the channel has been adjusting to their presence and hence whether or not removal will be beneficial to the channel should be carefully considered prior to undertaking any restoration measures.

Provision of Erosion and Slope Stability Setbacks – Sufficient setbacks from bluffs and the meandering planform is recommended to reduce risk to private property, structures and infrastructure while allowing for the continuation of natural channel processes.

Protecting Natural Coarse Sediment Sources – in restoration strategies, natural sources of coarse sediment should remain available to Markham watercourses.

Vegetative cover – enhancement of tree cover within a subwatershed is effective in intercepting rain (i.e., reducing volume of precipitation that reaches ground) providing shade to watercourses, stabilizing channel banks, and increasing terrestrial habitat in addition to improving air quality.

9.2.3 Reach and Site Level Measures

In this study, erosion areas were specifically identified when they were considered to be a potential risk to public health and safety. Mitigation of these risk areas can be accomplished through two means:

- moving the item that is at risk away from the watercourse, or
- minimizing the risk of further erosion.

Removing Risk

Moving the item that is at risk away from the watercourse is desirable in the sense that interference with channel movement and adjustment processes will be minimal. This course of action is best taken at the time that private property boundaries are defined or structures are planned in proximity to the watercourse through the establishment of appropriate setbacks. In general, regulatory agencies provide effective assistance in establishing setbacks through the review process.

When there is an existing, or future potential, risk to public health and safety, it is desirable to consider options that reduce the level of risk without interfering with channel form and function or aquatic habitat. That is, by moving the perceived public health and safety risk away from the watercourse, the level of risk is reduced. Action that may be considered include:

- Moving subsurface infrastructure away from watercourses – this could occur on a more widespread scale during scheduled maintenance or replacements activity or in lieu of undertaking restoration works.
- Relocating manholes away (or out of) watercourses rather than hardening channel banks or modifying channel form.
- Expropriating private property so that property lines can be moved to a suitable distance away from the watercourse.
- Altering landuse activities that affect site processes (e.g., reconfigure parking areas, create buffer between site and landuse etc.)

Addressing the Risk

In some circumstances, the risk to public health and safety is more immediate and action to move structures or property lines is not feasible in the short term. In such cases, minimizing the risk is a suitable course of action. By taking pre-emptive action, the extent and severity of erosion restoration works can be reduced. That is, when there is still some distance between the watercourse and the item that is at risk, then the restoration options that can be used to minimize risk are more varied and can be 'softer' than if the risk of failure or destruction is imminent. Typically, a cost saving may be expected when restoration works consist of 'softer' approaches. In these situations, mitigative action could also include burial of erosion protection measures that will allow the channel to continue to migrate and develop – these processes would be halted once the channel intercepts the buried protective materials. This would represent a cost saving and minimize immediate interference with channel processes.

This study has identified the priority erosion sites which pose a risk to public health and safety. It is imperative that an understanding of reach scale and watershed scale processes is attained so that the cause, rather than only the symptom, of perceived erosion areas is identified. Such knowledge and understanding enable appropriate restoration solutions to be identified for particular erosion sites. Information presented in **Chapter 5 and 7** provides some of this understanding which is expected to be supplemented by more detailed field assessments at the time that restoration works would be undertaken for any erosion site that is considered to pose a risk to public health and safety. **Table 9.2** provides an overview of factors that affect channel processes within Markham watercourses. These pertain primarily to the priority erosion sites that were identified in **Chapter 8**.

Table 9.2. Salient channel characteristics that will influence the identification of reach and site level restoration measures.

Factor	***Characteristic/Consideration***
Geologic materials	- clay - variable boundary materials
Dominant processes	- Lateral migration - Deposition and lateral migration - Lateral migration and downcutting - Expansion through widening - Expansion and downcutting - Deposition

Erosion Types

Potential risks to public health and safety were typically associated with several types of channel processes and characteristics.

The list is followed by **Table 9.3** which provides a linkage between channel process and observed erosion/channel instability.

a. Erosion along outside meander bends (i.e., both channel banks and valley wall erosion) often resulting in a loss of private property or compromising structural stability;

b. Abandoned or dysfunctional dams and weirs spanning the channel or a portion thereof, functioning as base level control points and impediments to downstream sediment movement;
c. Erosion around bank protection structures or outfalls associated with channel enlargement and expansion scour;
d. Deflection of flow around abandoned in-stream structures.
e. Proximity of subsurface infrastructure to channel banks (e.g., in meanders)

Table 9.3. Link between channel process/adjustment type and the observed erosion or channel instability. *Note: The channel processes/adjustments are natural and necessary channel responses to changing conditions with respect to flow and sediment regimes, but become problematic when they create a public (including property), structures, terrestrial or aquatic risks.*

Process/Adjustment Type	**Observed Resulting Erosion and Potential Risk**
ENLARGING – typically through channel widening to increase cross-sectional area so that increased flows can be accommodated. This is a necessary process and should be accommodated	- bank erosion (bank and bluff) and/or oversteepening - potential for large sediment loading - outflanking of structures - property and tree loss - bank undercutting - bankside structures end up in creek
LATERAL MIGRATION – as a result of meander development or movement, erosion is most often focused on the downstream end of the bend	- erosion along outside meander bends which provides sediment to the channel, can lead to property and tree loss, and oversteepening of the banks - may pose risk to structures, roads, property lines - accelerated erosion leads to sediment loading - thalweg oriented against, or adjacent to, valley wall or banks can compromise bank stability and private property/structures - abandonment of channel spanning structures
DEPOSITION – this occurs when the sediment load is greater than the ability of the channel to transport.	- excess sediment loading - trapping of sediment in bed materials, leading to siltation of channel bed (reducing channel capacity and affecting aquatic habitat) - accumulation of sediment behind channel spanning structures and in areas of slack water
BED LOWERING – this is typically a gradual process that is part of larger watershed wide processes	- knickpoint development or upstream migration - destabilization of bank protection structures - exposure of subsurface infrastructure may occur

At the site level, it is important to identify the cause of instability such that the proposed channel works will be sustainable, and will effectively mitigate the 'symptom' that instigated the restoration works. A range of restoration options should be considered before a final selection is made. The preferred restoration option should be informed by a deeper understanding of site processes on varying temporal and spatial scales and should be augmented by background materials presented in **Chapters 5 and 7**. Wherever possible, natural processes/functions should be maintained to ensure that other channel processes are not adversely affected (e.g., maintain sediment supply from erosion of valley walls and channel banks wherever feasible).

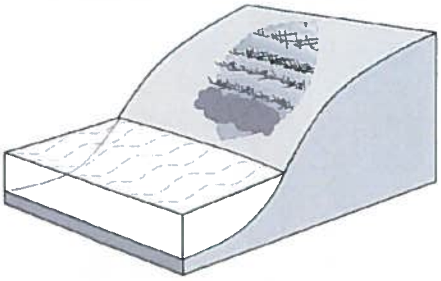
Of the channel processes that are identified in **Table 9.3**, meander migration can pose the greatest risk to the public, structures, and terrestrial resources and yet is also an important process that enables channel features such as pools to form, delivers sediment to the channel to maintain natural channel functions and enables a manipulation of channel slope. Contemporary erosion hazard set backs (e.g., greater of the meander belt or 15 m set back from channel) are intended to reduce risk to public property and structures. Along Markham watercourses, however, many of the areas that pose a risk to the public are in proximity to the channel, presumably before conservative erosion hazard regulations were in effect. Subsurface infrastructure is often routed through valleys and stream corridors due to ease of construction in this area and resultant beneficial grading.

Bed lowering poses the greatest risk to subsurface infrastructure when the infrastructure is situated under the channel and would be recommended for movement (of infrastructure) or more permanent stabilization. In general, natural channel processes should be maintained wherever possible but, in the event that risks associated with public, structure or terrestrial and aquatic resources is considered to be unacceptable, then mitigation solutions that seek to maintain as many of the natural processes as possible is preferred.

Overall, all restoration options may be classified into several categories which are outlined in **Table 9.4** and further illustrated and described in **Figure 9.2a-k**. The long list of alternatives that was developed for addressing local or reach level treatments considered the suite of different problems that were identified along Markham watercourses. From a Fisheries Act perspective, it is likely that in cases where intervention is undertaken to protect properties, that compensation may be required.

Many stream restoration strategies that may be applied at the reach or site level rarely utilizes only one approach. Instead, a combination of approaches or combination of treatment types for one approach may provide the best solution to rehabilitate the channel and to address areas of existing or anticipated erosion concerns. Selection of any alternative(s) should be based on a more detailed field assessment of the erosion site and local conditions and should consider implications of the preferred option on surrounding channel processes. For example, deflection of a current away from one area may shift the erosion problem downstream. Thus, action needs to be taken to minimize negative impacts resulting from the preferred option. Often, this can be accomplished through

Branch Packing



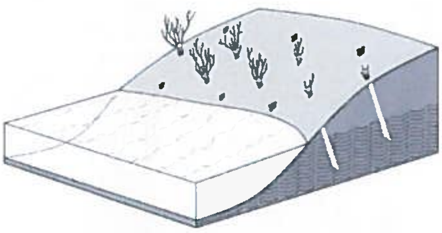
Alternate layers of live branches and compacted backfill which stabilize and revegetate slumps and holes in streambanks.

Application and Effectiveness

This is a bioengineering method that offers immediate slope protection provided the original cause of the bank instability has been remedied. It may be used to patch local bank scour and gullies eroded by overbank runoff. The area needing repair must be smaller than 1.2 m square and less than 1.2 m deep. The soil should be sufficiently moist to encourage plant rooting and growth. When established, the vegetation will provide aquatic and wildlife habitat and protect soil from stream erosion and/or overbank erosion.

References: NYDT (2002); USDA (1998, 2002)

Live Stakes



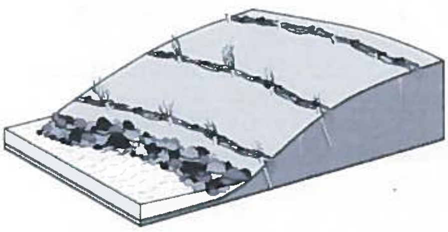
Live, woody cuttings which are tamped into the soil to root, grow and create a living root mat that stabilizes the soil by reinforcing and binding soil particles together, and by extracting excess soil moisture.

Application and Effectiveness

Live stakes offer a quick, low cost method to repair small patches of bare bank, slumps and gullies caused by overland runoff. They are suitable for remedying simple erosion problems on gentle slopes (3H:1V) and where minimal disturbance is desired. The method is appropriate for the protection of the middle and upper bank where no structures are at risk. Toe protection may be required if scour is anticipated. Often, the technique is combined (where appropriate) with other bioengineering methods or to stabilize areas between other soil bioengineering sites. The plantings rapidly restore riparian vegetation and streamside habitat. No maintenance is required after plantings are established.

References: MTO (1995); NYDT (2002); OSRM (2002); USDA (1998, 2002)

Live Fascines (Wattles)



Dormant branch cuttings bound together into long sausage-like, cylindrical bundles and placed in shallow trenches on slopes to reduce erosion and shallow sliding.

Application and Effectiveness

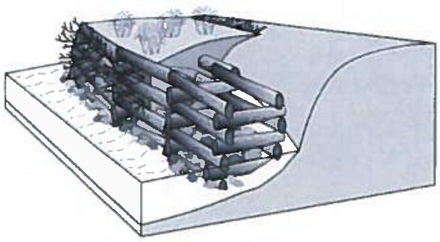
Live fascines trap and hold soil on the streambank by creating small dam-like structures and by reducing the slope length into a series of shorter slopes. Fascines offer immediate protection on slopes as steep as 1H:1V, although 1.5H:1V is optimal. They function best on streams less than 5 m wide and bank heights less than 1.5 m. Fascines should not be used on unstable slopes, and toe protection should be incorporated into the design if scour is anticipated. The technique is often used in conjunction with other bioengineering methods. Fascines cause minimal site disturbance and can be used to "soften" harder structures. They plantings, once established, enhance riparian habitat and encourage the colonization of native vegetation.

References: OSRM (2002); USDA (1998, 2002)

Figure 9.2a Streambank Treatments- Bioengineering

Aquafor Beech Limited

Live (Vegetated) Cribwalls



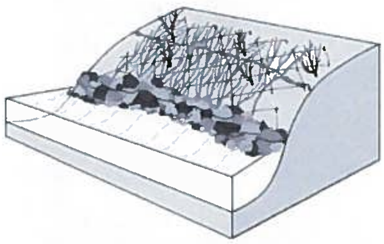
Hollow, box-like interlocking arrangements of untreated log or timber members filled above baseflow with alternate layers of soil material and live branch cuttings that root and gradually take over the structural functions of the wood members.

Application and Effectiveness

Live cribwalls are used to treat local bank scour, including the slope toe and upper bank. They are commonly used along the outside of stream bends where strong currents are present, and are particularly suited to steep (0.5H:1V) slopes or where slopes need to be increased due to limited space. The materials used to build cribwalls should be obtainable on site. Completed structures, which should be no higher than 1.8 m and no longer than 6 m, offer immediate bank protection. The vegetation, once established, provides good habitat and a natural bank appearance. The chief limitation of cribwalls is that they can require excavation of the bank..

References: MTO (1995); USDA (1998, 2002)

Brush Mattresses
Brush Layering



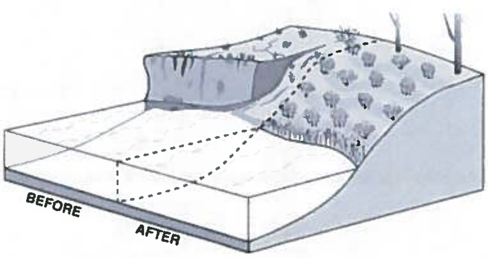
Combination of live stakes, live fascines and branch cuttings installed to cover and physically protect streambanks; eventually to sprout and establish numerous individual plants.

Application and Effectiveness

These methods are used to remedy debris scour as well as local and general bank scour occurring during high flows. They also capture sediment during flood flows. The techniques are suitable for steep, fast streams and provide immediate cover over the streambank and the established vegetation encourages the colonization of native vegetation. Treatments should not exceed 15 m in length nor should they be used on unstable slopes or slopes steeper than 3H:1V. Toe protection will be required where toe scour is anticipated. Brush layers are specifically suited for providing deeper soil reinforcement but are difficult to construct and generally not suited for use along waterways. They are typically best implemented when bank building sediment is in ample supply (i.e. High sediment loadings).

References: NYDT (2002); RBSA (1999) USDA (1998, 2002)

Bank Shaping & Planting



Regrading streambanks to a stable slope, placing topsoil and other materials needed for sustaining plant growth, and selecting, installing and establishing appropriate plant species.

Application and Effectiveness

This treatment is most effective on streambanks where moderate erosion and channel migration are expected. It is accompanied by other protective strategies where flow velocities exceed the tolerance range for available plants, and where erosion occurs below baseflow. Established vegetation further protects the slope and encourages the colonization of native species. Streambank soil materials, probable groundwater fluctuation, and bank loading conditions are factors for determining appropriate slope conditions. The slope toe often needs to be reinforced and slope stability analyses are recommended.

Reference: USDA (1998)

Figure 9.2b Streambank Treatments- Bioengineering

Aquafor Beech Limited

Joint Plantings, Vegetated Rock Revetment, Vegetated Riprap

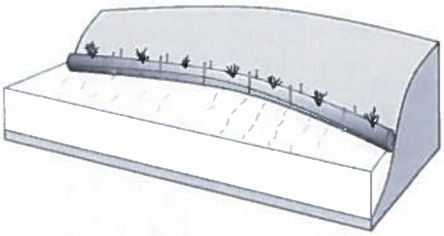
Live stakes tamped into joints or openings between rock previously been installed on a slope or while rock is being placed on the slope face.

Application and Effectiveness

Joint plantings can reduce general bank scour in areas where there is a lack of desired vegetative cover on the face of existing or required rock riprap. This method is particularly suited for use along steep, high gradient streams. The roots systems provide a mat upon which the rock riprap rests and prevents the loss of fines from the underlying soil. Plants establish quickly but survival rates may be low, due lack of soil or damage to cambium layer. The plantings should accompany vegetative plantings of the upper bank thus ensuring a regenerative source of streambank vegetation. Cuttings are susceptible to damage by flood debris and beavers.

References: OSRM (2002); USDA (1998, 2002)

Coir/Coconut Fiber Roll



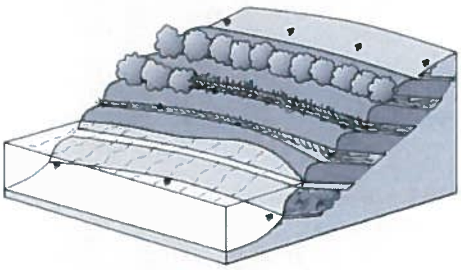
Cylindrical structures composed of coconut husk fibers bound together with twine woven from coconut material to protect slopes from erosion while trapping sediment which encourages plant growth within the fiber roll.

Application and Effectiveness

This is a method of toe protection suitable for sensitive sites that require a minimum of disturbance. Typically made in 6 m lengths, fiber rolls are flexible and can be moulded to match the shape of the existing shoreline. They are typically staked with dormant cuttings and rooted plants that are inserted into slits cut into the rolls. As such, they provide an excellent medium for promoting plant growth (and protection) at water's edge. Fiber rolls should be used in conjunction with other bioengineering techniques and plantings to stabilize the upper banks and ensure a source of regenerative vegetation. The rolls, which can be expensive, are not appropriate for sites exposed to high velocity flows, water level fluctuations or large ice build up.

References: NYDT (2002); USDA (1998, 2002)

Vegetated Geogrids



Alternating layers of live branch cuttings and compacted soil with natural or synthetic geotextile materials wrapped around each soil lift to rebuild and vegetate eroded streambanks.

Application and Effectiveness

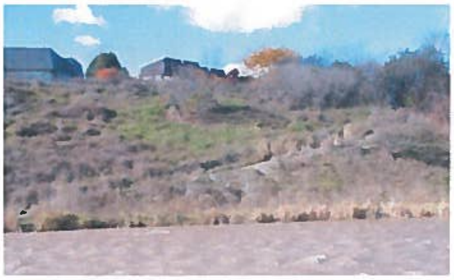
This technique quickly establishes riparian vegetation and produces a newly constructed and well-reinforced slope (upland or streambank), protecting the entire bank (toe to top) from surface erosion, high velocity scour as well as deeper slope instability. The method is used on steep slopes (1H:1V, or steeper) where space is limited. Geogrids are intended for use on small streams (drainage area < 8 km^2) and along outside bends where erosion is a problem. The vegetation captures sediment and promotes the colonization of native species. Vegetated geogrids require a stable foundation and slope stability analyses are recommended. It is a complex and expensive method requiring a team of interdisciplinary professionals.

References: USDA (1998, 2002)

Figure 9.2c Streambank Treatments- Bioengineering

Aquafor Beech Limited

Grass Seeding



Credit River downstream of Creditview Rd.

Establishment of native grass or herbaceous vegetation on stable river banks or slopes

Application and Effectiveness

Grass seeding is one of the first bank treatment alternatives that should be considered. It is simple, effective, low cost and requires no maintenance once the vegetation becomes established. Seeding should occur near the beginning of the growing season (after spring high flows) to ensure sufficient soil moisture for germination and to ensure plants have sufficient time to become established. Problems include rilling and gullying on long or steep slopes and/or where soils exhibit low infiltration capacity.

References: RBSA (1999)

Brush Traps

Credit River, (Upper Credit Watershed)

Vegetative material established on point bars or on the floodplain to trap sediment.

Application and Effectiveness

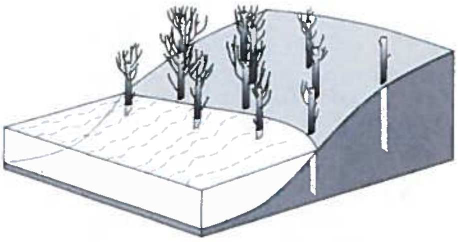
Brush traps are a low cost method of rehabilitating channel banks and improving fish habitat. Brush (e.g. branches) is placed and secured on point bars, on the floodplain or any area where sediment is to be trapped. The purpose of this technique is two-fold: to remove and trap (store) excess fluvial sediment (silt and sand), and to promote the build-up of river the banks along channels that are over-wide. The rate at which material is trapped depends primarily on the sediment transport rate.

References: CVC (2003)

Figure 9.2d Streambank Treatments- Bioengineering

Aquafor Beech Limited

Dormant Post Plantings, Willow Posts



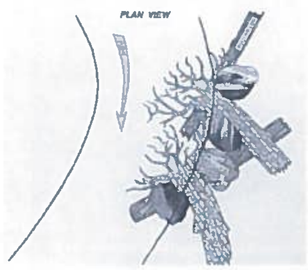
Plantings of cottonwood, willow, or other tree species embedded vertically into streambanks to increase channel roughness, reduce flow velocities near the slope face, and trap sediment.

Application and Effectiveness

Dormant posts are best suited to secure the banks of small, non-gravel bed streams. They should not be used along streams where damage by ice is an issue or if the soil has a high clay content. Willow posts are similar to live stakes but the construction guidelines are more complex and installation is often more expensive if heavy machinery is needed to drill pilot holes.

References: OSRM (2002); USDA (1998, 2002)

Log, Rootwad & Boulder Revetment



Boulders and logs with root masses attached placed in and on streambanks to prevent streambank erosion, trap sediment, and improve habitat diversity.

Application and Effectiveness

This bank treatment is suited to low gradient, meandering streams with substrate no coarser than gravel. It can tolerate high shear stresses, provided the logs are well anchored. The technique provides toe protection but a combination of other bioengineering treatment and vegetative plantings may be required to stabilize the upper bank. The root wads will need to be replaced if vegetative plantings are not used or if they do not survive. Heavy equipment will be required to position root wads into the bank. Submergence of the root wad in a pool will promote longevity.

References: NYDT (2002); USDA (1998, 2002)

Armourstone

Credit River downstream of Eglinton Av.

Large, rectangular blocks of cut stone packed in rows to protect banks from toe erosion and general bank scour. The weight of the stones also serves to enhance slope stability.

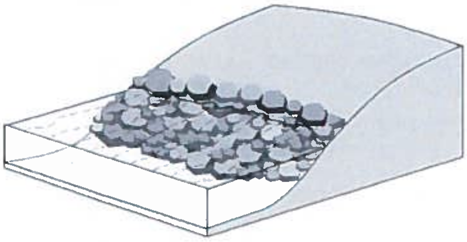
Application and Effectiveness

Armourstone is more durable than riprap. The stones can be stacked into steep, near vertical, walls thus making the technique suitable for sites where space is limited. Armourstone is frequently used for sites with serious erosion and instability issues. The potential for stream bed degradation (downcutting) needs to be assessed prior to installing armourstone to ensure the treatment is not undermined. Installation and material costs are high. This bank treatment was frequently observed along the Credit River.

Figure 9.2e Streambank Treatments- Structural

Aquafor Beech Limited

Stone Toe Protection



A ridge of quarried rock or stream cobble placed at the toe of the streambank as an armour to deflect flow from the bank, stabilize the slope and promote sediment deposition.

Application and Effectiveness

This structural method is applied along streams where banks are being undermined by toe scour, and where vegetation cannot be used. The stone prevents the removal of the failed bank material that collects at the base of the slope, thus promoting vegetation growth and stabilization. Rock toes should be used with other soil bioengineering systems and vegetative plantings to augment stability of upper bank. The method will address local erosion problems but should be used sparingly. If used excessively, the increased amount of stone in the watercourse will decrease resistance, resulting in increased flow velocities and a heightened potential for erosion problems elsewhere. Toe protection is ineffective if the stream is downcutting.

References: OSRM (2002); USDA (1998, 2002)

Rock Riprap

Credit River at QEW

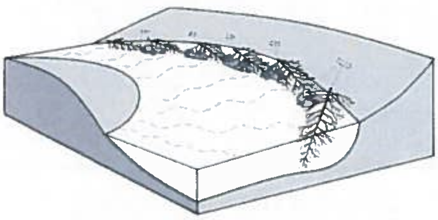
A blanket of appropriately sized stones extending from the toe of slope to a height needed for long term durability.

Application and Effectiveness

Riprap is appropriate where long term durability is needed, design discharge is high, there is a significant threat to life or high-valued property, or where there is no practical way to incorporate vegetation or "softer" bioengineering solutions into the treatment. Riprap is low maintenance, shade tolerant and can protect the entire bank (toe to upper portion). The appearance and function of riprap can be softened considerably when augmented with vegetation (see Joint Plantings). Riprap should not be used at elevations where soil bioengineering methods will suffice.

References: MTO (1995); NYDT (2002); OSRM (2002); USDA (1998, 2002)

Tree Revetment



A row of interconnected trees attached to the toe of the streambank or to deadmen in the streambank to reduce flow velocities along eroding streambanks, trap sediment, and provide a substrate for plant establishment and erosion control.

Application and Effectiveness

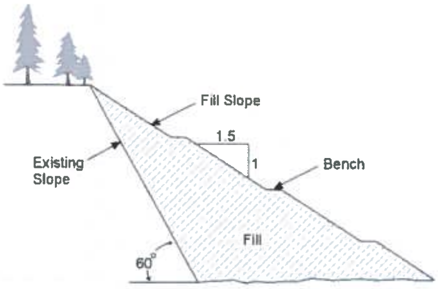
Tree revetments provide temporary protection from general bank scour near the base of the bank slope. There are numerous designs, all of which typically involve the anchoring of trees to boulders or stakes located on the bank or within the channel. They work best on banks less than 3.5 m high and where stream velocities do not exceed 1.8 m/s. Their function is transitory to allow banks time to stabilize and become vegetated. Materials are inexpensive, if locally obtainable, and should be used in conjunction with other appropriate soil bioengineering and vegetative plantings. In Ontario, *Thuja occidentalis* (cedar) is preferred because of its longevity. Disadvantages include safety hazards (from anchoring system), limited life, susceptibility to damage by ice, and the potential to become dislodged and damage downstream structures, such as bridges.

References: NYDT (2002); USDA (1998, 2002); MDC (2004); MNR (1995)

Figure 9.2f Streambank Treatments- Structural

Aquafor Beech Limited

Valley Wall Treatment: Stable Slope Lines



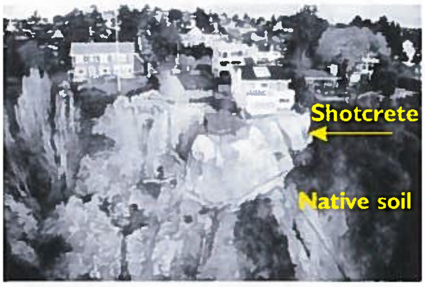
The regrading of an over steepened slope by cutting at the top and/or filling at the bottom until achieving a stable profile.

Application and Effectiveness

This treatment is sometimes undertaken to protect eroding valley walls where structures at the top are at risk. Depending on the slope height and the amount of fill required, this treatment may also involve the relocation of the channel. The regraded slope is benched and vegetated with a variety of tree species and understory vegetation. This technique has the advantage of permanently stabilizing the entire slope and removing the stress that caused the instability. The regraded slope has a natural appearance that generally will not require armourstone or other hard structures that need to be maintained. The chief disadvantages are the considerable cost and the temporary disruption to the channel, if relocated.

References: Gray and Sotir (1996)

Valley Wall Treatment: Shotcrete Application



Ocean bluff, Washington State

Concrete-like material sprayed onto surfaces as a liquid that later hardens to provide a resistant, durable coating that reduces erosion.

Application and Effectiveness

Shotcrete has been used to prevent surface erosion and headward migration eroding bluffs. It is a relatively simple approach which may be applied to slow the retreat of eroding shale/limestone bluffs without undertaking extensive stabilization works. To be effective, drainage must be directed away from the base of the cover so that the shotcrete will not be undermined by the surface erosion. The drainage must also be continually maintained in order to be effective. If material behind the shotcrete is washed away, it will fail.

Reference: Gerstel (et al) 1997

Figure 9.2g Streambank Treatments- Structural

Aquafor Beech Limited

Boulder Clusters

Credit River upstream of Dundas St.

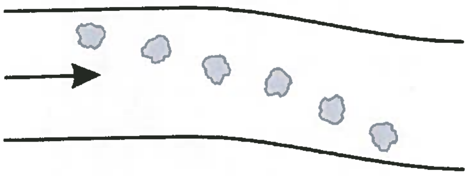
Groups of boulders placed in the base flow channel to provide cover, create scour holes or areas of reduced velocity.

Application and Effectiveness

This is a low cost, alternative stream rehabilitation structure that creates hydraulic diversity. The boulders typically consist of quarried, angular limestone placed near the centre of the channel and function best when stream flow velocities are high (> 0.6 m/s). Boulders should not be used if the stream's bed sediment is mobile.

References: CRCCH (2000); USDA (2002);

Turning Stones



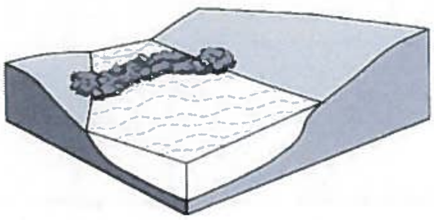
A series of boulders placed diagonally, from one bank to the other, with the purpose of redirecting the flow.

Application and Effectiveness

Turning stones can reduce the potential of erosion along a bank by redirecting the impacting flows away from the bank. They would be effective in wide, shallow streams with cobble or rubble beds, such as the Credit River. They also diversify flow velocities and habitat. Turning stones are not recommended in sand bed (and finer) streams as the boulders tend to get buried and they are not suitable in channels that are downcutting or where sediment is accumulating.

References: Chang (1998)

Weirs and Sills



Log, boulder or quarried stone structures placed across the entire width of the channel and anchored to the streambank and/or bed to create pool habitat, control bed erosion or collect and retain gravel.

Application and Effectiveness

There are many variations of weirs and sills with the specific design being dependant on channel morphology and the type of channel modification that is desired. Overall, these structures create pool habitat by redirecting and concentrating flow, usually into the center of the channel. As a result, the potential for erosion along the channel banks will be proportionally reduced. These structures are not recommended for bedrock channels or in cobble/gravel since the habitat they create should already exist. Undermining may occur in sand bed streams and there is a risk that the structures may become barriers to fish migration.

References USDA (1998, 2002)

Figure 9.2h In-Stream Treatments

Aquafor Beech Limited

Spurs, Deflectors, Barbs Constrictors, Jetties

Credit River upstream of Dundas St.

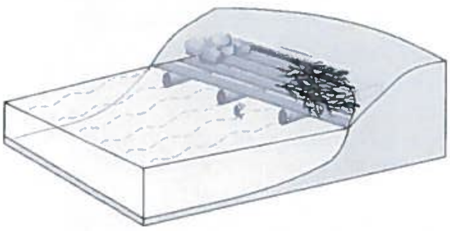
Structures made from a variety of materials that protrude from either streambank but do not extend entirely across a channel.

Application and Effectiveness

There are many different designs but all have the same basic function: to redirect flows away from the streambank, and to scour pools by constricting the channel and accelerating flow. Spurs, deflectors and barbs are used along bends whereas jetties are intended for straight sections of channel. Each design can be used to protect stream banks as well (by deflecting damaging flows). They are often built in arrays of three or more and made of logs, rocks, riprap, or backfill. Multiple deflectors need to be spaced in accordance with the thalweg meander wavelength. These designs may transfer energy (and erosion potential) downstream unless the designs are hydraulically rough. They function best in moderately confined streams and in meandering channels, such as the Credit River where several types of spurs and deflectors have been built. These structures should not be used along high gradient streams or where the substrate is unstable.

References: USDA (1998, 2002)

Shelters, Lunkers



Logs, brush, and rock structures installed in the lower portion of streambanks to prevent streambank erosion, enhance fish habitat, create food sources, and provide shelter.

Application and Effectiveness

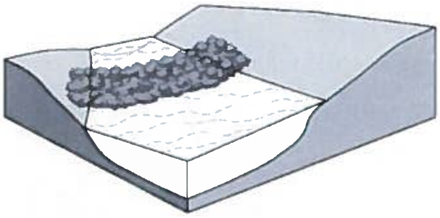
These structures are best suited to low gradient stream bends where pool habitat already exists and additional cover and food production are desired. Their function and durability will be enhanced by incorporating with other bioengineering and vegetative plantings. Shelters are best suited to meandering bedrock and cobble/gravel channels. They should not be used in high bedload streams or where there is severe erosion of the bed or banks unless combined with other types of protection. Heavy equipment is usually required for installation.

References: USDA (2002)

Figure 9.2i In-Stream Treatments

Aquafor Beech Limited

Grade Controls



Rock, wood, earth, and other material structures placed across the channel and anchored to the streambank to reduce provide a "hard point" in the streambed that reduces channel gradient and resists downcutting.

Application and Effectiveness

These structures stabilize the streambed, which is often an important consideration in the success of many bank treatment designs. Grade controls stop headcutting in degrading channels and they can be used to rebuild a channel to a higher elevation. They offer varied habitat, especially when downstream pools are excavated, and can be designed to permit fish passage. Cross vanes and W weirs are two forms of grade control. Problems include increase downcutting downstream of the structure, as well as upstream bank migration if siltation becomes an issue.

References: USDA (2002)

Constructed Riffles

Credit River near the Queensway

Riffles extend across the bankfull channel and are accumulations of coarse sediment that is stable during low flow but may move episodically when flows are higher. Riffles diversify flow and habitat and, in some cases, provide grade control.

Application and Effectiveness

Riffles are common structural elements found in most alluvial channels. Riffles are locally steep and somewhat narrower than the rest of the channel, resulting in locally higher velocities which flush fine sediment, thus leaving behind coarser material. The shape of the riffle increases channel roughness and moderates flow velocity throughout the channel as a whole, thus enhancing stability. Riffles tend to break up secondary currents that contribute to bank erosion, thus banks along riffles tend to be more stable than those along pools or bends. When incorporating riffles into an existing stream or a new engineered channel, parameters such as riffle width, depth and substrate size must accommodate the design flows for the watercourse.

References: USDA (2002)

Tree Cover/Woody Debris

Credit River downstream of Derry Rd.

Felled trees placed along the streambank to provide overhead cover, substrate suitable for benthic organisms, stream current deflection, scouring, and deposition.

Application and Effectiveness

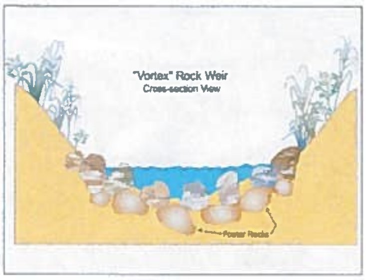
The purpose of tree cover is to improve aquatic habitat and to stabilize mobile stream beds by trapping sediment. A suitable anchoring system is necessary (logs are often cabled to stone) and the trees should not severely impede flow, which may cause erosion or flooding concerns. They are susceptible to ice damage and require frequent maintenance.

Reference: USDA (2002)

Figure 9.2j In-Stream Treatments

Aquafor Beech Limited

Vortex Rock Weir

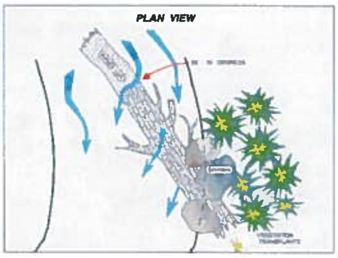


Large rocks or boulders placed on the channel bed to redirect stream energy away from the banks while enhancing habitat. This weir points upstream when viewed in planform.

Application and Effectiveness

In addition to maintaining bank stability, these structures can increase stream depth by changing width to depth ratio, increase sediment transport capacity, provide natural gravel sorting on the upwelling side of the structure (improves spawning habitat) and can provide grade control tp prevent downcutting. Generally suitable for smaller streams (use W weirs in streams 12 m wide). Not suitable for low width to depth ratios or bedrock streams which do not permit placed boulders to stabilize.

Log Spur Bank Feature

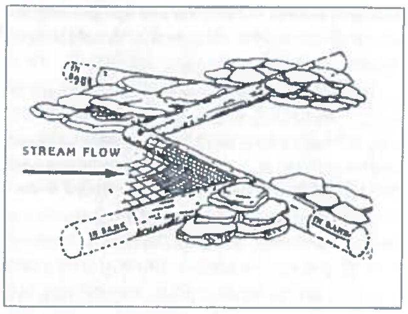


This feature protects stream banks by incorporating a combination logs, boulders and vegetation used in-stream and on the banks.

Application and Effectiveness

In this variation of the spur, the instream structure points upstream into the flow. These structures are typically used along bends to break up secondary circulation cells that may induce bank erosion and near bank erosion. They also provide varied habitat/cover and can hold water during higher flows. Bank stabilization and transplants are recommended. This technique is not recommended where banks are steep or in E-type channels where too much energy is deflected to the opposite bank.

Check Dam



Small dams constructed of logs, rocks or other materials designed to form a plunge pool below the structure.

Application and Effectiveness

There are generally two types of check dams: low stage (<1/3 bankfull stage) and medium stage (<3/4 bankfull stage). There are a variety of forms including straight log weirs, diagonal log weirs, K-dams, wedge dams and over pour ramps. The structures are placed on long shallow riffles along straight reaches and meanders. Generally not suitable for bedrock streams where pool formation is limited. Often must be accompanied by bank stabilization.

Figure 9.2k In-Stream Treatments

Aquafor Beech Limited

'rougher' treatments which aid in dissipating flow energy or prevent downstream transfer of energy.

Table 9.4. Examples of different options available for reach and site level restoration. The treatments types are illustrated and described in more detail on **Figures 9.2a – k**. Note that, during the detailed design stage, the preferred treatment type will be identified and other options not listed here may also be considered.

Approach	Purpose	Treatment types
1. Modification or Removal of In-Channel Structures	▪ Promote fish passage ▪ Alleviate flooding ▪ Alleviate excessive erosion	Modify or remove existing treatments
2. Maintenance of Existing Works	▪ Prolong durability of existing treatments	Repair existing treatments if demonstrated to be effective
3. Bank toe protection	▪ Protect lower bank from scour ▪ Safeguard upper bank treatments or structures ▪ Guard against ice/debris damage	**Bank (Bioengineering)** Crib walls, Coir rolls, vegetated geogrids **Bank (Structural)** Stone, tree revetments, dormant post plantings, revetments (S-5), Armourstone, Gabions **Instream** Turning stones, weirs/sills, spurs/deflectors/barbs, shelters/lunkers, grade controls, constructed riffles
4. Bank face protection	▪ Reduce overland erosion ▪ Decrease erosive force ▪ Increase resistance ▪ Improve habitat ▪ Improve water quality ▪ Reduce ice/debris damage	**Bank (Bioengineering)** Branch packing, live stakes, live facines, crib walls, brush mattresses/layering, bank shaping and planting, joint plantings, vegetated geogrids, grass seeding **Bank (Structural)** Rock riprap (see joint plantings), dormant post plantings, armourstone, rock/vegetated gabions
5. Restoration of Vegetative Cover	▪ Reduce overland erosion ▪ Decrease erosive force ▪ Increase resistance ▪ Improve habitat ▪ Improve water quality ▪ Promote sedimentation ▪ De-saturate soil ▪ Improve aesthetics Reduce ice/debris damage	**Bank (Bioengineering)** Branch packing, live stakes, live facines, crib walls, brush mattresses/layering, bank shaping and planting, joint plantings, coir rolls, vegetated geogrids, grass seeding **Bank (Structural)** Dormant post plantings, rock/vegetated gabions

Approach	Purpose	Treatment types
6. Stabilization – banks, valley wall,	▪ Protect structures and property ▪ Reduce excessive sediment loading ▪ Public safety	**Bank (Bioengineering)** Vegetated geogrids **Bank (Structural)** Armourstone, rock/vegetated gabions **Instream** Spurs/deflectors/barbs, grade controls, constructed riffles
7a. Induce Instream Sediment Deposition	▪ Improve water quality ▪ Improve aquatic habitat ▪ Reduce channel width (if over-wide)	**Bank (Structural)** Tree revetments **Instream** Weirs and sills, tree cover
7b. Induce Upland Sediment Deposition	▪ Reduce amount of fines entering watercourse ▪ Improve aquatic habitat ▪ Improve water quality	**Bank (Bioengineering)** Branch packing, live stakes, live facines, crib walls, brush mattresses/layering, bank shaping and planting, joint plantings, coir rolls, vegetated geogrids, grass seeding **Bank (Structural)** Dormant post plantings
8. Removal of Material in Depositional Areas	▪ Alleviate stress on adjacent banks ▪ Create aquatic habitat	**Bank (Bioengineering)** **Bank (Structural)** **Instream (to induce scour)** Weirs and sills, spurs/deflectors/barbs, constructed riffles
9. In-stream flow deflection	▪ Protect banks or valley wall ▪ Flush fine sediment ▪ Create pool habitat ▪ Reduce ice/debris damage	**Bank (Bioengineering)** **Bank (Structural)** **Instream** Turning stones, weirs and sills, spurs/deflectors/barbs, tree cover
10. In-stream energy dissipation	▪ Reduce erosion potential ▪ Improve aquatic habitat	**Bank (Bioengineering)** **Bank (Structural)** Dormant post plantings, log/rootwad/boulder revetments **Instream** Boulder clusters, turning stones, weirs and sills, spurs/deflectors/barbs, tree cover, grade control, constructed riffles
11. In-stream aquatic habitat	▪ Improve aquatic habitat	**Bank (Bioengineering)**

Approach	Purpose	Treatment types
enhancement	▪ Protect bank toe	**Bank (Structural)** log/rootwad/boulder revetments **Instream** Boulder clusters, turning stones, weirs and sills, spurs/deflectors/barbs, shelters/lunkers, tree cover, grade controls, constructed riffles
12. Realignment	▪ Increase amount of land available for development ▪ Naturalize previously straightened/modified channels	Treatments will vary depending on geology, hydrology, hydraulics and slope stability conditions
13. Reconstruction Using 'hardened natural' Approach	▪ Protect areas experiencing serious slope stability concerns and structures or properties that are at risk	**Bank (Bioengineering)** Crib walls, vegetated geogrids **Bank (Structural)** Stone riprap with joint plantings, Armourstone, rock/vegetated gabions **Instream** Grade control
14. Reconstruction Using 'soft' Approach	▪ Limit excessive erosion ▪ Improve habitat ▪ Improve water quality ▪ Augment aesthetics	**Bank (Bioengineering)** Branch packing, live stakes, live facines, brush mattresses/layering, bank shaping and planting, joint plantings, coir rolls, grass seeding **Bank (Structural)** **Instream** Shelters/lunkers, tree cover, constructed riffles
15. Monitoring	▪ Evaluate the effectiveness and appropriateness of existing treatments	N/A

9.3 Markham Restoration Goals and Objectives

Prior to selecting a preferred alternative for the priority erosion sites, it is important to clearly define restoration goals and objectives. Each of the alternatives identified in the short list can then be evaluated against the restoration objectives to carefully select the most appropriate mitigative option(s).

The primary goal of the erosion restoration works is to eliminate or reduce risk to public health and safety. In conjunction, stabilization of channels and enhancement of channel processes and aquatic habitat are corresponding goals. The objectives keep in mind those factors that are currently affecting the system, creating a risk, and appropriate solutions for improvement. These solutions must meet the expectations of residents and the people managing the resource on their behalf.

Restoration objectives that have been identified for watercourses situated within the Town of Markham are as follows:

1. provide erosion protection that is compatible with the natural tendencies of the creek (i.e., maintain natural river function)
2. low future maintenance
3. accommodate long response time associated with past impacts
4. enable adaptive management
5. maintain or reduce the need for erosion control
6. provide environmental enhancement wherever possible
7. maintain connection of channel for seepage in banks and valley walls
8. be visually 'natural' in appearance
9. minimize environmental impacts during and post construction
10. decrease property loss
11. minimize capital and maintenance costs

9.4 Selection of the Preferred Alternatives

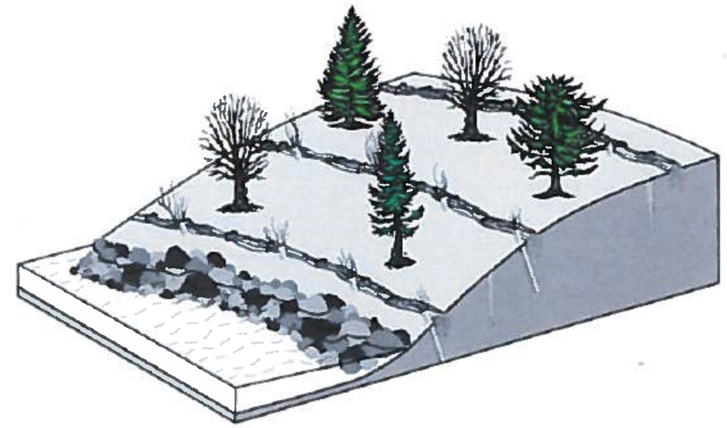
Selection of a short list of preferred alternatives for each of the priority erosion sites was completed through an evaluation process similar to that used in a class environmental assessment. The various alternative groupings (e.g., bank treatment, realignment etc., see **Table 9.4**) were assessed using a set of criteria developed to ensure that the preferred alternative would satisfy as many of the restoration objectives as possible. The criteria considered overall river processes, characteristics, and requirements to maintain natural channel functions to the extent that this was discernable from the background investigations). Examples of criteria used to evaluate and select the preferred alternatives were as follows:

a) minimize risk to infrastructure;
b) decrease property loss
c) effectiveness at reducing existing and future erosion risk;
d) maintain continuity of sediment supply and conveyance;
e) promote long term stability and sustainability;
f) enhanced stability from vegetation/terrestrial habitat perspective;
g) enhanced aquatic habitat value;
h) adaptable to accommodate relevant watershed and reach level processes (e.g., migration, enlargement);
i) continuity of existing and anticipated future channel adjustments without compromising treatment sustainability;

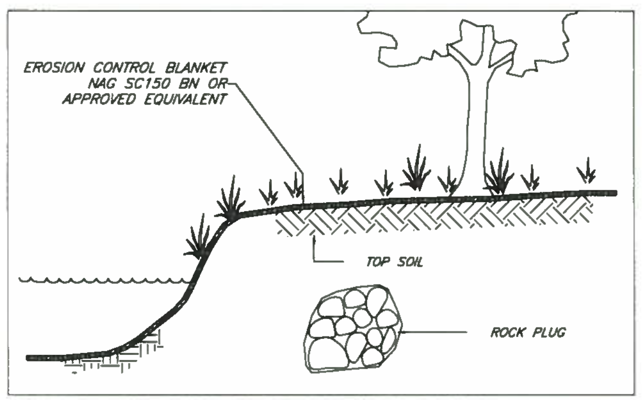
Application of the evaluation criteria enabled a short list of alternatives to be identified for each area of erosion concern. Through completion of the field reconnaissance along Markham's watercourses, the success of varying treatment types was observed and also used as a guide for defining a short list of potential solutions (e.g., placement of armourstone along both sides of the cross-section. While this treatment is effective in controlling channel position, it is likely that softer approaches could have been used). General recommendations for treatment of the erosion priority sites is shown on **Figure 9.3** as an example and in **Appendix E**

When integration of more than one approach is possible to reduce environmental impact or enhance an environmental component (e.g., regrade slope and provide toe protection to minimize height of protection), then this should be considered. Final selection of restoration approach will need to be determined at the detailed design stage upon further detailed field assessments of erosion cause and risk.

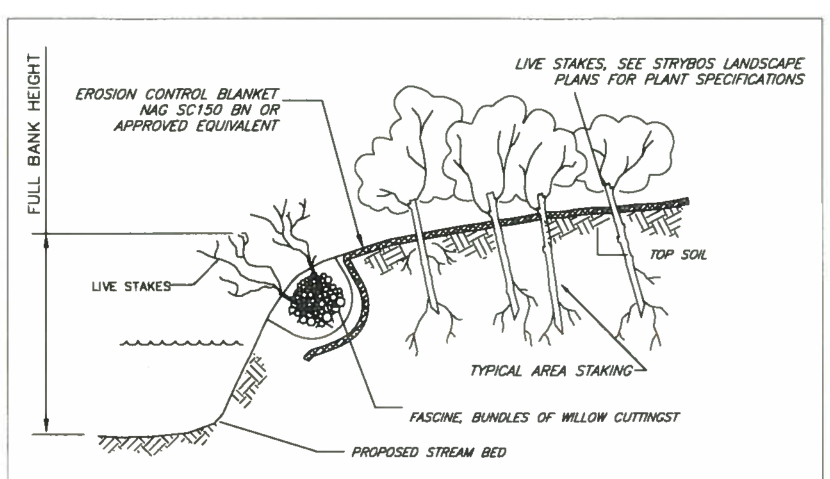
An implementation strategy for the Restoration Plan is presented in **Chapter 10**. In areas where opportunities for riparian or aquatic enhancements exist, or removal of garbage, then these are also identified.



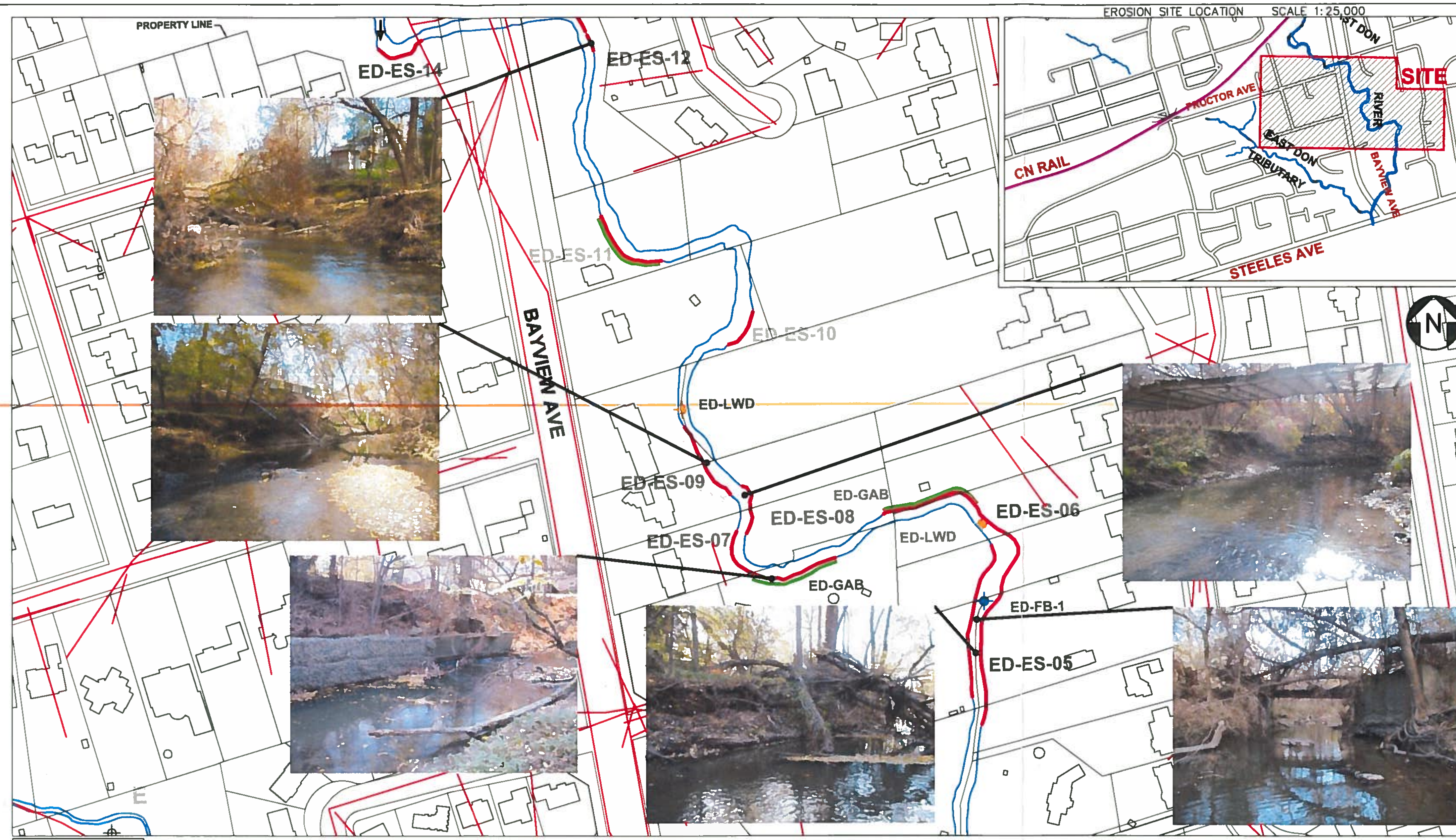
ROCK TOE PROTECTION AND FASCINES



STONE TOE AND VEGETATION COVER



FASCINE VEGETATION COVER



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SCALE IN METRES
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CONCEPTUAL RESTORATION

1. REMOVE CONCRETE DEBRIS
2. REMOVE/REPAIR/REPLACE EXISTING BANK TOE PROTECTION ONLY AS NECESSARY
3. EXAMINE FISH BARRIER AND DETERMINE IF REMEDIATION IS NECESSARY TO PROMOTE FISH PASSAGE
4. SET STORMWATER OUTFALL BACK FROM CHANNEL
5. REMOVE BRIDGE CROSSING (SITE ES-06) AND REPLACE ONLY IF NECESSARY WITH A SUFFICIENTLY WIDE SPAN TO AVOID CREATING A FLOW CONSTRICTION
6. ADDRESS LARGE WOODY DEBRIS ACCUMULATIONS ONLY IF THIS POSES A RISK, OTHERWISE LEAVE AS A CONTRIBUTION TO AQUATIC HABITAT
7. ADDRESS EROSION ONLY WHERE IT POSES A RISK, OTHERWISE MAINTAIN AS A SEDIMENT SOURCE
8. STABILIZE SLOPES
   - 8.1 REGRADE OR REFILL BANKS AND VEGETATE
   - 8.2 BIOENGINEER SLOPE TOE (E.G. FASCINES)
   - 8.3 BURY ROCK TOE PROTECTION WHERE REQUIRED TO PROTECT INFRASTRUCTURE
9. ENHANCE RIPARIAN VEGETATION WITH TREES AND SHRUBS WHERE POSSIBLE

LEGEND

(red line)	PRIORITY EROSION SITE
EDT-ES-#	PRIORITY EROSION SITE NUMBER
E	EROSION (NON PRIORITY)
(green line)	GABION
(blue symbol)	FISH BARRIER
(orange symbol)	LARGE WOODY DEBRIS
(line)	PROPERTY LINE
(red line)	SANITARY SEWER LINE
(orange line)	STORM SEWER LINE
(symbol)	BUILDING

PROJECT:
TOWN OF MARKHAM
EROSION RESTORATION
IMPLEMENTATION PLAN

MARKHAM

Aquafor Beech Limited

WATERCOURSE: East Don River

EROSION SITE: ED-ES-05-09&12

REACH: ED-1 FIGURE: 9.3

AQUAFOR PROJECT NO.: 64550

10.0 IMPLEMENTATION OF THE RECOMMENDED RESTORATION PLAN

10.1 General

The Town of Markham is drained by nineteen watercourses, which includes tributaries that flow into the East Don River and the Rouge River. Both of these rivers are important resources of southern Ontario and the focus of specialized study by regulatory agencies and municipalities through which they flow. Development within the Town of Markham predates 1900 and has increased noticeably in the last 25 years. To establish baseline conditions and to enable a detection of channel changes, the Toronto and Region Conservation authority has established geomorphic monitoring sites within all watershed that are under its jurisdiction.

Impacts of urbanization on the natural processes that occur within a watershed are generally understood to result in alterations of the receiving watercourse. Specific impacts include hydrology, erosion, sediment transport, and water quality. Each of these impacts can create a risk to public health and safety and affects the quality of terrestrial and aquatic habitat. The Town of Markham has recognized these impacts and, like many other municipalities imposes development charges against land to pay for increased capital costs required due to increased needs for services arising from development through its Development Charges by-law.

Included in the Development Charges is the Allocation of Costs for the purpose of addressing stream conditions that would be exacerbated by development (i.e., primarily through change in hydrologic regime). The Markham Erosion Restoration Implementation Plan was undertaken to identify areas of erosion concern within the Town and to develop a plan for addressing erosion with the Development Charges that have been collected to date. The focus of the study was to identify erosion sites, evaluate risk to public health and safety, to identify alternatives for restoration and to prepare preliminary cost estimates.

A Master Planning approach may be followed for studies where it is expected that a series of measures which are distributed geographically throughout the study area will be implemented over an extended period of time. This approach explicitly recognizes that there are real benefits in terms of better planning when long range holistic studies are undertaken over logical planning units, such as a subwatershed or municipality. This long range planning approach enables the municipality to identify opportunities and be proactive in addressing issues before they become a problem. It also allows the municipality to implement individual works which collectively become part of a larger management system.

Each of the chapters that have been presented within this study outlines the steps that were undertaken in fulfillment of the Environmental Assessment process. An overview of the Class Environmental Assessment process and clear identification of the study goals and objectives was provided in **Chapter 1**. Each of the subsequent chapters provided details with respect to methods, results and analyses to address the goals and objectives outlined in **Chapter 1**.

The first goal of the Markham Erosion Restoration Implementation Plan was to complete a comprehensive inventory of Markham's watercourses that identified erosion sites which could pose a risk to public health and safety in addition to sites requiring maintenance and potential fish barriers. **Chapter 2** outlined the general problems associated with urbanization and observed impacts within the Town of Markham including risks to subsurface infrastructure, manholes in channel, exacerbation of erosion rates, erosion of private property, and outflanking of weirs and erosion restoration structures. **Chapter 3** provided a context for the Town of Markham with respect to study area characteristics that influence channel form and function with a focus on geology, land use and development history in addition to identification of aquatic and terrestrial resources.

An integral component of a Class Environmental Assessment is the public consultation process in which the public is invited to actively participate in the study process. In this study, involvement of regulatory agencies was undertaken early on in the process to solicit input, especially with respect to identification and evaluation of erosion risks to public health and safety. Through a Public Meeting, the problems and issues identified in the background review phase of the study were presented. The public was invited to comment on the materials presented at the meeting and to provide their perspective with respect to erosion occurrence within the Town and alternatives for restoration. Results from the Public Consultation are presented in **Chapter 4** and **Appendix A**.

Identification of sites that may pose a risk to public health and safety, and which may be recommended for restoration requires understanding of the channel form, function, and processes. **Chapter 5** provides an overview of the controlling and modifying influences of channel form and typical urban impacts on receiving watercourses. Modes of channel change and response to urbanization were also explained to provide a basis for understanding erosion processes that are occurring along Markham's watercourses.

In fulfillment of the goals and objectives of this study, a key component was the erosion inventory. Through a reconnaissance level field walk along all nineteen watercourses, which included approximately 105 km of channel, a detailed inventory of erosion sites, potential fish barriers, and areas requiring maintenance was mapped. A photographic inventory and documentation of site conditions was compiled to accompany the mapping. During the field walk, areas of previous erosion restoration works (e.g., gabions, rip-rap, armourstone) were also mapped. Each of the components of the Erosion Inventory were outlined in **Chapter 6**. Observations with respect to local controls and modifying influences, and channel adjustment processes that appeared to be dominant along the watercourses were also noted and used as background materials for subsequent chapters of the report.

Insight into Markham watercourse conditions was achieved by reviewing results of the background investigations and the field inventory in **Chapter 7**. Through this review, it became apparent that there are numerous erosion sites situated along Markham's watercourses. While erosion is a natural and necessary process, some of the erosion rates appear to have been exacerbated due to urban development and some are clearly a result of altered flow regimes due to upstream changes in land use (i.e., urban). In addition to general impacts from land use alteration in the watersheds, human activity has also led directly to impacts on watercourse stability (e.g., removal of riparian vegetation, placement of dams and weirs across channel, etc.). All observations of channel conditions were illustrated on profiles of the watercourses to provide a spatial context that is intended to guide the selection of a short list of restoration options. Through this, it became apparent that some watercourses are still in a state of adjustment to changes in land use that occurred during the 1800s; in addition to more recent urbanization.

Since erosion is a natural and necessary process that occurs along all watercourses, it is important that this continues and is not unnecessarily impeded through restoration works. A prioritization scheme was developed, with input from the Toronto and Region Conservation Authority to identify those erosion sites that pose a risk to public health and safety. This scheme is presented in **Chapter 8**. Application of this prioritization methodology enabled identification of those sites which pose the greatest risk and those which would have greatest benefit of reducing risk to public health and safety from restoration.

Following a Class Environmental Assessment process, a long list of alternatives was developed that might be used to mitigate the effects of urbanization on watercourses at the watershed scale, reach, and site level. The most effective approaches will be based on sound watershed planning of future developments that seek to minimize and mitigate alteration of the hydrologic regime in receiving watercourses. Incorporation of various source, conveyance, and end-of-pipe solutions into development plans will reduce the impact to public health and safety by limiting impact to equilibrium form and natural rates of channel change.

Establishment of clear objectives for rehabilitating priority erosion sites enabled a suite of criteria to be developed for the purpose of evaluating alternatives (**Chapter 9**) that are suitable for mitigating risk to public health and safety from within the channel corridor. Through completion of the assessment, a short list of alternatives was identified that could be effectively used to mitigate the observed erosion areas. Background materials presented in this report and site specific information gathered during the detailed design phase would inform the selection of a final preferred alternative to address the erosion concerns. The selection of an alternative is intended not only to reduce or eliminate risk to public health and safety, but also to promote a continuity of natural channel form, function and processes by taking into account site specific controlling and modifying influences and characteristics (e.g., anticipated future changes in flow regime due to upstream urbanization, typical channel processes for setting (including geology, riparian vegetation, base level controls).

The intent of this chapter is to present the steps required to implement the recommended restoration plan for the purpose of addressing the erosion concerns identified within this study. The restoration plan identifies the prioritized erosion sites and the restoration recommendations that were presented in **Chapter 9**. A plan that promotes the successful implementation of the recommended restoration plan is presented in this chapter. Watercourses situated within the Town of Markham that would benefit from further detailed study, in order to develop a comprehensive management strategy and/or restoration plan to mitigate urban impacts are also identified in this chapter.

10.2 Watershed Considerations and Additional Study

It is well documented that urbanization of watersheds alters the hydrologic regime of the receiving watercourses. Channels adjust to altered flow regimes by increasing their capacity through enlargement and making corresponding changes to planform configuration. Exacerbation of existing erosion rates is not uncommon which can increase risk to public health and safety. While this study has focused on identifying those sites that pose more immediate risks to public health and safety, it must be recognized that good watershed planning especially within urbanizing areas will minimize future impacts to the watercourses and therefore reduce risk to public health and safety. In addition to contemporary pre-post flood peak control and Distributed Runoff Control, minimizing the volume of water that is delivered to receiving watercourses will benefit the receiving watercourse. Maintaining or, when possible, enhancing the drainage density through a swale network, will similarly benefit the receiving watercourse by attenuating the hydrograph and promoting infiltration. Several strategies for watershed level stormwater management are provided in **Chapter 9**.

Through the field inventory and review of background materials, it became apparent that several watersheds may benefit from further study and action at the watershed level, to address systemic erosion concerns. Similarly, several watercourses were identified that appeared to be sensitive or highly altered and are thus expected to continue large scale changes in channel form – some of this has started already. These special study, or special interest watercourses are identified under various categories below:

<u>Modification of flow regime</u>
Initiation of programs across the city that encourage site-level stormwater retrofits (e.g., disconnect downspouts, biofilters) and swale drainage will be beneficial in reducing the volume and rate of urban runoff delivery to the watercourse. Action taken across the city, and especially in older developed neighbourhoods of watercourses which currently exhibited erosion sites with risk to public health and safety will provide immediate benefit. Watercourses that would benefit from watershed scale stormwater reduction include:

- East Don River
- Pomona Mills Creek (note: study is currently underway)
- German Mills Creek
- German Mills Creek Tributary
- Robinson Creek
- Mount Joy Creek

The East Don River, German Mills Creek and their tributaries receive significant drainage from upstream municipalities (e.g., Town of Richmond Hill, City of Vaughan). Mitigation of the flow regime of these watercourses through the Town of Markham will require action on the part of the neighbouring municipalities.

Sensitive watercourses

During the course of the field inventory, several watercourses were identified as sensitive to change, both from historic landuse changes (e.g., European settlement) and more recent urbanization. Degradation of aquatic habitat has occurred in these channels:

- Burndenet Creek – substantial evidence of floodplain migration and incision, resulting in terraced downstream of 16th Avenue; very active meander migration processes upstream of Hwy 7
- Morningside Creek Tributary – substantial evidence of widening downstream of stormwater management pond
- Carlton Creek – evidence of aggradation in channel

Highly altered/modified watercourses

Several watercourses have, historically, been significantly impacted by human activity. Channel works completed at the time are now in a state of failure and compromise aquatic habitat. Wide scale study and restoration would benefit the following watercourses:

- Pomona Mills Creek – multiple weirs, significant alteration of channel form, significant introduction of rip-rap materials into creek
- Mount Joy Creek – loss of natural channel form and function due to presence of geogrid bed protection; piping of headwater section of creek underground
- Tributary 1 – agricultural land use has enabled cattle access to watercourse
- Milne Creek – modified within private property; downstream actively eroding within wooded area.

Actively migrating channels

A few watercourses were identified as migrating actively across their floodplains within the watercourse corridor. While these adjustments do not pose an immediate risk to public health and safety, suitable lateral migration zones should be considered given any future development in or around the corridor. Appropriate setbacks for infrastructure and property should be determined to avoid future erosion risks. Active lateral migration was noted on the following watercourses:

- Beaver Creek – downstream reaches adjacent to Hwy 407
- Rouge River – particularly between Hwy 7 and Kennedy Road
- Burndenet Creek – upstream of Hwy 7
- Little Rouge Creek – upstream of Reesor Road

10.3 General Channel Enhancement Opportunities

There are various opportunities to enhance conditions along the Town's watercourses through routine maintenance (**Table 10.1**). These were identified in **Chapter 7** and are repeated here as they can be implemented in conjunction with maintenance activity.

Table 10.1. Potential opportunities associated with maintenance of previously installed in-channel erosion control

Issue	Opportunity
Rip-Rap	Few sections of rock lining have incorporated any vegetation. Placement of live stakes or plugs within the rip-rap could contribute to stabilization of bank materials while enhancing terrestrial and aquatic habitat and increasing aesthetic appeal. See **Chapter 9** for a range of restoration options.
Gabions	Many gabions are towards the end of their life span, as evidenced by extensive corrosion of the wire baskets and loss of rock content. During routine maintenance, consideration should be given for replacing the gabions with softer, but equally effective solutions that promote stability, enhance terrestrial and aquatic habitat, and increase aesthetic value. See **Chapter 9** for a range of restoration options.
Armourstone	Where armourstone was previously placed, modification to cross-sections may be necessary to ensure that cross-sectional capacity is sufficient for the existing and anticipated future flow regime that is to be conveyed through the watercourse.
Landscaping	Many sections of Markham's watercourses flowed directly through, or adjacent to, private property. Landscaping of the properties resulted in a loss of riparian vegetation or decreased quality with respect to benefits to banks.
Riparian Vegetation	Vegetation exerts a substantial influence on channel form and stability as well as contributing to aquatic habitat, terrestrial habitat and other environmental benefits. Enhancement of vegetation along the drainage network is considered to be beneficial (including backyard swales)
Stormwater management	Source control to reduce the volume of water that enters the stormwater drainage network is desirable and can be achieved through landowner co-operation. See **Chapter 9** for further details.

Further opportunities for works that can occur along specific watercourses, through public volunteer groups or with initiatives by other agencies have been identified in **Chapter 7**, and specifically in **Table 7.5**. While the table is not repeated here, opportunities identified within **Table 7.5** includes:

- Removal of urban debris (garbage bags, refrigerator etc.)

- Removal of concrete debris from within channel
- Restoring riparian zones in areas where this has been removed by private landowners
- Replacing crossing structures that create a flow constriction

10.4 Proposed Erosion Restoration Measures

There are numerous approaches that can be used to address reach level instability and specific erosion concerns. These approaches were described in Chapter 7 and should be used in the context of understanding local and reach level channel processes. The information that was available for this study was used to develop an implementation plan. The implementation plan is presented in **Table 10.2**. The table provides a summary of the information required to successfully implement the proposed measures. Further details are provided in the sections below. For each proposed measure, the following is provided:

- Project category and priority
- Project number
- Location
- Action
- Measure
- Habitat Class
- Class Environmental Schedule
- Approvals Required
- Benefits
- Funding Sources
- Costs

10.4.1 Project Category and Priority

Thirty projects have been identified for restoration based on results of the erosion risk assessment (see **Chapter 8**). While these sites represent areas of more immediate erosion concern, there are numerous other erosion sites and reaches wherein restoration/rehabilitation is considered to be beneficial.

The long list of alternatives that were considered and used to select a suite of treatments were grouped according to their general purpose. In total, there were six categories including:

1. Bank protection
2. Valley wall protection
3. Instream works
4. Riparian enhancement
5. Aquatic enhancement
6. Repair or modification of existing works

Each of the thirty erosion sites was assigned a relative priority based on the potential risk that they create to public health and safety. **Table 10.2** places each of the thirty erosion sites within short term and medium time frames for restoration. This approach is based on the premise that undertaken works early allows for softer approached to be utilized than if the works are left until there is an imminent risk to public health and safety. Addressing the erosion sites does not presuppose that restoration at a site scale is the only solution that should be incorporated within the Town. Instead, good watershed planning and mitigation of urban effects on a watershed scale is considered to be desirable and beneficial to reducing impact on receiving watercourses and thereby reducing risk.

Aquatic and riparian enhancement opportunities have not always been explicitly identified but these may be completed in conjunction with detailed design of the restoration work and/or as separate initiatives with volunteer groups, private property owners, or the parks department. Priority locations for enhancement change through time and may be dependent on priorities and vision of the volunteer groups. Undertaking of the projects requires co-ordination with the Parks Department, volunteer groups, and Town Maintenance crews.

There are three different timeframes that have been identified which define when projects should be carried out, subject to adjustment. These groups are described below:

Short Term - Year 1 to 4

- Projects in this timeframe are the most pressing because they have the greatest potential to provide benefit. They occur at active sites where failure could have severe negative consequences.

Intermediate Term - Years 4 to 7

- The risk of failure of these sites is high but not immediate for these projects. These projects also rank high in the provision of benefit to the watercourses through the Town of Markham.

Long Term - Years 7 to 10

- These projects are important but less pressing. Addressing these erosion sites provides an opportunity to be proactive and minimize extent of interference with the natural environment. These sites may be reprioritized based on subsequent site evaluations in the future.

It is important to note that when other initiatives are undertaken within the Town of Markham (e.g., road widening or other works undertaken by Region), then an opportunity exists to co-ordinate restoration within the objectives of this report. This may result in some works being undertaken more quickly than outlined in **Table 10.2**.

10.4.2 Project Number

Each erosion site that was identified along a Markham watercourse was assigned a code consisting of an abbreviation for the watercourse name, an abbreviation for whether the site was a fish barrier (FB), erosion site (ES) or site requiring maintenance (M), and the number of the erosion sites (e.g., PM ES 20 refers to erosion site # 20 along Pomona Mills Creek). Erosion sites were numbered sequentially along each watercourse and not all erosion sites were identified as being a priority site for restoration. This unique site identifier is used on **Figure 10.1** and within **Table 10.2** to identify the erosion site

10.4.3 Location

Each erosion site was assigned a code that identifies the name of the watercourse and a sequential number indicating its position along the watercourse. The actual location of the priority sites are demonstrated on **Figure 10.1**. The location of all erosion sites (priority and non-priority) are illustrated mapping found in **Appendix B**.

10.4.4 Action

Through the field assessments that were completed for each watercourse and field site, insight into the causes of erosion could, in general, be ascertained. This insight was also useful for identifying the implications of various restoration approaches on the reaches and watercourses in which the erosion sites occur. The future potential effect of long term channel processes or requirements were identified. Consideration of each of these factors led to identification of various actions that could be undertaken and are recommended for the restoration strategy. Review of background materials presented in this report is recommended during detailed design phases of the restoration works to inform final selection of restoration alternative (i.e., reach level processes, controlling influences on channel form, anticipated future channel changes etc.)

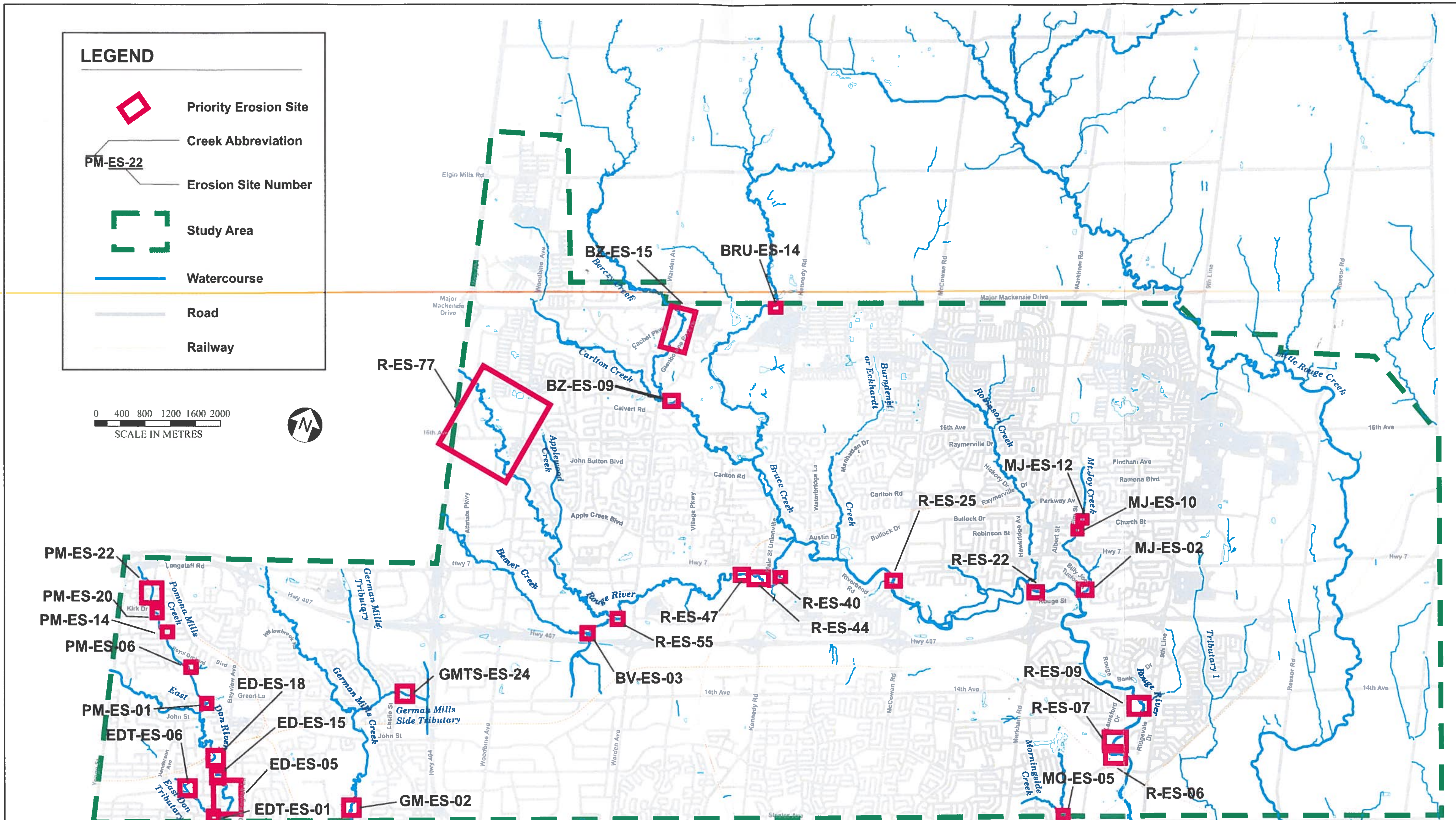
10.4.5 Measure

Restoration alternatives were presented for the purpose of addressing the erosion concerns at each erosion priority site (**Figure 10.1**). Evaluation of the alternatives using a set of criteria (Section 9.4) led to the identification of a short list of preferred alternatives. The selected alternatives were presented on corresponding reach maps in **Figure 9.3** and **Appendix E**; these are summarized within the Implementation Plan (**Table 10.2**).

10.4.6 Class Environmental Schedule

The Municipal Class EA applies to municipal infrastructure projects including roads, water and wastewater projects. As the projects which are undertaken can vary in their environmental impact, such projects are classified in the Class EA in terms of schedules.

Schedule A projects generally include normal or emergency operational and maintenance activities. These projects are pre-approved.



MARKHAM

Aquafor Beech Limited

FIGURE 10.1

TITLE: THIRTY PRIORITY EROSION SITES

Note: Refer to Table 10.2 for details of each priority erosion site and nearby non-priority erosion sites.

Schedule B projects generally include improvements and minor expansions to existing facilities and are subject to a screening process. Schedule B projects include works undertaken in a watercourse for the purposes of flood control or erosion control, which may include:

- bank or slope regrading
- deepening the watercourse
- relocation, realignment or channelization of the watercourse
- revetment including soil bio-engineering techniques
- reconstruction of a weir or dam

A majority of the projects proposed for the study fall under Schedule B.

Schedule C projects generally include the construction of new facilities and major expansions to new facilities. Phase 3 and 4 of the Class EA process must be completed for these projects.

10.4.7 Approvals

This study has followed the Master Plan process for the Municipal Class Environmental Assessment process. Once project sites were identified, these were grouped into six categories.

1. Bank protection
2. Valley wall protection
3. Instream works
4. Aquatic enhancements
5. Riparian enhancement
6. Repair or modification of existing works

In **Table 10.2**, application of only the first three categories of treatments is presented. The last three categories pertain to general recommendations for restoration and improvement of Markham's watercourses which may typically occur in parks and golf courses. Undertaking of such works may be as separate initiatives with local interest groups (e.g., volunteer groups (e.g., scouts), specialist groups (e.g., anglers)), private property owners and the Parks department.

The typical next steps, after selecting a project for restoration works are identified below and presented in more detail within **Section 10.3**:

- Site specific investigations for preparation of detailed design;
- Resolution of funding sources;
- Detailed design preparation;
- Submission to regulatory agencies for approvals;
- Tender/contract document specifications

The selected preferred alternative for most of the projects identified within this study are treatments that do not require extensive channel modification. As such, approvals for completing the designed restoration works will generally need to be obtained only from the Town and the Toronto and Region Conservation Authority (TRCA). At the detailed design stage, TRCA will determine the level of involvement of the Department of Fisheries and Oceans, which is contingent upon whether the proposed works require Authorization under the Fisheries Act for the Harmful Alteration Disruption and Destruction of fish habitat (HADD). Under the updated Lakes and Rivers Improvement Act (LRIA), involvement of the Ministry of Natural Resources (MNR) is unlikely to be required (i.e., limited primarily to dam removal).

From a Fisheries Act perspective, it is recommended that most of the intervention type of erosion projects with risk to property would require some compensation. Rougher treatments than usual and the incorporation of large woody material should provide sufficient habitat and prevent transferring energy downstream that would otherwise induce more erosion. Further, only sites that are enlarging or downcutting are perhaps better candidates for permanent stabilization and ecological restoration. These types of erosion projects may be self-compensating but given their scale, costs, duration, visibility and need for navigational reviews, an authorization from DFO and MNR is likely to be recommended.

Banking of required compensation or other more efficient integrated approaches may be explored and implemented. It is likely that this will be discussed between TRCA and DFO for each erosion project upon review of background materials and application of this study. It is anticipated that additional site information will be required beyond what was presented in this report to support the detailed design for each erosion site. It is anticipated that MNR will also be consulted on each project. It is obvious that a partnership, rather than a competing plan, be adopted by all stakeholders.

10.4.8 Costs

Cost estimates for each project have been provided in **Table, 10.2.** Unit costs have been used to estimate the costs of the restoration projects. The cost estimates include capital costs as well as a 15 percent allowance for design and administration. There are five general categories of treatments which are defined as:

- Bank protection
- Instream works
- Riparian enhancement
- Valley wall protection
- Repair or modification of existing works

Unit costs were provided for bank protection, valley wall protection and instream works. Unit costs were not provided for riparian enhancements since they may be part of separate initiatives with other groups. Costs pertaining to repair or modification of existing works were not included in this study since they may fall under maintenance expenditures.

Monitoring of all erosion sites within the Town of Markham is recommended to enable early detection of risk to the public, to structures, and to fisheries or terrestrial resources. Such monitoring can also be used to alter the priority of any one site given new observations regarding these risks. Documentation of erosion conditions can be accomplished through a detailed photographic record and re-assessment of any placed erosion pins. Both of these activities can be undertaken through field walks along watercourses within the Town (approximately three weeks). Observations and measurements can be compiled to create a temporal record of changes observed at each erosion site. While such a record will be invaluable in documenting changes to erosion site conditions, the information should not replace appropriate studies that would need to be undertaken in preparation for detailed design of restoration works.

The unit cost for valley wall protection works is $ 3,000/m for construction plus 15 percent for design and administration. This estimate was based on recent projects completed within the Greater Toronto Area

The unit cost for channel bank works was $ 1500/m for construction plus 15 percent for design and administration. This estimate was based on recent projects completed within the Greater Toronto Area.

Total costs for undertaking the erosion restoration works of the 30 sites identified in Table 10.1 is estimated to be $12, 767,000.

10.4.9 Funding Sources

The erosion sites that have been identified for priority restoration are situated on lands which are owned by various groups including private landowners, the Town of Markham, Region of York, Ontario Hydro and the Toronto and Region Conservation Authority. As such, discussions pertaining to funding for the restoration works should be held with all affected parties. In addition, external funding initiatives from provincial and federal agencies could be explored to determine eligibility (e.g., Great Lakes Clean-Up Fund) and application requirements. Accordingly, implementation is subject to funding from various stakeholders.

Capital projects should be included in the normal capital budgeting process by the Town of Markham. Part of the funding will be available from Development Charges levied by the Town as outlined in a Development Charges study completed by Aquafor Beech (2004) and to be updated in 2006. These Development Charges are levied against land to pay for increased capital costs required due to increased needs for services arising from development. Capital costs associated with new development or growth can include both the construction of new as well as the upgrading of existing services, where it must be changed to accommodate the new development. This applies to all forms of municipal services including stream erosion controls. The remainder will come through general tax levies subject to Markham Council approval.

Ongoing maintenance may be required in some areas (e.g., bridges or weirs) where projects are in areas that are stressed but cannot be addressed until higher priority sites are remediated. Collaboration with other agencies (e.g., Region, MTO) may be possible to address the erosion concern. Funding for maintenance projects should continue to be based on funding availability within the 'Creek Works' portion of the Town's current budget process. Costing for routine maintenance has not been provided for in this study.

Project performance monitoring is intended to enable early detection in the event of failure; such monitoring is a typical requirement of regulatory agency authorizations and is likely to be undertaken by the detailed design team. Costs for project performance monitoring would typically be absorbed by the Town. Projects initiated by development proponents are initially included as part of the performance bond agreement. Subsequent monitoring may be the responsibility of the development proponent. Alternatively, the Town of Markham must provide for performance monitoring in the capital budget.

Revegetation of the stream corridor (and watershed) can be accomplished through many means. The TRCA has a stewardship program and other tools useful for restoration of watercourses within the Town of Markham. Coordination with the Town's Parks department should be sought to tie into their Naturalization Efforts when revegetation is required as part of restoration activities. Community stewardship and education programs can also foster revegetation efforts.

10.4.10 Benefits

The benefits of the proposed actions are provided for each site and corresponding restoration strategy. The benefit is presented qualitatively in fulfillment of a specific objective (e.g., reduce stress on channel banks) and from a City Management perspective (e.g., reduced maintenance costs).

10.4.11 Habitat Class

Five habitat classes were defined for Markham's watercourses and used within the erosion priority ranking scheme. Consideration of habitat class when undertaking any restoration project is necessary and will affect the approval process.

General characterization of each of the five habitat classes are summarized below:

5 – *intolerant coldwater fish community*: Aquatic habitats are characterized by cold water temperatures; high dissolved oxygen levels; stable, moderate gradient streams; groundwater dominated flows; cobble/gravel/sand substrates; well developed

pool:riffle morphology. Fish communities are very sensitive to disturbance. While not strictly a coldwater species, fish habitats supporting redside dace would also fall in this category.

4 – *tolerant coldwater fish community*: Aquatic habitats similar to the above, but generally characterized by larger order streams, coarser substrates, larger pools to support adults. Stream temperatures may be warmer, and streams generally only support salmonids during their juvenile life stages, with adults migrating to the lake.

3 – *diverse warmwater fish community*: Aquatic habitats very diverse ranging from moderate to large river habitats similar to 4 above to low gradient rivers with aquatic macrophytes as a significant habitat element. These are generally runoff dominated streams that are more nutrient rich, but are generally stable.

2 – *moderately tolerant warmwater fish community*: Aquatic habitats are generally moderately degraded in terms of natural hydrology, stream stability and water quality. Generally these systems supported fish communities typical of 3 – 5 above, however loss of groundwater discharge; shift from pool:riffle to flat:run morphology; habitat instability from "flashy" hydrology; and water quality degradation eliminate sensitive species from the fish community

1 – *tolerant/highly tolerant warmwater fish community*: Similar to 2 above, however, instream habitats are degraded to the point where only the most tolerant species can survive

When alterations to the watercourse are recommended, the Toronto and Region Conservation Authority may involve DFO in review of detailed designs.

10.5 Additional Considerations

10.5.1 General

As outlined in the beginning of this document, this study has followed the Master Planning Process under the Class Environmental Assessment. The implementation plan that has been developed for the Town of Markham's Erosion Restoration Plan identifies and prioritizes restoration works. The plan has also provided details from a management planning perspective in terms of the approval process and forecasting of estimated construction costs. In addition to the information presented in **Table 10.2**, there are several other considerations that need to be identified and discussed as part of the Implementation Plan. These additional considerations are presented in the following sections.

10.5.2 Work on Private Property

Some of the erosion sites that were documented and identified as priority for restoration occur on private property. A number of municipalities within southern Ontario have undertaken erosion control works on private property as a result of request from homeowners, municipal desire, court order or political pressure. These municipalities recognize that while erosion is a natural process, the impacts of development are significant on the erosion process.

General steps followed by municipalities in dealing with private land owners are:

a) Landowner Contact

- Discussion with landowner to explain what the problem is, and why restorative measures are required
- Obtain approval to undertake work on their property. This will include an agreement noting that:
    - The Town is not admitting any liability
    - The property owner will indemnify the Town
    - The Town does not guarantee the effectiveness of the work to prevent additional erosion
    - The need for an easement (in cases where public infrastructure is at risk on private property

b) Funding Sources

c) Construction of proposed works

d) Inspection of final works including signoff

- Obtaining signoff on the items listed under Landowner Contact

e) Town Policy – Town will separately develop policies for treatment and funding of erosion sites on private property.

10.5.3 Monitoring

Watercourses are dynamic and in constant adjustment to changes in controlling and modifying influences. The rate of adjustment through erosion processes, is based on a number of factors which includes soil type, development patterns, and age of development among others. Exacerbation of erosion can occur in any one location as a result of new changes within the watershed and/or due to local factors. Monitoring of erosion sites on a fairly regular basis is therefore recommended to enable early detection of any new or exacerbated problems which may cause its priority to change. Similarly, TRCA recommends that an erosion monitoring program be developed to quantify rates of erosion at each of the priority erosion restoration sites. TRCA further recommends that the rate of erosion be confirmed at the detailed design stage.

As part of any class environmental assessment, this document should be reviewed on a 5 year rotation basis to ensure consistency with new policies. It is recommended that the field inventory be completed at least every 5 years to determine whether there are any new erosion sites that pose a risk to public health and safety or whether previously identified sites should receive greater priority for restoration. The detailed field mapping and corresponding photographic inventory will be an invaluable tool in identifying locations of erosion sites and ascertaining qualitative changes in erosion appearance. Similarly, by monitoring erosion pins at the priority erosion restoration sites, erosion issues and level of risk can be confirmed.

Monitoring of restoration works is recommended to enable adaptive environmental management (AEM) which recognizes that managed ecosystems are complex and inherently unpredictable. In AEM, the uncertainties of system responses are embraced and attempts to structure management actions as 'weak' experiments from which learning is a critical product (CVC, 2004). Implementing adaptive management can be considered as a cycle consisting of a number of steps which are repeated: develop/implement a solution; monitor for effectiveness; develop/adapt new solutions; implement and monitor again. Overall, this will benefit Markham by resulting in lower expenditures on water resources projects than current budgeting that is completed on a "crisis" basis.

In practical terms, adaptive management strives to manage natural river processes to reduce risk of flooding and erosion, rather than trying to control these processes whenever a site specific problem reaches an unacceptable level of risk. Key benefits of an adaptive management approach are:

1) the river system retains its natural characteristics and processes resulting in a healthier environment for plants, animals, fish, birds and people;
2) the total cost of river management including addressing flooding and erosion hazard is reduced;
3) a naturalized river and valley system provides more human "quality of life" benefits - recreation and aesthetics.

As already noted, monitoring is a common requirement within regulatory agency authorizations to undertake restoration works. Such monitoring, typically completed by the design team, provides insight into success or failure of implemented restoration works. This knowledge should be used in subsequent restoration plans to promote use of approaches that are effective and sustainable.

The Toronto and Region Conservation Authority currently has 24 regional monitoring sites situated along watercourses within the Town of Markham. Remeasurement of key channel parameters on a 3 year cycle basis provides data that, over the long term, will provide insight into changes in channel form and thus response of the watercourses to watershed level changes.

During the intervening years between implementation plan updates, monitoring of erosion sites can occur informally by various interest groups including *professionals,* *managers of the system, and residents.* Through routine work along the watercourses, each of these interest groups may be encouraged to report any specific erosion concerns to the Town, to ensure that significant risks to public health and safety are identified early on. This will minimize risk and promote incorporation of softer restoration approaches than if the risk is imminent and requires a 'harder' solution.

10.5.4 Subsequent Class EA Requirements

This study followed the Class Environmental Assessment for the Municipal Water and Wastewater Projects process, and is subject to the requirements of the Class Environmental Assessment Act. The Master Planning approach was followed for this study as it was anticipated that a series of measures which are distributed geographically throughout the study area and will be implemented over time would be undertaken.

When projects are undertaken which implement specific elements that are recommended in the Master Plan, it is necessary to determine the applicable Schedule. As is illustrated in **Table 10.1**, all projects are defined as Schedule B projects. If the proponent so desires, the Master Planning process may be used to satisfy the requirements of the Phases 1 and 2 of the Class EA process (Approach #2, Appendix D – Municipal Class EA document). Alternatively, the Master Plan may become the basis for, and be used in support of, future investigations for specific Schedule B projects identified within it (Approach #1, Appendix D – Municipal Class EA Document).

The intent of this document was to satisfy Phases 1 and 2 of the Class EA process (Approach #2 as outlined above). This, in essence would allow the municipality to proceed directly to detail design for the individual projects as outlined in **Table 10.2**.

It is, however, recommended that a brief Public Meeting be held prior to initiating detail design in order to:

- Define the goals and objectives of this study as well as the individual projects;
- Review the process used to identify the preferred alternative solution;
- Introduce local site considerations for the individual projects; and
- Summarize the Environmental Assessment Process.

The additional study requirements, in addition to the above, will require that a sequence of steps be undertaken as part of a process to develop a detail design package. These steps are identified below:

10.6 Site Investigation

Specific tasks that may need to be undertaken at the site level, depending on the preferred alternative and site characteristics are identified and described within this section.

Topographical Information

A topographical survey of the study area should be undertaken to obtain the following:

- ✓ Current data on the geometry of the bed and banks and channel profile
- ✓ Accurate representation of all significant vegetation including type and size
- ✓ Confirmation of the location of municipal infrastructure
- ✓ Accurate representation of all private utilities
- ✓ Detailed topographic data of all affected lands adjacent to the study area.

Erosion Assessment

An assessment of the rate of erosion and associated level of risk should be re-assessed at the detailed design stage. This will confirm issues and level of risk. That is, while some sites may appear to be actively eroding, the actual rate of annual change may be minimal. TRCA has recommended that a monitoring program be initiated in advance of undertaking erosion restoration design to provide relevant background information for this task.

Geotechnical Investigation

A geotechnical investigation should be undertaken to determine the engineering properties of the existing soils. This is of particular importance in areas where the stream has been disturbed during the construction of local infrastructure. A minimum of four (4) boreholes should be advanced to a depth of 4.0m. Borehole logs containing appropriate and sufficient data should be prepared. In addition, grain size analysis and proctor density should be conducted on samples obtained from each homogenous stratigraphic unit. Information from the boreholes would enable a determination of stable slope angles and stability of slope materials for planning purposes.

Prior to undertaking any geotechnical investigations, TRCA requires details of the proposed investigation to be provided to them so that they can determine whether approvals are required to undertake the work. That is, TRCA Permits and formal review under the Federal Fisheries Act may be required for the geotechnical investigations, and will be contingent upon the proximity of the work to the watercourse and the level of risk to the aquatic community.

Utility Locations

All utilities organizations should be contacted for as-constructed drawings and field staking of all underground services in the work area. Upon completion of the field staking, a topographic survey should be undertaken identifying the location (vertical and horizontal alignment) of these utilities for inclusion in the detailed design drawings. The utilities for this area includes, but are not limited to, electricity, natural gas, cable television, telephone, water, sanitary sewer and storm sewer.

Existing Sanitary Sewer Crossings

In locations where the creek is in close proximity to the existing alignment, the sanitary sewer crossing should be exposed to confirm a concrete encasement or cradle has been installed and determine the extent and condition of these concrete works. If no concrete encasement/cradle exists, the detailed design should consider exposing and protecting the sewer. For the purposes of the cost estimate it has been assumed that all sanitary sewer crossings will require concrete encasement.

Vegetation Inventory and Tree Protection/Removal

A vegetation inventory and assessment may need to be undertaken in the event that vegetation will need to be removed and restored, during the construction activity (e.g., access routes, treatment location);

All existing trees in excess of 100mm diameter should be located during the topographic survey and included on the detailed design drawings. Trees affected by construction activities shall be shown on the drawings as requiring removal. Trees close to the work area or those requiring preservation shall be protected using appropriate tree protection fencing which will be included as a detail on the drawings.

Hydraulic Analyses

Hydraulic analyses should be undertaken to identify key water level elevations which would help to plan extent of slope toe protection, height of valley wall protection and assist in determining appropriate bank treatments. That is, knowledge of velocity, depth and stress conditions at a site are integral to appropriately planning details of erosion restoration types.

Site Access

Site access for construction equipment, imported materials and exported fill should be defined for each work area. It should not be necessary to require a temporary crossing but if it is deemed required for a particular site, details of the temporary crossing including estimates of the creek flow will be provided. Staging areas for equipment and materials should also be indicated on the design drawings.

Erosion and Sediment Control

A detailed erosion and sediment control plan including construction staging shall be prepared. Contact the Toronto and Region Conservation Authority to determine the construction timing window for the site and include this information on the design drawings.

Restoration Plantings

A restoration planting plan will be required to address the following site restoration components:

- ✓ Vegetative erosion control of the banks and floodplain
- ✓ Erosion and sediment control of the banks and disturbed overbank area
- ✓ Provision of terrestrial habitat
- ✓ Provision of shading of the creek water to enhance aquatic habitat

Stabilization of the active channel should include bio-engineering techniques including live staking, live fascines and bio-logs.

Only native, locally present trees, shrubs and grasses should be used to restore the site. The Toronto and Region Conservation Authority are typically able to provide a list of species suitable for restoration within the study area.

Permitting
Permits will be required from the following agencies prior to commencement of works:
- ✓ Toronto and Region Conservation Authority
- ✓ Town of Markham Works Department
- ✓ Town of Markham Parks Department

10.7 Selection of Preferred Treatment Approach

The restoration strategy developed for this study evaluated various treatment types using a set of criteria, which has led to the selection of a short list of preferred alternatives. As part of the implementation process, the most feasible treatment to accomplish the preferred approach needs to be determined which may require some additional study that is site specific. For example, if it has been determined that toe erosion protection is the preferred alternative for reducing erosion potential, then this may be accomplished through the application of armourstone, rip-rap, and/or vegetated rip-rap (e.g., see alternatives identified in **Table 9.4** and in **Figures 9.2a to 9.2i**). The precise treatment (e.g., stone type, vegetation type) would be determined by the consultants retained to prepare the detailed design drawings and would require consideration of information contained within this report and specifically in **Chapters 3 and 7** and in **Appendix D**. Information presented in **Table 9.4** and in **Figures 9.2a to 9.2i** will also be helpful.

Although not explicitly mentioned, wherever possible, any site restoration should seek to further the restoration goals (e.g., habitat enhancement) identified in **Chapter 9.3**. Consideration of the overall restoration goals and channel processes will ensure that the preferred treatment approach is effective and sustainable into the future. Background information pertaining to the reaches and erosion sites that have been presented in **Chapters 3** and 7 and in **Appendix D** provides further understanding of the erosion sites from a reach and watershed perspective. The preferred treatment approach should seek to enhance natural channel form and process and account for implications of future changes in channel position (e.g., migration) and form (e.g., further enlargement due to urbanization).

Wherever possible, mitigation of erosion risk should consider land acquisition or easements to establish an appropriate channel corridor. Similarly, alteration of landuse in proximity to the erosion site should be considered (e.g., altering configuration of parking area, establishing buffer between site and landuse). Landowner education as it pertains to activities which may exacerbate the erosion site should also be undertaken to reduce risk.

Further, when feasible, protective measures can be buried to protect the element at risk. This would allow channel processes to continue until it intercepts the protective works, thereby minimizing interference with the channel and enabling natural adjustments to continue.

10.8 Detailed Design

As part of the detailed design process, the following site specific tasks will need to be undertaken:

- Detailed design drawings including planform and sections of treatment along erosion site that determine extent of treatment;
- Details of the treatment and construction phasing;
- Determination of access route and construction staging;
- Preparation of restoration plan including seeding, sodding, planting, and tree protection details;
- Material quantity estimation;
- Stabilization details.

TRCA will require confirmation of erosion risk (i.e., confirm level of risk as a function of erosion rate).

10.9 Tender/Contract Specification Documents

Once the detailed design drawings have been prepared and appropriate approvals obtained, then the restoration designs are typically tendered for bidding by qualified contractors. Items that are included in the tender and contract specification documents include:

Items that are included in the tender documents include:

- Detailed design drawings sealed by a qualified Professional Engineer
- Bid document including, but not limited to, the bid form, a contract price schedule and various contractual schedules.
- "Articles of Agreement" document, along with the bid document, forms the bulk of the contract
- "General and Supplementary Conditions" outlining terms common to most contracts
- "Special Provisions" detailing materials, placement and payment for items such project specific items as silt fences, dewatering, seeding, planting, geotextile, earthworks and supply/placement of armour stone.

It should also be noted that the Master Plan should be reviewed every five years to determine the need for a detailed formal review and/or updating. Potential changes which may trigger the need for a detailed review include:

- Major changes to original assumptions;

- Major changes to components of the Master Plan
- Significant new environmental effects; and
- Major changes in proposed timing of projects within the Master Plan

10.10 Agency Approvals

As discussed under Section 10.4.6, agency approvals will need to be obtained for any restoration works that are undertaken. When the works may result in an alteration of habitat, then from a Fisheries Act perspective, most of the intervention type of erosion projects with risk to property would require some compensation. TRCA is responsible for evaluating proposed works as to their impacts on fish habitat within their jurisdiction and will thus determine the level of DFO involvement at the detailed design stage. When works may result in a harmful alteration disruption or destruction of fish habitat, then TRCA is likely to involve DFO to determine appropriate compensation. The possibility of banking compensation will need to be discussed between TRCA DFO, and any other interested groups/stakeholders.

Table 10.2 Recommended Implementation Plan. (Category A = public infrastructure, Category B = private damage, Category C = erosion not related to urbanization. For further explanation of information contained within this table, please see Chapter 10.4 of this report). [1] Note: Bolded/underlined numbers refer to priority erosion sites; adjacent, non-priority erosion sites were listed if their coincident restoration was considered feasible.

PROJECT NO.[1]	REACH	LOCATION	ACTION	MEASURE	BENEFITS	HABITAT SENSITIVITY CLASS	SCHEDULE A, B, C	APPROVALS REQUIRED	COSTS ($) (incl 15% contingency)	FIGURE (APPENDIX E)
				Short Term – 1 to 4 years						
R-ES-**55**, 56	R-8	Rouge River - upstream of Warden Avenue	-protect sanitary sewer from erosion -minimize damage to slope to protection -consider reconfiguration of parking area and establishment of buffer between edge of valley and tableland land uses	-regrade and vegetate valley wall slope -rock toe protection (buried if possible) -potential flow deflection	-reduce risk to parking lot -reduce risk to sanitary sewer	4	B	Markham TRCA	345,000	29
GM-ES-01, **02**, 02b, 03, 04, 05, 06	GM-1	German Mills Creek -upstream of Steeles Avenue	-protect parking lot from erosion -stabilize channel banks	-slope toe protection adjacent to parking lot -revegetation of bank faces	-reduce risk to private property -reduce sediment loading -enhance terrestrial and aquatic habitat -stabilize channel form	1	B	DFO, TRCA, Markham	520,000	10
EDT-ES-**06a**, **06b**, 07, 08	ED-T	East Don River Tributary -downstream of Proctor Avenue	-protect private property -protect subsurface infrastructure -consider land acquisition or easements to create appropriate channel corridor -undertake public education	-move manholes away from/out of creek if possible -increase channel capacity where constricted -restore channel banks -replace crossing with channel spanning structure	-opportunity to address potential fish barrier -enhance channel function and form -reduce risk to subsurface infrastructure and manholes	3	B	Markham TRCA DFO Region	725,000	9
R-ES-**22**, 23, 24	R -4	Rouge River -upstream and downstream of Markham Road	-protect private property -protect Markham Road footings -protect subsurface infrastructure	-protect bank toe by burial of rock toe protection and vegetation -fill slope, grade, and vegetate -move manhole if possible	-reduce hydration of slope toe materials -reduce risk to property	4	B	Markham TRCA	225,000	24
GMTS-ES-**24a**, **24b** & 25	GMTS Side tributar y	German Mills Creek - upstream and downstream of Leslie Street	-protect manhole -remove/repair/replace existing geogrid and restore natural channel form and function -stabilize channel banks -remove garbage -repair stormwater outfall -remediate potential fish barrier under Leslie Street	*Upstream of Leslie St.:* -riparian enhancement -natural channel design -garbage removal *Downstream of Leslie St.* -regrade banks and vegetate -move manhole away from creek	-reduce potential for breakage of pipe -reduce potential for undermining Leslie Street -remove any fish barrier improve aquatic habitat -enhance channel function -reduce sediment loading	1	B	DFO, TRCA, Markham	175,000	11
R-ES-**40**	R-8	Rouge River -upstream of Hwy 7	-protect private property -protect sanitary sewer	-bank toe protection -stabilization of bank face with vegetation	-reduce sediment loading to channel -reduced risk of public health and safety	4	B	Markham TRCA	190,000	26
MJ-ES-**10**	MJ-4	Mount Joy Creek -downstream of Church St.	-protect subsurface infrastructure -stabilize banks -potential to undertake maintenance of nearby gabion bank protection	-remove/relocate manhole out of creek if possible -consider replacement of gabions with softer approach, if protection is required -stabilize banks through vegetative plantings and regrading as necessary	-adjustment of cross-sectional capacity -maintain bank protection but at increased benefit to aquatic and terrestrial habitat	4	B	Markham TRCA DFO Region	265,000	14

	PROJECT NO.[1]	REACH	LOCATION	ACTION	MEASURE	BENEFITS	HABITAT SENSITIVITY CLASS	SCHEDULE A, B, C	APPROVALS REQUIRED	COSTS ($) (incl 15% contingency)	FIGURE (APPENDIX E)
	R-ES-**47a, 47b**	R-8	Rouge River -upstream of Warden Ave, below Beaver/Rouge confluence	-remove undersized private crossing -protect subsurface infrastructure and manhole	-relocate manhole away from creek -remove concrete debris from channel -repair outfall structure -enhance riparian vegetation to stabilize banks	-remove flow constriction -reinstate natural channel form -protect private property -enhance terrestrial and aquatic habitat through riparian vegetation	4	B	Markham TRCA DFO Region	420,000	28
	MJ-ES-01, **02a, 02b**	MJ-4	Mount Joy Creek -upstream and downstream of Tuclor Lane	-mitigate fish barrier -protect subsurface infrastructure -protect crossing -stabilize channel banks	-remove/relocate manhole from creek -assess potential fish barrier and mitigate to enable fish passage -modify crossing structure to reduce erosive shear on downstream channel banks and stormwater outlet pipe that is in wingwall -stabilize banks through use of bioengineering treatments -enhance riparian vegetation with trees and shrubs	-reduced risk to subsurface infrastructure -enhancement of riparian zone which benefits terrestrial and aquatic habitat	4	B	Region Markham TRCA DFO	300,000	13
	MJ-ES-11, **12**	MJ-5	Mount Joy Creek -upstream of Church St.	-reduce risk to sanitary sewer and manhole	-remove/relocate manhole from creek -enhance riparian vegetation to stabilize banks -stabilize banks through planting on bank face and regrade only if necessary	-reduce risk to subsurface infrastructure -enhance terrestrial and aquatic habitat through riparian plantings	4	B	DFO Markham Region TRCA	195,000	15
	PM-ES-**20**,21	PM-7	Pomona Mills Creek -upstream of Kirk Dr.	-protect private property from erosion -protect subsurface infrastructure improve natural channel form	-create flooding relief for more frequent flows – e.g., two tier channel if possible through regarding -enhance riparian plantings to promote stability to bank face and bank top -slope toe protection should consider bioengineering (e.g., fascines), rock toe if necessary should be naturalized (e.g., vegetated rip-rap), -removal of weir should consider existing base level controls exerted by weir, and maintenance of natural channel form	-reduce risk to private property -improve aquatic habitat through removal of weir -re-instate natural channel form -enhancement of terrestrial and aquatic habitat through riparian plantings	1	B	DFO Markham TRCA	320,000	19

	PROJECT NO.[1]	REACH	LOCATION	ACTION	MEASURE	BENEFITS	HABITAT SENSITIVITY CLASS	SCHEDULE A, B, C	APPROVALS REQUIRED	COSTS ($) (incl 15% contingency)	FIGURE (APPENDIX E)
	Intermediate Term – Years 4 to 7										
	R-ES-77	R-12	Rouge River -in Markham Golf Club, between Woodbine Avenue and Hwy 404	-stabilize channel banks -replace/modify existing bank protections (gabion, rip-rap)	-establish riparian zone along channel banks -plant bank faces -ensure all channel crossings have sufficient span -replace/enhance existing rip-rap protection with softer approach (e.g., use fascines or incorporate joint plantings)	-reduce sediment loading into watercourse -stabilize/naturalize channel form	4	B	Markham TRCA	1,900,000	30
	PM-ES-06	PM-4	Pomona Mills Creek -upstream of John St., northern limit of Ladies Golf Course	-remove obstruction to flow and aquatic habitat -protect subsurface infrastructure -restore natural channel form and function	-remove concrete fence post footings out of creek -move end of fence to a distance away from edge of bank -protection of subsurface infrastructure may require structure in creek to protect invert -consider mitigation of downstream fish barrier by modifying/removing weir, and replacement of low-level concrete crossing with bridge	-remove existing structures from creek that interfere with natural processes -protect subsurface infrastructure. -restore channel form	1	B	DFO, TRCA Markham	242,000	17
	ED-ES-05, 06, 07, 08, 09, 12	ED-1	East Don River -between Steeles Ave . and Bayview Ave	-examine potential fish barrier -protect private property from bank erosion -repair outfall and protect storm sewer -consider opportunity to acquire land or easements to establish an appropriate corridor.	-Remove/repair/replace existing bank toe protection -Set stormwater outfall back from channel -Remove bridge crossing (Site ES-06) and replace only if necessary with a sufficiently wide span -Stabilize slopes (regrade or fill banks; bioengineer slope toe, bury rock toe protection if needed.	-removal of concrete debris from channel -enhancement of riparian zone with benefit to terrestrial and aquatic habitat -remove flow constriction -enhancement of fish passage -reduce interference with natural channel form (i.e., storm sewer outfall)	3	B	Markham TRCA DFO	1,270,000	5
	ED – ES-18	ED-1	East Don River -downstream of CN track	-protect subsurface infrastructure -protect private property	-consider relocating manhole and sanitary sewer -stabilize valley wall toe by regarding/filling and grading/bury rock toe protection -repair existing bank toe protection only as necessary	-reduce risk to private property -reduce risk to sanitary sewer -enhance terrestrial habitat on slope	3	B	Markham TRCA DFO Region	240,000	7

	PROJECT NO.[1]	REACH	LOCATION	ACTION	MEASURE	BENEFITS	HABITAT SENSITIVITY CLASS	SCHEDULE A, B, C	APPROVALS REQUIRED	COSTS ($) (incl 15% contingency)	FIGURE (APPENDIX E)
	PM-ES-**22**	PM-7	Pomona Mills Creek -in Holy Cross Cemetery	-stabilize banks to protect graves -enhance corridor function -replace gabion with other structures	-Increase capacity of higher frequency flows through multi-stage channel if possible -regrade banks to a more stable configuration and vegetate if possible -bank toe protection of stone and vegetation -create variability in bed morphology Enhance riparian vegetation with shrubs and trees where possible	-enhance flow conveyance -improve aquatic habitat -enhance terrestrial habitat through riparian plantings protection of grave sites from erosion	1	B	Markham TRCA DFO	470,000	20
	ED-ES-14, **15**	ED-1	East Don River -upstream of Bayview Ave.	-repair stormwater outfall -protect sanitary sewer - relocate sanitary sewer and manhole away from river if possible -move outfall further back from creek	-stabilize banks where risk occurs by regrading slope, vegetation -bury rock toe protection if required	-reduce sediment loading to watercourse -reduce risk to manhole and sanitary sewer	3	B	Markham TRCA	220,000	6
	EDT-ES-**01**,02	EDT	East Don River Tributary -upstream of Bayview Ave.	-protect road -reduce erosion of private property -consider land acquisition or easements to establish an appropriate corridor	-remove gabion where not necessary -replace gabion treatment with softer approach -replace/reinforce bridge to protect from failure	-enhance naturalized appearance of treatments -replace hard structures with softer approaches	3	B	Region? Markham TRCA DFO	445,000	8
	BZ-ES-**09**, 10, 11	BZ-10	Berczy Creek -upstream and downstream of Warden Ave.	-protect road from channel erosion -reduce potential of valley wall failure -soften existing erosion protection works	-toe protection along valley wall – minimize hardening -potential realignment to be determined in conjunction with Warden Ave. widening -replace\modify existing erosion protection works	-reduce risk to road -protect trees on valley wall -protect private property -enhance natural appearance, restore natural channel form	5	B	Region Markham TRCA DFO	400,000	2
	PM-ES-**01**	PM-1	Pomona Mills Creek -upstream of confluence with East Don River	-repair/replace/modify bridge crossing and associated berm. -mitigate erosion concerns	-study should be completed to determine if crossing structure can be replaced by a channel spanning bridge -consideration of current base level control influence must be taken in any restoration plans -address downstream erosion with use of bioengineering approaches (fascines) -remove fish barrier -enhance downstream natural channel functions, perhaps through incorporation of channel bed features to stabilize creek	-removal of fish barrier -enhancement of natural channel functions -removal of flow constriction -protection of public health and safety	1	B	Markham TRCA DFO	195,000	16

	PROJECT NO.[1]	REACH	LOCATION	ACTION	MEASURE	BENEFITS	HABITAT SENSITIVITY CLASS	SCHEDULE A, B, C	APPROVALS REQUIRED	COSTS ($) (incl 15% contingency)	FIGURE (APPENDIX E)
	MO-ES-**05**	MO-1	Morningside Creek Tributary -upstream of Steeles Ave.	-protect Steeles Ave. from erosion	-repair erosion scar with filling and planting- bury rock toe protection where required -undertake minor realignment only if this reduces impact to Steeles Road	-reduce risk to road -stabilize watercourse -enhance riparian vegetation	5	B	Markham TRCA DFO	175,000	12
	BV-ES-**03**	BV-4	Beaver Creek -upstream of confluence with Rouge River, parallel to Hwy 407	-remove/replace pipe that projects out of bank -stabilize banks to protect stormwater outfall	-increase bank stability by slight modifications -minimize risk to stormwater structure -enhance riparian vegetation -consider moving outfall	-enhance bank stability and terrestrial habitat through riparian vegetation -reduce risk to stormwater outfall -reduce sediment loading to stream	4	B	Markham TRCA	175,000	1
	PM-ES-**14**	PM-6	Pomona Mills Creek -Baythorn-Brae Drive footpath	-remove channel constriction -protect public health and safety	-consider replacing existing crossing with channel spanning structure – identify implications for flow conveyance and base level control -provide for multi-tier channel to enhance 'floodplain' access during more frequent (e.g., < 5 yr flows) -bank protection/stabilization should be based on bioengineering approaches and incorporate vegetation wherever possible (fascines, vegetated rip-rap) -enhance riparian plantings	-enhance channel function -reduce erosive stress on banks through flood relief -reduce risk to public health and safety.	1	B	Markham TRCA DFO	460,000	18
Long Term – Years 7 to 10											
	R-ES-**06**	R-1	Rouge River -upstream of CN line	-protect slope from failure -consider land acquisition or easement to establish corridor -consider landowner education to minimize impact to affected area	-regrade slope to stable configuration and vegetate -incorporate buried rock near toe if necessary	-reduce risk to private property/golf course	4	B	Markham TRCA	395,000	21
	R-ES-**07**	R-1	Rouge River ` -upstream of CN rail, adjacent to Rouge River Drive	-stabilize slope to protect private property	-regrade or refill banks -bury rock toe protection where necessary	-enhance slope stability -enhance riparian vegetation which provides terrestrial and aquatic benefits.	4	B	Markham TRCA	345,000	22
	BZ-ES-14, **15**,16, 18	BZ-9	Berczy Creek -downstream of Major Mackenzie Drive	-protect private property from erosion -restore channel connectivity and channel functions -consider opportunity to acquire land or easements to establish a corridor	-examine potential fish barrier -use bioengineering approaches to stabilize banks -move-pond offline if possible and repair erosion around dam	-reduce risk to private property -restore natural channel form -enhancement of riparian vegetation -enhance aquatic habitat	5	B	Markham TRCA DFO	645,000	3

	PROJECT NO.[1]	REACH	LOCATION	ACTION	MEASURE	BENEFITS	HABITAT SENSITIVITY CLASS	SCHEDULE A, B, C	APPROVALS REQUIRED	COSTS ($) (incl 15% contingency)	FIGURE (APPENDIX E)
	R-ES-**44,** 43	R-8	Rouge River - upstream of Main St. Unionville in Unionville Fairways Golf Course	-protect golf course property from erosion by enhancing bank protection	-use bioengineering approaches where possible -protect slope toe enhance riparian vegetation	-reduces rate of erosion -enhances terrestrial and aquatic habitat	4	B	Markham TRCA	675,000	27
	R-ES-**25**,26	R-6	Rouge River -upstream of McCowan Road	-protect private property -minimize interference with natural channel processes -	-remove crossing if possible, if replacement is necessary then ensure that span is sufficiently wide to minimize interference with flows. -address large woody debris only if this poses a risk to aquatic habitat -where slope stabilization is required, consider regrading and bioengineering approaches -enhance riparian vegetation	-remove flow constriction -enhance aquatic and terrestrial habitat through riparian plantings. -stabilize channel	4	B	Markham TRCA DFO	175,000	25
	BRU-ES-13, **14**	BRU-3	Bruce Creek -downstream of Major Mackenzie Drive	-reduce risk to road -protect subsurface infrastructure -minimize interference with natural channel form and processes	-consider moving manholes away from the creek -move fence out of creek -address erosion only where it poses a risk -protect bank toe if necessary using soft approaches where feasible -consider instream works only where necessary -enhance riparian vegetation to promote bank stability	-stabilization of channel banks -enhance terrestrial and aquatic habitat through riparian plantings	5	B	Markham TRCA Region DFO	195,000	4
	R-ES-**09**	R-1	Rouge River -downstream of 14th Ave.	-mitigate nearby fish barrier if necessary -protect private property through slope stabilization -consider land acquisition or easements to create appropriate corridor -education opportunity for landowner to reduce impact on affected area	-stabilize slope (fill erosion scars, bank toe protection, bioengineer toe) -instream works only where necessary (e.g.,. flow deflection)	-enhance fish passage through mitigating/removing potential fish barrier -reduce risk to private property -enhance terrestrial and aquatic habitat through riparian vegetation	4	B	Markham TRCA DFO	465,000	23
									TOTAL Cost	**12,767,000**	

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