# FLUVIAL GEOMORPHOLOGY

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# 7.0 FLUVIAL GEOMORPHOLOGY

Fluvial geomorphology is a study of the processes responsible for the shape and form, or morphology, of a watercourse. In simple terms, fluvial geomorphology describes the processes whereby sediment (e.g., silt, sand, gravel, stones) and water are transported from the headwaters of a river system down to its mouth. Fluvial geomorphology studies identify and quantify these processes which are dependent on climate, land use, topography, geology, vegetation and other natural and anthropogenic influences.

Protecting, managing and restoring the shape and form of watercourses requires a thorough understanding of fluvial geomorphology and, in highly urbanized watersheds such as the Etobicoke and Mimico Creeks, it also requires an understanding of the effects of urbanization on geomorphic processes. In addition to the run-off related effects of increased imperviousness associated with urban land uses, there are a number of other activities that can affect channel form. These include: direct modification of watercourse channels, approaches to engineered erosion protection, natural channel design approaches that attempt to consider geomorphic and ecological processes, and increasingly sophisticated stormwater management measures that attempt to mitigate the imbalance between the urban hydrologic regime and channel form. Understanding the inter-relationships among these activities and physical processes can better inform management decisions. An overview of the factors influencing fluvial geomorphologic processes and the various effects of urbanization on channel form is provided in **Appendix 7-A**.

This **Fluvial Geomorphology Section** addresses a knowledge gap identified in previous watershed strategy and report card documents, by analysing and interpreting the fluvial geomorphic data collected in Etobicoke and Mimico Creeks. These data were collected in response to recommendations of the previous watershed strategy. The section introduces a set of objectives, indicators and targets for fluvial geomorphology in these watersheds and it summarizes the available information regarding the shape, form and physical processes affecting the morphology of Etobicoke and Mimico Creeks. Based on this assessment management considerations are presented.

## 7.1 WATERSHED OBJECTIVES INDICATORS AND TARGETS

In the report *Turning over a new leaf: The Etobicoke and Mimico Creeks Watersheds Report Card 2006*, a fluvial geomorphic component was not included due to insufficient monitoring data necessary to provide a basis for objective setting at that time. As part of the watershed planning process, Toronto and Region Conservation Authority (TRCA) has now adopted a common reporting protocol for the fluvial geomorphic component in an effort to provide a level of consistency across each of the watersheds. **Table 7-1** outlines an objective and various indicators and targets for monitoring and reporting on fluvial geomorphic conditions within a watershed. For the purpose of this Technical Update the fluvial geomorphic data collected in 2001 has been used as an initial reference condition, from which to track change. Further monitoring and collection of data are required to develop a sufficient understanding of the fluvial geomorphic processes within the Etobicoke and Mimico Creeks watersheds to establish targets, on a reach by reach basis.

**Table 7-1: Etobicoke and Mimico Creeks Watersheds, Objectives and Targets**

| **Fluvial Geomorphology**<br>**Objective:** The natural form and function of the Etobicoke and Mimico Creek Corridors is protected and regenerated. | |
|---|---|
| **Indicator** | **Target** |
| Channel Morphology | Maintain or restore natural channel structure and rates of morphologic change (initial reference condition as per 2001 longitudinal profile survey, migration rates and substrate characterization data at RWMP* sites). |
| Flow Regime and Erosion Potential | Maintain baseline erosion index where stream banks are stable and decrease and/or restore to baseline erosion index where stream banks are unstable (measured at stream flow gauge sites; initial reference condition as per RWMP data 2001). |
| | Maintain baseline stream bank erosion rate (cross-sectional analysis; initial reference condition as per RWMP data 2001). |
| Stream Corridor Integrity and Continuity | By 2025, 75 % of the riparian zone should contain natural cover;<br>By 2025 the long term target is that 75 % of the riparian zone should be made up of forest cover. |
| Risk to Public and Private Property from channel evolution and change | Reduce or eliminate buildings, infrastructure and private property at risk from channel evolution. |

*RWMP – Regional Watershed Monitoring Program

## 7.2 OBJECTIVES OF TECHNICAL UPDATE

The previous watershed strategy and report card documents identified a lack of data necessary to develop an understanding of the fluvial geomorphology of the Etobicoke and Mimico Creeks. In response, in 2001 TRCA incorporated a fluvial geomorphology component in its Regional Watershed Monitoring Program (RWMP), and collected baseline fluvial geomorphic data. Additional data sets have been collected in 2004 and 2007 and other relevant data and information is available from various other watershed partners.

Drawing upon this new information, the principle objectives of the Fluvial Geomorphology component of this Technical Update are as follows:

- Review and analyze available fluvial geomorphic data for the Etobicoke and Mimico Creeks watersheds;
- Document the existing fluvial geomorphic conditions within these watersheds as they relate to the indicators outlined in **Table 7-1**;
- Provide insight into regional targets and trends (“regional” as in a physical watershed context, referring to an area of similar physiographic and geomorphologic characteristics);
- Present management considerations to achieve the overall watershed objectives as identified in **Table 7-1.**

## 7.3 DATA SOURCES AND MONITORING

### *7.3.1 Data Sources*

Characterization of conditions in a large area with respect to fluvial geomorphology is made difficult by limitations in the ability to collect information. As there are 330 kilometers of defined watercourse in the Etobicoke and Mimico Creeks watersheds, it is not practical or economically possible to maintain current data describing the condition of each segment of watercourse. Thus, for the purposes of this **Fluvial Geomorphology Section,** data were used from the following sources.

TRCA – Regional Watershed Monitoring Program (RWMP) has established a long-term geomorphic monitoring network. The focus of this network is on a limited number of sites that were initially selected to be representative of the broader range of conditions (i.e. regional perspective) within each watershed. In the Etobicoke Creek watershed ten geomorphic monitoring sites were established and in the Mimico Creek watershed five sites were established. Baseline information was collected at each of these stations in 2001, with repeated measurements in 2004 and 2007. Future monitoring is scheduled to take place on a three-year rotational basis.

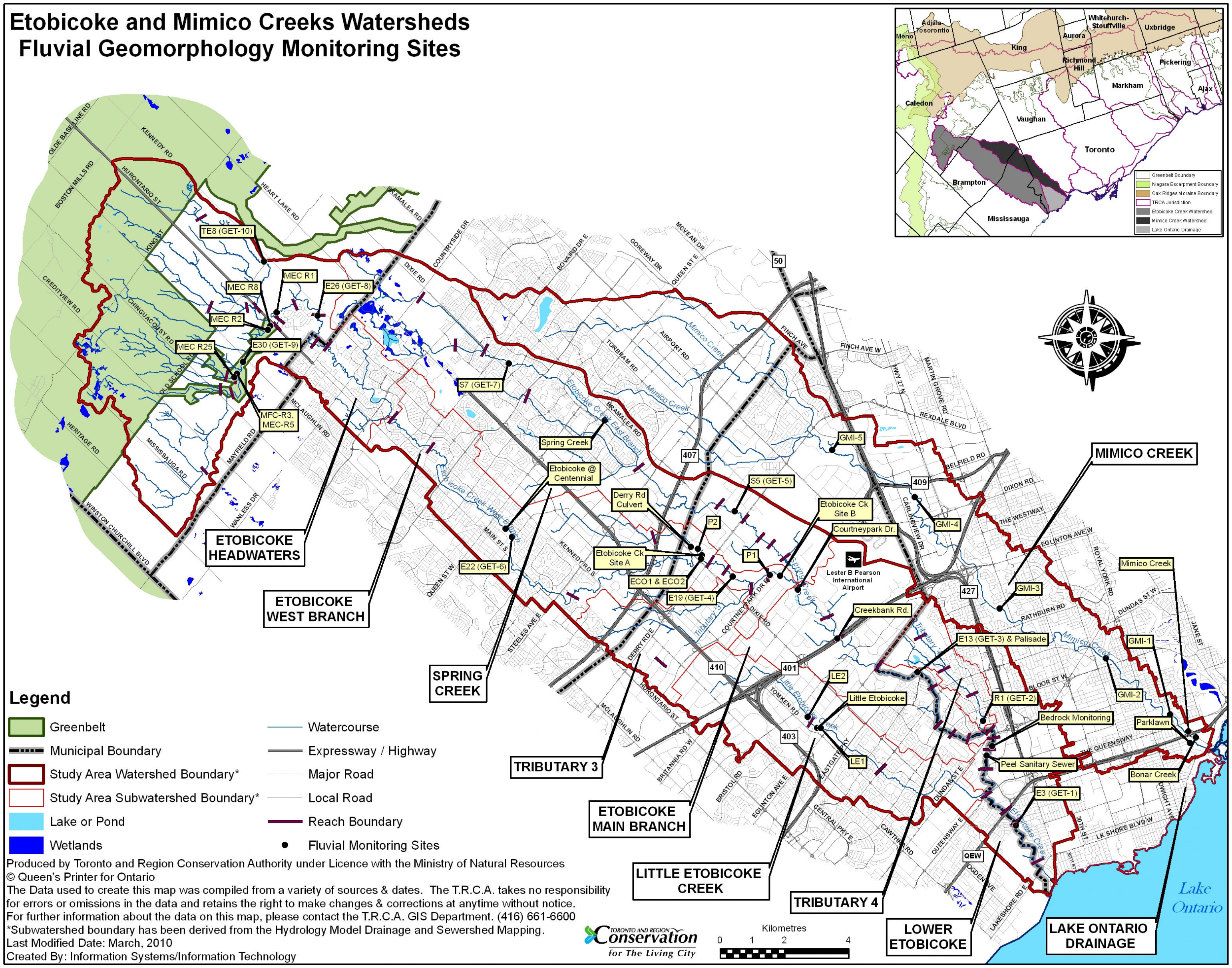
In 2008, TRCA hired Parish Geomorphic Limited to review and analyze the available TRCA RWMP geomorphic data. As part of the Parish Geomorphic Ltd. study, the TRCA geomorphic data set was augmented with data from an additional 20 field sites. This data was collected under private contracts held between Parish Geomorphic Limited and numerous partners including municipalities, regions and regulatory agencies. The scope of data collected at the Parish Geomorphic Limited sites was dependent on the nature of the project for which the monitoring work was initiated, such that the level of detail and suite of parameters for each of the Parish Geomorphic Limited sites may not be identical to what was collected at the TRCA's RWMP sites. For this reason, not all sites provided useful data for all analyses (Parish, 2009). **Figure 7-1** illustrates the compilation of monitoring sites used**.**

The study entitled *TRCA Fluvial Geomorphology Study and Erosion Assessment: Etobicoke Creek (Parish, 2005)* provided an overview of existing geomorphic conditions for Etobicoke Creek (both form and active processes) at a basin scale. Observations were carried out on a reach basis and were used to define the erosion sensitivity of the majority of reaches. Detailed field monitoring was also carried out at a number of sites. This information was used to determine appropriate erosion thresholds.

The study *Bankfull Channel Characteristics and Erosion Thresholds for TRCA RWMN Detailed Sites (Parish, 2003)* provided information relating to bankfull channel characteristics and erosion thresholds for all RWMP sites jurisdiction-wide. The information relating to erosion threshold values for Mimico and Etobicoke Creeks was used for this report.

To date, TRCA erosion inventories of Etobicoke and Mimico Creeks have not been completed due to limited budget resources; however, a number of sites have been flagged by members of the public, municipal staff or other TRCA staff. Inventories are underway by TRCA, and will follow a process of identification and assessment for potential risk. Results will then be used to develop overall priority lists for sites which are most urgently in need of remedial works.

## Figure 7-1: Fluvial Geomorphology Monitoring Sites



Water Survey Division of Environment Canada and TRCA RWMP provided stream flow data used for the erosion index analysis. **Table 7-2** outlines the streamflow gauge information including location, owner and period of record used. This stream flow data includes four Etobicoke Creek stations and two Mimico Creek stations.

As part of the 2006 Etobicoke and Mimico Creeks Watersheds Report Card, an assessment to define the riparian zone as 30 m in each direction from the centerline of the stream plus the average stream width was completed. This forms the basis for a discussion of riparian cover.

**Table 7-3** provides a summary of all sites monitored and data collected for each of the analyses.

### Table 7-2: Streamflow Gauge Etobicoke and Mimico Creeks Watersheds

| Gauge Name | Location | Operator | Period of Record used |
|---|---|---|---|
| Etobicoke Creek @ Brampton | Etobicoke Creek West Branch - north of Church Street , near Queen and Main Street | WSC | 2004 - 2007 |
| Etobicoke Creek @ QEW | Lower Etobicoke Creek - south of QEW Highway | WSC | 2005 - 2007 |
| Spring Creek | Spring Creek - west of Bramalea Road. and north of Drew Road | TRCA | 2004 - 2007 |
| Etobicoke Creek @ Derry and Dixie | Etobicoke Creek West Branch – north of Derry Road and east of Dixie Road | TRCA | 2004 - 2007 |
| Mimico Creek @ Islington | Mimico Creek – north of Bloor Street and east of Islington Avenue | WSC | 2005 - 2007 |
| Mimico Creek – Wildwood Park | Mimico Creek – south of Derry Road and west of Goreway Drive | TRCA | 2004 - 2007 |

## Table 7-3: Inventory of Fluvial Geomorphic Monitoring Sites and Data Usage Summary

| Site | Data Source | | | Data Usage Summary | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2002, 2003, 2005 RWMP (15 sites) | 2008 TRCA/Parish (35 sites) | 2005 TRCA/Parish (54 reaches) | Migration Rates | Bankfull Gradient | Erosion Threshold Values | Erosion Index | Cross-Sectional Area | Regional Curves | Erosion Sensitivity |
| **ETOBICOKE CREEK** | | | | | | | | | | |
| **Headwaters (18 Sites)** | | | | | | | | | | |
| GET10 (TE8) | X | X | X | | X | X | | X | X | X |
| GET9 (E30) | X | X | X | | X | X | | X | X | X |
| GET8 (E26) | X | X | X | X | X | X | | X | X | X |
| MEC-R1 | | X | | | | | | X | X | |
| MEC-R2 | | X | | | | | | X | X | |
| MEC-R25 | | X | | | | | | X | X | |
| MEC-R8 | | X | | | | | | X | X | |
| TE2 | | | X | | X | | | | | |
| TE3 | | | X | | X | | | | | |
| TE4 | | | X | | X | | | | | |
| TE5 | | | X | | X | | | | | |
| TE6 | | | X | | X | | | | | |
| TE7 | | | X | | X | | | | | |
| E28 | | | X | | X | X | | | | X |
| E29 | | | X | | | | | | | |
| E27 | | | X | | X | X | | | | X |
| E25 | | | X | | X | X | | | | X |
| E24 | | | X | | X | | | | | |
| **Little Etobicoke (3 sites)** | | | | | | | | | | |
| LE1 | | | X | | X | X | | X | | |
| LE2 | | | X | | X | | | | | |
| Little Etobicoke | | X | | | | | | | X | |
| **Etobicoke West Branch (14 sites)** | | | | | | | | | | |
| GET4 (E19) | X | | X | X | X | X | X | X | X | X |
| GET6 (E22) | X | | X | X | X | X | X | X | X | X |
| Etobicoke at Centennial | | X | | | | | | | X | |
| Derry & Dixie | | X | | | | | | | X | |
| P2 | | X | | | | | | | X | |
| Etobicoke Creek Site A | | X | | X | | | | | | |

| Site | Data Source | | | Data Usage Summary | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2002, 2003, 2005 RWMP (15 sites) | 2008 TRCA/Parish (35 sites) | 2005 TRCA/Parish (54 reaches) | Migration Rates | Bankfull Gradient | Erosion Threshold Values | Erosion Index | Cross-Sectional Area | Regional Curves | Erosion Sensitivity |
| Etobicoke Creek Site B | | X | | X | | | | | | |
| P1 | | X | | | | | | | X | |
| E17 | | | X | | X | X | | | | X |
| E18 | | | X | | X | | | | | X |
| E20 | | | X | | X | | | | | X |
| E21 | | | X | | X | | | | | X |
| E23 | | | X | | X | | | | | |
| TS1 | | | X | | X | | | | | |
| **Etobicoke Main (11 sites)** | | | | | | | | | | |
| GET3 (E13) | X | X | X | | X | X | X | X | X | X |
| Courtney Park | | X | | | | | | | | |
| Creekbank Rd | | X | | | | | | | X | |
| Palisade | | X | | X | | | | | X | |
| E9 | | | X | | X | | | | | |
| E10 | | | X | | X | | | | | |
| E11 | | | X | | X | | | | | |
| E12 | | | X | | X | | | | | X |
| E14 | | | X | | X | | | | | |
| E15 | | | X | | X | X | | | | X |
| E16 | | | X | | X | X | | | | X |
| **Spring Creek (12 sites)** | | | | | | | | | | |
| GET5 (S5) | X | X | X | X | X | X | X | X | X | X |
| GET7 (S7) | X | X | X | | X | X | | X | X | X |
| East Etobicoke | | X | | X | | | | | | |
| Spring Creek | | X | | | | | | | | |
| S1 | | | X | | X | | | | | X |
| S2 | | | X | | X | | | | | X |
| S3 | | | X | | X | | | | | X |
| S4 | | | X | | X | X | | | | X |
| S6 | | | X | | X | | | | | X |
| S8 | | | X | | X | | | | | |
| TS2 | | | X | | X | | | | | |
| TS3 | | | X | | X | | | | | |
| **Lower Etobicoke (12 sites)** | | | | | | | | | | |
| GET1 (E3) | X | X | X | X | X | X | | X | X | X |

| Site | Data Source | | | Data Usage Summary | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2002, 2003, 2005 RWMP (15 sites) | 2008 TRCA/Parish (35 sites) | 2005 TRCA/Parish (54 reaches) | Migration Rates | Bankfull Gradient | Erosion Threshold Values | Erosion Index | Cross-Sectional Area | Regional Curves | Erosion Sensitivity |
| Winter Greck | | X | | | | | | | X | |
| Peel | | X | | X | | | | X | X | |
| Bedrock Monitoring EC01 | | X | | | | | | X | X | |
| Bedrock Monitoring EC02 | | X | | | | | | X | X | |
| E1 | | | X | | X | | | | | X |
| E2 | | | X | | X | | | | | X |
| E4 | | | X | | X | | | | | |
| E5 | | | X | | X | | | | | |
| E6 | | | X | | X | | | | | X |
| E7 | | | X | | X | | | | | X |
| E8 | | | X | | X | | | | | X |
| **Trib 3 (1 site)** | | | | | | | | | | |
| TE1 | | | X | | X | | | | | |
| **Trib 4 (3 sites)** | | | | | | | | | | |
| GET2 (R1) | X | X | X | | X | X | | X | X | X |
| R2 | | | X | | X | | | | | X |
| R3 | | | X | | X | | | | | X |
| **MIMICO CREEK** | | | | | | | | | | |
| GMI-1 | X | X | | X | X | X | | X | X | |
| GMI-2 | X | X | | | X | X | | X | X | |
| GMI-3 | X | X | | | X | X | | X | X | |
| GMI-4 | X | X | | X | X | X | | X | X | |
| GMI-5 | X | X | | | X | X | | X | X | |
| Bonar Creek | | X | | | | | | | X | |
| Mimico Parklawn Cut & Fill operation | | X | | X | | | | | X | |

x = data used

## 7.4 MEASURING FLUVIAL GEOMORPHOLOGY

The examination of fluvial geomorphology and geomorphic processes involves both the measuring of channel morphology and the monitoring and analysis of the flow regime and sediment supply that drives geomorphic processes in the watershed. These measurements allow for the geomorphic characterization of the watershed to be determined, and repeated measurements over a period of time allow for the migration rates to be quantified and for the impacts of land use change and urbanization to be evaluated.

### *7.4.1 Channel Morphology*

Measuring channel morphology involves an examination of the complex three-dimensional geometry of a watercourse. Typically, channel morphology is defined in three different planes:

> Plan Form - the form of the channel when viewed from above (used to determine migration rates);
> Longitudinal Profile - the elevation and gradient of the bed in a lengthwise direction; and
> Cross-Section - the size and shape of the channel in cross-profile.

*Plan Form*
An historic assessment of plan form was carried out in 2002 (and reported in 2003 Parish) to determine rates of migration and evidence of anthropogenic modifications within the Etobicoke and Mimico Creeks watersheds. This was accomplished through a review of available floodplain mapping and aerial photography, spanning the last 15-20 years, to establish broad-level land use changes and channel modifications. The intent of this assessment was to provide a general indication of channel adjustment. In 2008, an effort was made to re-assess the migration rates established in 2002 and to document migration rates for any additional sites through the information provided by Parish Geomorphic Limited. Measurements were undertaken for a minimum of six points along the channel using a known control point. These measurements were then averaged to determine migration rates for the site. At a number of sites migration rates could not be established because of insufficient coverage or resolution of aerial photography or because of historic channel alterations.

Longitudinal Profile and Cross-Section
Measurements in these planes are taken using topographic survey equipment and then transferred into two-dimensional representations that can be interpreted and compared with subsequent surveys. The survey parameters are often guided by the placement of erosion pins. Erosion pins are used at monitoring sites to mark the location of specific channel features (i.e. top of bank) on a given date. Subsequent surveys of the pin locations can then be used to identify rates of erosion and morphological change.

Another fundamental aspect of channel morphology is the bed material or substrate, which is an important factor in determining the overall channel dimensions. The composition of bed material or substrate may provide insight into the watershed sediment supply. Bed material is characterized by sampling the substrate and analyzing the particle size distribution of the sampled material.

Channel dimensions and substrate characterization were measured as part of the baseline monitoring for TRCA RWMP sites, using standard geomorphologic techniques to quantify and characterize the channel. The following measurements were collected at ten cross-sections spread over a minimum distance of 20 times the bankfull width:

- substrate characterization: Wolman pebble count, particle shape, hydraulic roughness and embeddedness;
- bank characterization: height, angle, degree of vegetative protection, rooting depth and density;
- bankfull dimensions: width, depth, degree of entrenchment;
- wetted width and depth;
- general observations with respect to land use and riparian conditions.

Included in the ten cross-sections, was the establishment of a top-of-bank control cross-section which was typically situated mid-site at a riffle. Five erosion pins were installed in the channel banks to monitor rates of bank erosion over time. All of this information was tied together with a longitudinal profile to document channel bed morphology and cross-section locations. A temporary benchmark was established at each site to provide a reference for future survey work. Baseline monitoring was conducted in 2001, with additional monitoring undertaken by TRCA staff at each of the 15 sites in 2004 and 2007 and by Parish in 2008. Survey data from each year was plotted and overlaid to quantify changes in cross-sectional area and to track changes in longitudinal profile.

### *7.4.2 Flow Regime and Erosion Potential*

Flow regime can be measured directly by gauging flow in a watercourse at discrete locations. Empirical streamflow data is measured directly from gauges in the watercourse at specific sites. Alternatively, the flow regime is sometimes predicted using hydrologic computer models. This data is then related to channel morphology and erosion threshold values, using various indicators that relate the effect, or potential effect, of changes in flow to sediment transport and erosion.

*Erosion Threshold Analysis*
Erosion threshold values represent the critical depth, velocity and rate of flow at a particular location within the watershed. When conditions in the watercourse exceed the threshold values, erosion is assumed to occur. Streams continually adjust their dimensions to accommodate changes in their sediment transport and flow regimes, such that thresholds will vary spatially and temporally as watercourses adjust to local conditions.

Erosion threshold values are determined through a series of analyses based on critical shear stress (Shields, modified by Miller *et al*., 1977) and permissible velocity (Chow, 1959; Neill, 1967; Komar, 1987; Fischenich, 2001). Generally, critical shear stress and permissible velocity equations for non-cohesive materials are applied to the bed materials. The erosion thresholds are based on the threshold for the $D_{50}$ (median grain size), which is the general practice. If a large portion of the bed material is cohesive and the erosion threshold was greater than the threshold associated with the $D_{50}$, then the cohesive materials estimated shear strength is used to provide a characteristic threshold. These thresholds are based on tables provided in Chow (1959). Finally, if there is evidence of excessive bank erosion, a threshold related to the bank material is also calculated. The relative proportion of bank shear stress to the maximum shear stress is calculated. Threshold depths are based on this proportion. The lower of bank and bed threshold (or more conservative measure) is used to define the critical erosion threshold for the channel.

In 2003 erosion thresholds were calculated for each of the 15 RWMP sites. Threshold values were considered to be conservative in nature as they were developed prior to the collection of any monitoring information within each watercourse that would provide additional insight with respect to stream sensitivity. In 2003 the threshold values were based on simplified trapezoidal channel geometry of a single characteristic riffle cross-section which was extracted from each detailed site for threshold analysis. The depth and dimensions of this simplified geometry were then used to produce a meaningful erosion threshold discharge.

Updated threshold values were calculated in 2008 as part of the detailed field component for the three sites exhibiting the greatest degree of erosion. The modelling results for 2008 represent a more sophisticated approach through which five representative cross-sections were represented as opposed to using a simplified trapezoidal shape. Additional models were also used for the 2008 analyses which create a more robust analysis. These methods include Lane (1955) and Dunn (1959). Dunn (1959) is of specific interest, as it takes into account the percentage fines (silt and clay) within the substrate distribution and attempts to account for this component in the overall threshold. This methodology was employed for the revised GET-10 threshold to account for the large component of fines derived from the underlying Peel plain at this location. Finally, the Manning's 'n' values used for the 2008 values were for bankfull conditions and were derived from a combination of Limerinos' (1970) equation and visual estimates to account for factors such as channel geometry and the presence of wood debris and vegetation.

*Erosion Index Analysis*

An erosion index is an indicator of the length of time that flow in the creek exceeds the threshold at which erosion is assumed to occur (i.e. critical discharge), and the magnitude of flow during that time. In theoretical terms, an erosion index can be used to compare changes in erosion potential as a result of land use changes and/or changes in flow regime. Some caution however must be exercised when utilizing the results of an erosion index analysis. Complex erosive processes cannot always be described through the designation of a simple erosion threshold such that the amount of erosion or channel instability that will actually occur may not relate directly in all cases to the calculated erosion index.

In this Technical Update, an assessment was undertaken utilizing continuous streamflow data at four sites in Etobicoke Creek and two sites in Mimico Creek, to quantify the duration of time in which flow at each site exceeded the calculated erosion threshold value. While this exercise did not quantify a specific erosion index value, the results do provide an indication of the duration of time in which flow in the watercourse has exceeded the established erosion threshold over the period of record analysed.

### *7.4.3 Stream Corridor Integrity and Continuity*

*Riparian Cover*

A watershed-wide assessment of riparian cover was completed through application of a method that uses a Geographic Information System (GIS). Riparian areas were delineated around all watercourses based on a buffer on both sides of the stream centerline of 30 meters plus the average stream channel width by stream order (as determined through sampling of 2002 aerial photography). Land use and land cover information derived through interpretation of 2002 aerial photography was then correlated with riparian areas using the GIS and portions of the "riparian areas" lacking natural cover (forest, meadow, wetland or successional types) were identified and quantified. This assessment provided an indication of the percentage of watercourse banks that lacked the stabilizing influence and protection that natural riparian vegetation can provide.

### *7.4.4 Spatial Analysis and Regional Curves*

A spatial analysis was also completed to highlight any regional trends that arose as a result of changes in surficial geology or land use, or to identify regionally-based relationships between drainage area and various channel parameters. Each watershed was sub-divided into rural and urban land use based on 2008 satellite imagery available through Google Earth. The watersheds were also sub-divided into three primary zones: headwater, mid-watershed and tail water and further classified according to respective geological conditions. Regional curves were developed using known data points derived from available monitoring data. Statistical analysis of the curves was used to determine which relationships showed strong correlation and which relationships were poorly related.

## 7.5 EXISTING CONDITIONS AND INTERPRETATION

### *7.5.1 Channel Morphology*

*Migration Rates*

At a number of locations migration rates could not be established because of insufficient coverage or resolution of aerial photography or because of historic channel alterations. As presented in **Table 7-4**, migration rates have been determined for 13 sites within the watersheds. Of the 13 sites, ten are located within Etobicoke Creek and three are located in Mimico Creek. The rates range from negligible to 0.6 metres per year within Etobicoke Creek and from negligible to 0.18 metres per year in Mimico Creek. These baseline data will assist in the interpretation of future migration rate assessments. Additional data are provided in **Appendix 7- B**.

*Bankfull Channel Gradient*

Baseline conditions established for each of the 15 TRCA RWMP sites included a survey of the longitudinal profile, or bankfull channel gradient. Additional information provided in the 2005 Parish report also identified bankfull channel gradients for a number of reaches within Etobicoke Creek. In total, bankfull channel gradient information was compiled for 57 locations within the watershed as indicated in **Table 7-5**. Comparison of changes in the profile from year to year provides a good indication of rates of channel incision within the watercourse. **Table 7-5** summarizes the channel gradient information for each location.

As previously mentioned, the 2008 Parish study included a detailed field component at three sites, GET-5 in Spring Creek, GET-6 in Etobicoke West Branch and GET-10 in Etobicoke Headwaters, where the greatest degree of erosion was observed. One of the components of the detailed field work was to reassess the bankfull channel gradient at the three sites. **Figure 7-2**, **Figure 7-3** and **Figure 7-4** illustrate the 2002 and 2008 longitudinal profiles for each site and show that the bankfull gradient at each location has remained relatively consistent over the last six years. Other observations show that bankfull gradient is steepest within GET-10, which is typical of headwater reaches, while slopes are the most moderate within the mid-watershed site of GET-6. GET-5 is located on Spring Creek, a tributary to Etobicoke Creek, which has a smaller drainage area and steeper gradient.

## Table 7-4: Migration Rate Assessment

| Site | 2002 Migration Rates | | 2008 Migration Rates | |
|---|---|---|---|---|
| | Time Frame | Migration Rate (m/yr) | Time Frame | Migration Rate (m/yr) |
| **Etobicoke Headwaters** | | | | |
| GET-8 | 1978 - 1995 | 0.11[1] | | |
| **Etobicoke West Branch** | | | | |
| GET-4 | 1954- 1999 | 0.28 | | |
| GET-6 | | | 1994 - 2008 | 0.12 |
| Etobicoke Creek Site A | | | | 0.13[2] |
| Etobicoke Creek Site B | | | 1999 - 2006 | 0.14 |
| **Etobicoke Main** | | | | |
| Palisade | | | | 0.16[3] |
| **Spring Creek** | | | | |
| GET-5 | 1954- 1999 | 0.11 | 1966 - 2006 | 0.6 |
| East Etobicoke | | | 2002 - 2006 | 0.24 |
| **Lower Etobicoke** | | | | |
| GET-1 | 1954- 1999 | Negligible change | | |
| Peel | | | 2006 - 2007 | 0.21 |
| **Mimico Creek** | | | | |
| GMI-1 | 1954 - 1978 | Negligible change | | |
| GMI-4 | 1954 - 1978 | 0.04 | | |
| Mimico Parklawn | | | 1954 – 2006 | 0.18 |

Notes:
1. A max rate of 0.3 m/yr was observed;
2. A max rate of 0.41 m/yr was observed;
3. A max rate of 0.52 m/yr was observed

## Table 7-5: Bankfull Channel Gradient (BFG - %)

| Etobicoke Headwaters | | Little Etobicoke | | Etobicoke West Branch | | Etobicoke Main Branch | | Spring Creek | | Lower Etobicoke | | Tributary 3 | | Tributary 4 | | Mimico Creek | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | BFG | Site | BFG | Site | BFG | Site | BFG | Site | BFG | Site | BFG | Site | BFG | Site | BFG | Site | BFG |
| GET8 | 0.96 | LE1 | 0.73 | GET4 | 0.77 | GET3 | 0.39 | GET5 | 0.44 | GET1 | 0.57 | TE1 | 0.92 | GET2 | 1.39 | GMI1 | 0.68 |
| GET9 | 0.035 | LE2 | 0.56 | GET6 | 0.2 | E9 | 0.35 | GET7 | 0.205 | E1 | 0.21 | | | R2 | 0.57 | GMI2 | 0.49 |
| GET10 | 0.72 | | | E17 | 0.41 | E10 | 0.53 | S1 | 0.29 | E2 | 0.68 | | | R3 | 0.82 | GMI3 | 0.18 |
| TE2 | 0.77 | | | E18 | 0.50 | E11 | 0.70 | S2 | 0.54 | E4 | 0.64 | | | | | GMI4 | 0.09 |
| TE3 | 0.18 | | | E20 | 0.25 | E12 | 0.38 | S3 | 0.43 | E5 | 0.58 | | | | | GMI5 | 0.13 |
| TE4 | 0.5 | | | E21 | 0.10 | E14 | 0.41 | S4 | 0.41 | E6 | 0.45 | | | | | | |
| TE5 | 0.7 | | | E23 | 0.31 | E15 | 0.29 | S6 | 0.51 | E7 | 0.47 | | | | | | |
| TE6 | 0.36 | | | TS1 | 0.4 | E16 | 0.22 | S8 | 0.56 | E8 | 0.28 | | | | | | |
| TE7 | 0.76 | | | | | | | TS2 | 0.81 | | | | | | | | |
| E24 | 0.23 | | | | | | | TS3 | 0.89 | | | | | | | | |
| E25 | 0.06 | | | | | | | | | | | | | | | | |
| E27 | 0.02 | | | | | | | | | | | | | | | | |
| E28 | 0.14 | | | | | | | | | | | | | | | | |

**Figure 7-2: Longitudinal Profile Comparison of Bankfull Gradient for Site GET-5, Spring Creek**

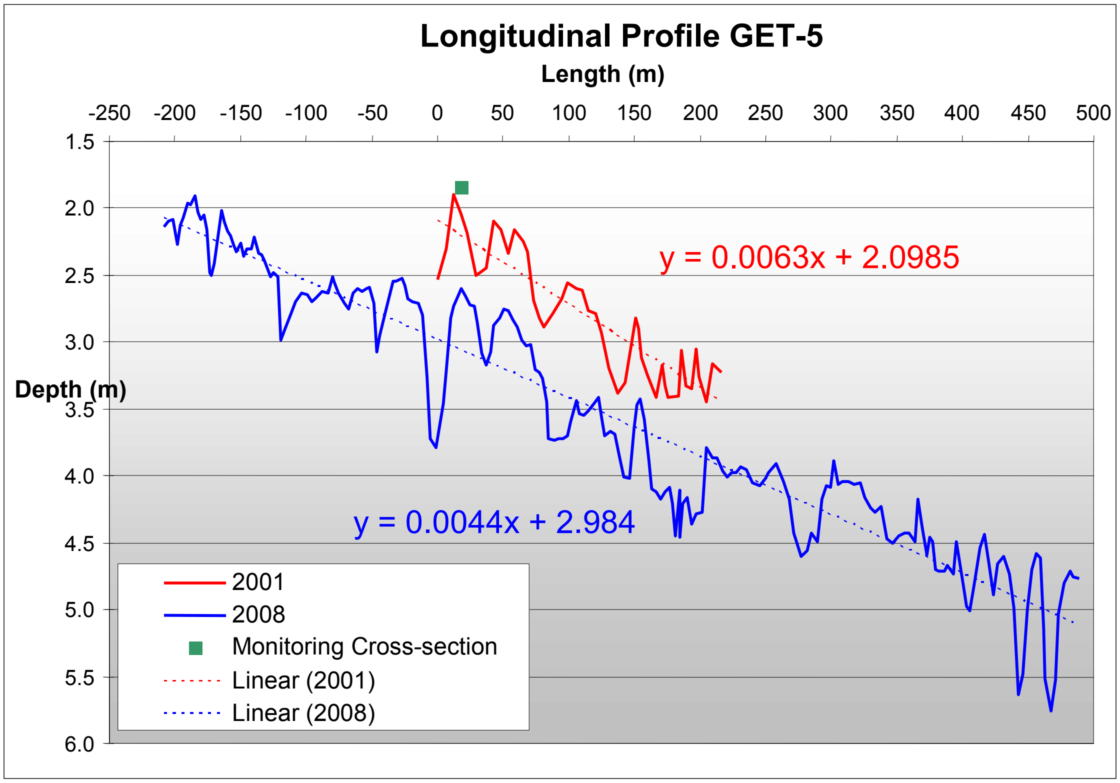



**Figure 7-3: Longitudinal Profile Comparison for Site GET-6, Etobicoke Creek West Branch**

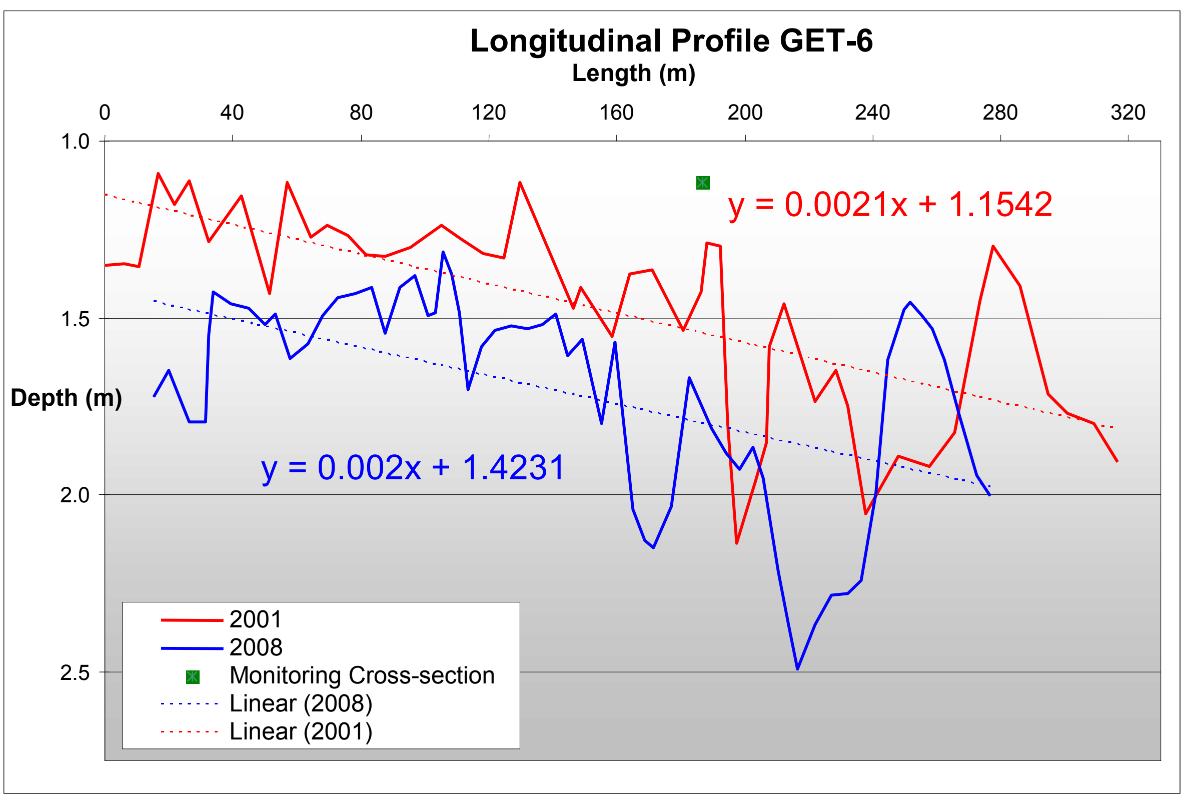
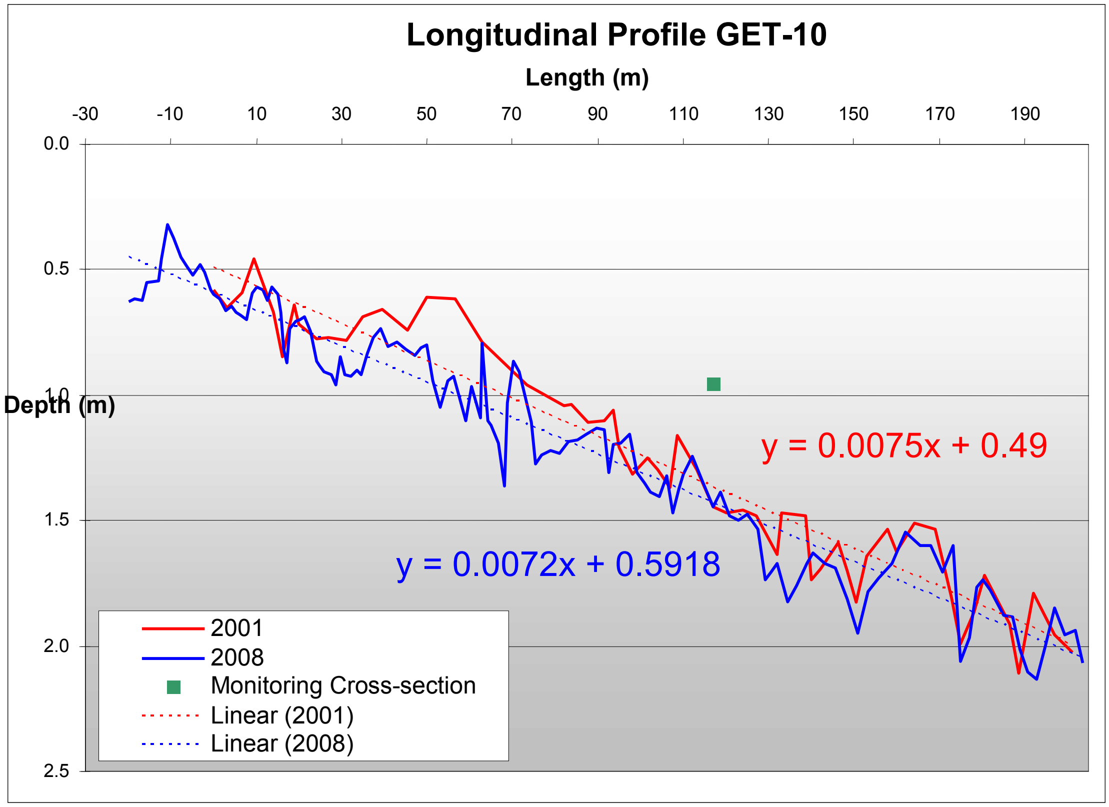


**Figure 7-4: Longitudinal Profile Comparison for Site GET-10, Etobicoke Creek Headwaters**




*Stream Bank Erosion Rates/Cross-Sectional Area Analysis*
In 2008 the control cross-section at each of the 15 TRCA RWMP sites was resurveyed. A comparison of the 2008 data was made with the results collected by TRCA in 2001, 2004 and 2007. The time-series of monitoring data was plotted on a site-by-site basis to quantify and qualify change in cross-sectional area over time. In order to account for issues of scale, this change was represented as a percentage of the original bankfull cross-sectional area. This standardization allowed for the identification of those sites which have experienced the greatest change; while also discriminating between the type of change (i.e., erosion or deposition).

**Table 7-6** provides a summary of the cross-sectional area analysis, while graphical representation of the data itself can be found in **Appendix 7-C**. An increase in cross-sectional area (i.e., erosion) is shown as a positive value, while a decrease in cross-sectional area (i.e., deposition) is shown as a negative value.

**Table 7-6: Cross-Sectional Area Analysis**

| ETOBICOKE CREEK | | | | | |
|---|---|---|---|---|---|
| **Site** | **2001 Area m$^2$** | **2004 Area m$^2$** | **2007 Area m$^2$** | **2008 Area m$^2$** | **Total % Change** |
| **Etobicoke Headwaters** | | | | | |
| GET 8 | 5.96 | 5.61 | 5.65 | 5.86 | -1.53 |
| GET 9 | 9.22 | 9.01 | 8.03 | 9.01 | -2.25 |
| GET 10 | 2.36 | 2.58 | 2.95 | 2.88 | 21.79 |
| MEC-R1 | | | 3.43 | 3.103 | -9.53 |
| MEC-R2 | | | 2.23 | 2.193 | -1.68 |
| MEC-R25 | | | 2.514 | 2.246 | -10.66 |
| MEC-R8 | | | 3.579 | 3.564 | -0.42 |
| **Etobicoke West Branch** | | | | | |
| GET 4 | 14.97 | 12.37 | 11.86 | 13.51 | -9.74 |
| GET 6 | 19.36 | | 18.52 | 21.92 | 13.23 |
| **Etobicoke Main** | | | | | |
| GET 3 | 41.60 | 47.25 | 39.09 | 43.62 | 4.84 |
| **Spring Creek** | | | | | |
| GET 5 | 11.35 | 9.81 | 12.08 | 12.63 | 11.35 |
| GET 7 | 3.07 | | 2.75 | 2.73 | -10.98 |
| **Tributary 4** | | | | | |
| GET 2 | 9.24 | | 8.82 | 8.28 | -10.36 |
| **Little Etobicoke** | | | | | |
| LE2/LE1 | | | 3.183 | 3.183 | 0.00 |
| **Lower Etobicoke** | | | | | |
| GET 1 | 47.46 | 40.72 | 43.06 | 46.63 | -1.74 |
| EC02[1] | | 7.97 | 9.17 | 6.55 | -17.82 |
| EC01[1] | | 7.59 | 7.14 | 9.73 | 28.19 |
| Peel | | | 16.61 | 16.06 | -3.31 |
| **MIMICO CREEK** | | | | | |
| GMI1 | 17.94 | 17.95 | 14.07 | 16.93 | -5.61 |
| GMI2 | 31.06 | 29.47 | 28.01 | 31.17 | 0.37 |
| GMI3 | 16.23 | 13.91 | 15.05 | 16.14 | -0.53 |
| GMI4 | 15.59 | 15.47 | 14.00 | 14.94 | -4.15 |
| GMI5 | 13.03 | 13.08 | 12.28 | 13.17 | 1.05 |

Note 1: monitoring dates for these sites include 1998, 1999, 2000

In general, for changes in cross-sectional area that fall within 5 %, it is difficult to differentiate between the inherent quantitative error associated with repeated measurement of channel dimensions versus actual change. As such, any values provided in **Table 7-6** that are within 5 % are not necessarily considered to be representative of actual, measurable change. Sites illustrating change in cross-sectional area beyond 5 % are considered to be in a state of active adjustment; however, to provide context, typical subwatershed-scale studies only identify the need for mitigation for changes in cross-sectional area in excess of 20 %. Only two sites (EC01 in Tributary 4 and GET-10 in Etobicoke Headwaters) exhibit erosion rates in excess of 20 % over the entire monitoring period. While excessive deposition can occasionally represent a concern if it triggers maintenance requirements (i.e. at a stream road crossing) or elevated flood levels, excessive erosion generally represents the greatest threat to infrastructure and private property. For the purposes of this study, sites exhibiting signs of erosion were considered to be of greater concern and therefore subject to further investigation.

Within Etobicoke Creek, a total of ten sites showed greater than 5 % change. Of these sites, four showed greater than 5 % change in terms of erosion and the other six sites showed greater than 5% change in terms of deposition (aggradation). The four sites experiencing erosion are:

- GET-5 in Spring Creek,
- GET-6 in Etobicoke West Branch,
- GET-10 in Etobicoke Headwaters, and
- EC01 in Tributary 4

GET-5 in Spring Creek is a bedrock-controlled site (consisting of shale). This site is located just upstream of the Lester B. Pearson airport lands and has been highly influenced by the surrounding commercial and industrial land use. This site shows evidence of active planform adjustment and illustrates a long-term trend towards erosion.

GET-6, an erosion site within the Etobicoke Creek West Branch, appears to have been historically straightened in order to accommodate the surrounding residential lands. Erosion is typical within such systems as they attempt to dissipate excess energy that has resulted from this decrease in stream length.

GET-10 lies within the headwaters of Etobicoke Creek where sediment production is typically the dominant process. This site is surrounded by agricultural lands.

EC01 situated in Lower Etobicoke illustrates the greatest change of all sites. This site, however, was specifically established as a bedrock monitoring site, together with EC02 in the Lower Etobicoke Creek, within a section of channel identified as sensitive to change. With this in mind, this site might not necessarily be considered representative of conditions within that reach. Also, the sites were established roughly 40 m apart, with EC01 indicating active erosion and the site EC02 indicating deposition. Consequently, the overall trend between these two reaches is still towards erosion (typical of sediment-starved bedrock systems), but with an average change of only 10.4 %.

As noted above there were six sites in Etobicoke Creek which showed greater than 5 % change in terms of deposition. These sites are:

- GET-7 in Spring Creek,
- GET-2 in Tributary 4,
- GET-4 in Etobicoke West Branch,
- EC02 in Lower Etobicoke,
- MEC-R1 and MEC-R25 in Etobicoke Headwaters

GET-7 is located within the headwaters of Spring Creek, however in contrast to the headwaters of Etobicoke Creek; the surrounding lands have been urbanized. The site itself is located immediately downstream of a large stormwater management pond (Dixie Road and Bovaird Drive East). These two influences would typically indicate a more erosive system; however, monitoring results indicate minor deposition, with little change over the past year. The channel itself appears to have been designed and may have been oversized to mitigate flooding of the adjacent parklands. This could explain the apparent depositional environment, however further monitoring and observation would be necessary to draw conclusions.

GET-2 is located within the tailwaters of Tributary 4 (Renforth Creek), near its confluence with Etobicoke Creek and, as such, is pre-disposed to a depositional environment.

GET-4 within the West Branch of Etobicoke Creek is a bedrock-controlled site located within the Lester B. Pearson airport lands. While the overall trend at this site is one of deposition, **Appendix 7- C** results illustrate a clear pattern of erosion (widening) and deposition which is typical of a bedrock system in a state of geomorphic transition. Continued data collection is required to monitor the geomorphic transition at this site.

EC02 located in the Lower Etobicoke Creek illustrates deposition; however, this site is downstream of EC01, an active erosion site.

The sites of MEC-R1 and MEC-R25 are located in the headwaters of Etobicoke Creek in a reach which functions largely as an agricultural drain. These reaches tend to be oversized to facilitate drainage, which may lead to the expected deposition shown in these sites.

Initial interpretations of the Mimico Creek results indicate that the system is more susceptible to deposition. However, upon further evaluation, the adjustment noted at these sites is typically so small in scale that they would not necessarily trigger an indication of measurable change. Only one site (GMI-1) exceeded 5 % change in cross-sectional area in the form of deposition. This site, however, is located within the tailwaters of the system; an area characteristically associated with sediment storage due to lower gradients and the backwater effect induced by Lake Ontario.

One apparent trend that was observed, not only through the Mimico Creek data but also (to a lesser extent) through the Etobicoke Creek data, was a decrease in cross-sectional area in 2007 relative to the remaining years. This trend was observed regardless of whether the overall pattern at the site was towards erosion or deposition. Given that 2007 was noted as an extremely dry year hydrologically, this pattern would suggest that deposition is a dominant process during low flow conditions. The 2008 data shows however, a trend back to erosion or an increase in cross-sectional area which would indicate that flow rates in 2008 had increased to a sufficient level such that any previous depositions were mobilized from the area.

Based on the findings of the cross-sectional area analysis, three of the TRCA RWMP sites were identified as exhibiting the highest rates of adjustment (in the form of erosion): GET-5 in Spring Creek, GET-6 in Etobicoke West Branch, GET-10 in Etobicoke Headwaters. In order to gain a more detailed understanding of these three erosion sites, detailed field investigations including a resurvey of the original 10 cross-sections were undertaken at each of these locations.

**Table 7-7** compares the average values across all 10 cross-sections for each of the three erosion sites. The combined results provide a more robust interpretation of geomorphic processes that are occurring on a reach-basis, versus the site-basis provided by the individual control cross-sections. Interestingly, the overall changes in average bankfull dimensions presented in **Table 7-7** indicate that only one site (GET-6) appears to be actively eroding or enlarging at a reach scale. Contrary to results from the individual control cross-sections GET-5 and GET-10 appear to be tending towards deposition, when reviewing the results of the detailed cross-sectional assessment (see **Table 7-7**). Thus, it is premature to draw conclusions about the pattern of change at these sites or its correlation to surrounding land use, until further monitoring and analysis can be undertaken.

**Table 7-7: Detailed Cross-Sectional Assessment for GET-5, GET-6 and GET-10**

| Parameter (m) | GET-5 | | GET-6 | | GET-10 | |
|---|---|---|---|---|---|---|
| | 2001 | 2008 | 2001 | 2008 | 2001 | 2008 |
| **Avg Bankfull Width** | 9.42 | 8.47 | 10.38 | 11.21 | 3.8 | 3.05 |
| **Avg Bankfull Depth** | 0.62 | 0.58 | 0.71 | 0.88 | 0.34 | 0.36 |

GET-5 results reflect two primary modes of adjustment: widening and deposition. The combination of these processes helps to explain the apparent discrepancy between the site and reach scale field results at this location. Seasonal trends of deposition may also skew results for each year towards erosion or deposition. Given the bedrock-controlled nature of this site, widening is a typical form of adjustment given the underlying bedrock geology and the sandy bank materials. The dominant mode of change within the GET-10 control cross-section appears to be planform adjustment. This process can manifest itself as a combination of erosion and deposition, which would explain the apparent discrepancy between the site and reach-scale monitoring results. GET-6, meanwhile, clearly illustrates both the site and reach-scale trend towards channel enlargement. The uniform channelized cross-sectional form is typical of a system that has been historically modified as a result of land use change.

As can be seen from the conflicting results in assessment processes (site and reach), it is premature to draw conclusions relating to fluvial geomorphic conditions within these watercourses. It should also be noted that the watercourses of Etobicoke and Mimico have been experiencing adjustments due to urbanization long before measurements were being taken and therefore no baseline condition is available.

### *7.5.2 Flow Regime and Erosion Potential*

*Erosion Threshold Values*

Streams continually adjust their dimensions to accommodate changes in their sediment transport and discharge regimes. As such, thresholds of particle movement and transport will vary spatially and temporally as a watercourse adjusts to local variations in slope, bed material, discharge and modifying factors. The selection of appropriate thresholds is in part, dictated by indicators of the active processes (e.g. deposition and excessive erosion).

**Table 7-8** presents the erosion threshold values calculated from 2002 data; with values in parenthesis indicating the updated 2008 threshold value calculated for comparison.

Results of the erosion threshold analysis found that in the upper part of the watershed, the critical discharge values were well above bankfull given the very low gradients and the dominance of coarse materials provided by the Halton Till, which often behaves in ways similar to bedrock. Whereas, analysis showed the lower more urbanized reaches of the watershed represented erosive flow conditions much more frequently (within bankfull), considering the incised and channelized lower reaches which constrain flow within the channel and increase erosion potential. As previously discussed, threshold values will vary temporally as the stream continually adjusts its dimensions to accommodate changes in sediment transport and discharge. Therefore, the threshold values presented in **Table 7-8** should be treated as a guide.

*Erosion Index Values*

Erosion index values are used to indicate the length of time in which flow in the creek exceeds a level (or threshold), at which erosion is assumed to occur. In theoretical terms, an erosion index value can be used comparatively to examine the change in erosion potential as a result of different flow regimes. The results of such analyses however, should be used with caution as complex erosive processes cannot be described through the designation of a simple threshold, and therefore the amount of erosion or channel instability that will actually occur may not relate directly to the calculated erosion index.

The erosion exceedence analysis was undertaken for four sites in Etobicoke Creek and two sites in Mimico Creek. The intent of this exercise was to quantify the duration of time in which flow in the watercourse at each location exceeded the calculated threshold value. While this exercise did not quantify a specific index value, the results do provide an indication of the duration of time in which flow in the watercourse has exceeded the established erosion threshold over the period of record analysed. **Table 7-9** summarizes the exceedence intervals by day.

As shown in **Table 7-9,** the total number of days when flow exceeded the defined threshold appears to be declining over the period of record at GET5. For the remainder of the sites, the total duration of exceedence appears to be increasing over the period of record. While the 2007 values for all sites are less than the value for the previous year, it is noted that 2007 was a record dry year such that this value may not be representative of the long-term trend at these sites.

As previously cautioned it is difficult to describe the complex nature of erosive processes and predict the amount of erosion or channel instability (or stability). Thus with this caution and the variance in data results, it would be premature to draw conclusions of stability in these systems.

**Table 7-8: Erosion Threshold Values Calculated from 2002 Data**

| Site | Critical Discharge $m^3/s$ * | Critical Depth m | Critical Velocity m/s |
|---|---|---|---|
| **Headwaters** | | | |
| GET-8 | 1.61 | 0.28 | 1.00 |
| GET-9 | 30.82 | 1.76 | 2.15 |
| GET-10 | 0.25 (0.15) | 0.16 | 1.02 (0.74) |
| E25 | 1.37 | 1.37 | 0.69 |
| E27 | 4.53 | 1.10 | 0.47 |
| E28 | 1.44 | 0.35 | 0.72 |
| **Little Etobicoke** | | | |
| LE1 | 1.68 | 0.30 | 0.80 |
| **Etobicoke West Branch** | | | |
| GET-4 | 5.88 | 0.60 | 1.25 |
| GET-6 | 7.14 (2.75) | 0.52 | 0.67 (0.68) |
| E17 | 1.96 | 0.35 | 0.61 |
| **Etobicoke Main Branch** | | | |
| GET-3 | 6.38 | 0.53 | 0.82 |
| E15 | 21.18 | 1.40 | 0.91 |
| E16 | 6.15 | 0.60 | 0.76 |
| **Spring Creek** | | | |
| GET-5 | 2.19 (0.67) | 0.46 | 1.04 (0.65) |
| GET-7 | 0.05 | 0.19 | 0.22 |
| S4 | 1.23 | 0.33 | 0.84 |
| **Lower Etobicoke** | | | |
| GET-1 | 4.50 | 0.45 | 0.84 |
| **Tributary 4** | | | |
| GET-2 | 0.79 | 0.26 | 1.02 |
| **Mimico Creek** | | | |
| GMI1 | 1.01 | 0.25 | 0.52 |
| GMI2 | 2.65 | 0.34 | 0.60 |
| GMI3 | 9.30 | 0.94 | 1.05 |
| GMI4 | 2.05 | 0.54 | 0.54 |
| GMI5 | 1.7 | 0.48 | 0.62 |

* updated 2008 threshold value is shown in parenthesis.

**Table 7-9: Erosion Exceedence Analysis**

| Year | Duration of Exceedence in Days | | | | | |
|---|---|---|---|---|---|---|
| | 90 Spring Creek (GET5) | 91 Etobicoke @ Derry (GET4) | Etobicoke @ QEW (GET3) | Etobicoke @ Church St (GET6) | Mimico @ Wildwood (GMI5) | Mimico @ Bloor (GMI2) |
| **2004** | 64.8 | 9.7 | N/A | 13.6 | 23.5 | N/A |
| **2005** | 53.7 | 14.0 | 34.7 | 20 | 25.3 | 24.3 |
| **2006** | 55.6 | 18.9 | 44.5 | 26.3 | 34.4 | 31.3 |
| **2007** | 45.4 | 6.0 | 19.08 | 6.7 | N/A | 14.6 |

### *7.5.3 Stream Corridor Integrity and Continuity*

*Riparian Cover*

Riparian cover is the vegetation along the banks of a river or stream that is within the riparian zone which is defined as 30 metres in each direction from the centerline of a stream plus the average stream width. Riparian cover plays an important role in the health of a watercourse. Vegetation along a stream bank helps improve water quality, retain stormwater and protect against erosion. Woody vegetation (trees and shrubs) is especially important for preserving the shape of stream channels.

An assessment of riparian cover was undertaken as part of the 2006 report card update. Results of that analysis concluded that only 45 % of the riparian zone in the Etobicoke Creek and 49 % of the riparian zone in the Mimico Creek has natural cover. Within those areas, only 18 % of the riparian zone in Etobicoke Creek is made up of forest and only 16 % of the riparian zone in Mimico Creek is made up of forest. The overall rating established for riparian cover was poor for both watersheds. The established target for riparian cover is 75 % to benefit both the aquatic and terrestrial system; as well the increase in riparian cover would be most beneficial for channel stability. With the predictions of climate change of more frequent weather events, an increase in riparian cover would go a long way for these three watershed components.

### *7.5.4 Risk to Public and Private Property from Channel Evolution and Change*

*Erosion Hazard Sites*

TRCA implements a jurisdiction-wide Erosion Control Program, which seeks to remediate risks to life and property from the hazards of erosion instability. This program involves the identification of erosion hazard sites, long term monitoring and assessment of potential risk and implementation of remedial projects based on priority.

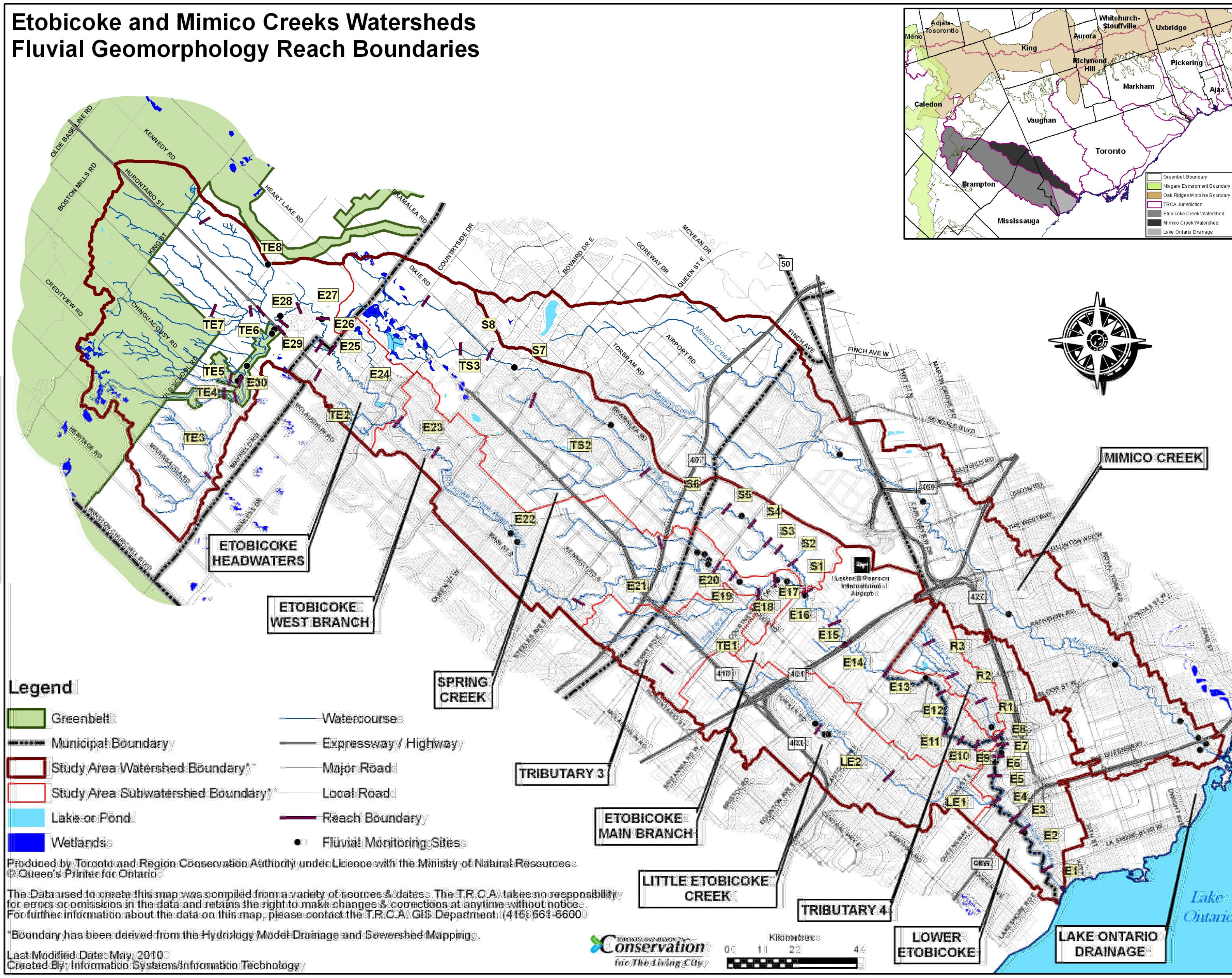
In the Etobicoke Creek, a total of 18 erosion hazard sites have been identified where it is deemed that infrastructure or property would be at risk (see maps in Section 11.4). Additional insights into erosion processes underway at the reach scale are available from the 2005 Fluvial Geomorphic Study of the Etobicoke Creek (Parish Geomorphic Ltd., 2005). That study included a cursory field assessment of potential erosion-prone reaches in the Etobicoke Creek watershed. Observations from the assessment were used to determine an erosion sensitivity rating for each of the reaches. As outlined in **Table 7-10** and shown in **Figure 7-5**, a total of 33

**Table 7-10: Erosion Sensitivity Ratings**

| SUBWATERSHED | REACHES | SENSITIVITY |
|---|---|---|
| **Headwaters** | TE8 | Moderate |
| | E30 | Moderate |
| | E26 | Moderate |
| | E28 | High |
| | E27 | High |
| | E25 | High |
| **Etobicoke West Branch** | E19 | Moderate |
| | E22 | Moderate |
| | E17 | Moderate |
| | E18 | Moderate |
| | E20 | Moderate |
| | E21 | High |
| **Etobicoke Main** | E13 | Moderate/High |
| | E12 | High |
| | E15 | High |
| | E16 | Moderate |
| **Little Etobicoke** | LE1 | Moderate/High |
| **Spring Creek** | S1 | High |
| | S2 | Moderate |
| | S3 | Low |
| | S4 | High |
| | S5 | Moderate |
| | S6 | Moderate |
| | S7 | Moderate |
| **Lower Etobicoke** | E3 | Moderate |
| | E1 | Moderate |
| | E2 | High |
| | E6 | High |
| | E7 | Moderate |
| | E8 | Moderate |
| **Tributary 4** | R1 | High |
| | R2 | Moderate |
| | R3 | High |

(Parish Geomorphic Ltd., 2005)

**Figure 7-5: Reaches Rated for Erosion Sensitivity**

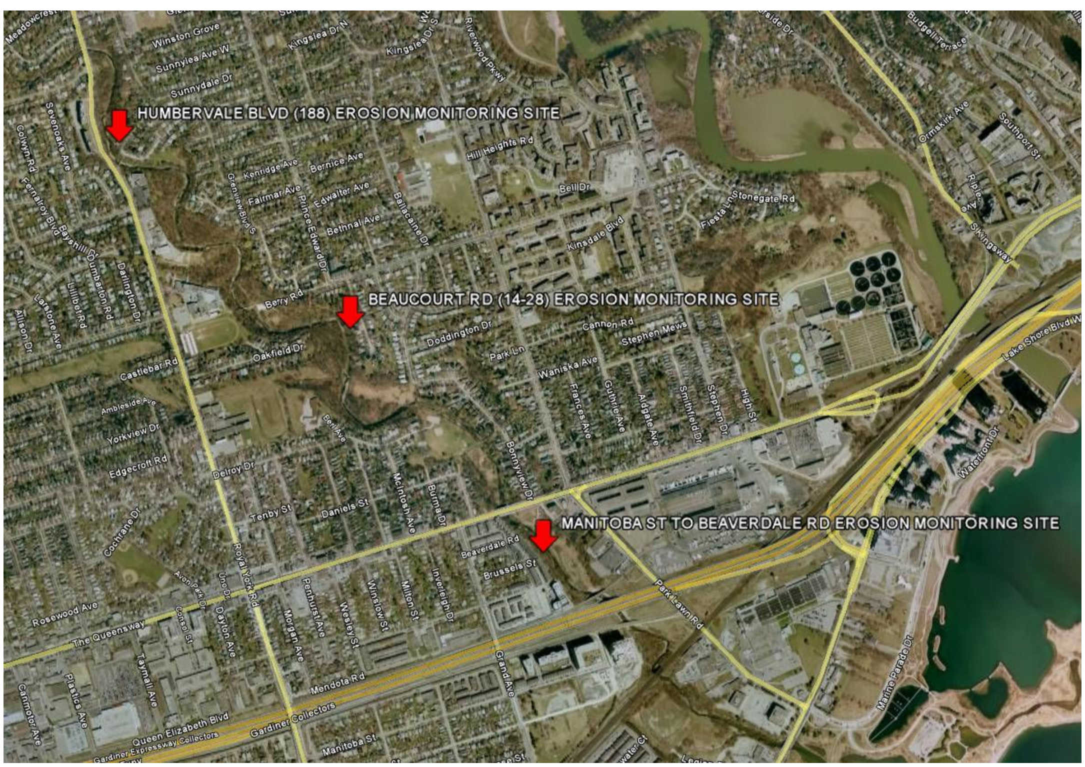


reaches were rated from low to high sensitivity.  Of the 33 reaches observed, 18 were noted as moderately sensitive, 12 were noted as highly sensitive and two sites received a combination, moderate/high rating.  Only one site was noted as having low sensitivity which was due to the fact that this portion of the watercourse had been previously channelized.   Eight of the 18 erosion hazard sites identified under TRCA's Erosion Control Program lie in reaches classified as moderately or moderately/highly sensitive to erosion, while the other sites were in reaches that were not rated as part of the Parish study.  This reach scale information can be used to guide decisions about remediation priority and areas that may be more vulnerable to erosion risks and worthy of regular monitoring.

In the Mimico Creek, in the absence of a comprehensive erosion hazard site inventory, staff have relied on members of the public, municipal staff or other TRCA field staff to identify significant areas of natural erosion.  When sites are identified, staff undertake a site visit to determine whether or not there is any risk to private or public property or infrastructure at the location.  If staff identify that a risk does exist, this site undergoes a priority assessment and is then added to the rotation for annual monitoring.

There are three erosion hazard sites identified on Mimico Creek, which are presented on **Figure 7-6** and include:  Manitoba Street to Beaverdale Road, Humbervale Boulevard and Beaucourt Road.  The Beaucourt Road site is situated in the same location as monitoring station GMI1.  As per the results of the cross-sectional analysis, described earlier in this section, this is the only location within Mimico Creek that exhibited greater than 5 % change in cross-sectional area.

**Figure 7-6:  Mimico Creek Active Erosion Hazard Sites**



*Structures*
In 2009 TRCA completed a field inventory of structures located within 5 m of either side of the Etobicoke Creek watercourse in Peel Region. Structures include outfalls, bridge abutments, channel protection etc.. The priority for maintenance of each structure was assessed based on the level of risk associated with its failure. A total of 1,947 structures were identified, including 68 classified as "high priority" for maintenance. A similar survey is underway in Mimico Creek.

### *7.5.5 Spatial Analysis and Regional Curves*

A spatial analysis was completed to highlight any trends that arose as a result of changes in surficial geology or land use. Having a general understanding of land use type and development trends provides insight into understanding and predicting rates of channel adjustment. Each watershed was sub-divided into rural and urban land use based on 2008 satellite imagery available through Google Earth©. In general, only the headwaters of Etobicoke Creek remain rural, while the remaining mid and tail waters have undergone urban development. Within the generalized urban zone, however, there are localized gradations with respect to development intensity which also play a role in channel stability.

The watersheds were also sub-divided into three primary zones: headwater, mid-watershed and tail waters. Not surprisingly, the majority of the channel enlargement noted within Etobicoke Creek, and to a lesser extent Mimico Creek, was within the headwaters and mid-waters of the watersheds; those zones responsible for sediment production (i.e. erosion) and transport.

The surficial geology of the mid-waters of Etobicoke and Mimico Creeks is dominated by the Peel Plain, a physiographic unit consisting of thin clay till soils. The creeks have cut into, and reworked, these deposits since deglaciation, creating corridors of alluvial sediments within the flood plain (Karrow, 1991). The alluvium is typically coarser-grained than the surrounding till. South of Dundas Street in both watersheds is the Iroqouis Shoreline where deltaic-lacustrine (sand-silt-clay) sediment dominates the surficial geology. These Creeks have carved a deep valley through these deposits and, in many places, have exposed the dolostone and grey shale of the Georgian Bay Formation.

Regionally-based relationships between drainage area and channel parameters such as bankfull geometry are useful watershed management tools for identifying the need for restoration and, ultimately, guiding the design of stable channels. The objective of regional curves is to develop a relationship based on known data points within a watershed from which to establish estimates of stable channel dimensions for portions of the watercourse lacking detailed geomorphic information or flow data. A key assumption of this approach is that the sites in the analysis share consistent topography, geology, flow regimes and land use.

**Appendix 7- D** presents the regional curve results for the Etobicoke Creek watershed. For each of the data plots, a trend line and r-squared value have been presented to indicate the strength of the relationship shown. From a geomorphic perspective, Etobicoke Creek presents several challenges with respect to establishing strong regional relationships in that the data available through various PARISH sources stems from differing land uses, geology and hydrologic regimes. As such, the data set does not meet the key assumptions noted above that provide the basis of the regional curve approach. That being said, one would be hardpressed to find a watershed in Southern Ontario that does meet these underlying assumptions. The data as presented in **Appendix 7- D**, therefore, combines urban and rural data points, as well as overburden and bedrock-controlled points. While this may not be ideal from an interpretation perspective, it results in the most robust data set. Separately, the database would likely not be strong enough to start deriving conclusions.

On each plot, bedrock-controlled sites have been highlighted in order to distinguish whether this parameter does in fact influence channel form. Results indicated that the bedrock-controlled sites tended to be wider and shallower than other sites of comparable drainage area within Etobicoke Creek. These two factors, however, appear to balance and maintain relatively consistent cross-sectional areas from a regional perspective. These sites were also associated with the highest critical discharge targets. The findings are not unexpected given the higher resistance of underlying bedrock to erosive forces. The strongest relationships identified through the regional curve results were with respect to bankfull discharge, cross-sectional area and bankfull width. The poorest relationships occurred with respect to D50 (mean particle size), D84 (particle size or diameter that is larger than 84% of particles from a given sample), bankfull velocity and stream power per unit width.

With respect to the results for Mimico Creek, while boasting fewer data points, the overall data set provides a higher degree of consistency with respect to land use, hydrology and geology than Etobicoke Creek. This consistency provides strong relationships through the regional curve results with respect to bankfull width and cross-sectional area. The poorest relationships occurred with respect to maximum bankfull depth and bankfull discharge. Interestingly, while Mimico Creek offered fewer points from which to draw regional trends, the relationships shown are generally much stronger than those presented for Etobicoke Creek. Having said that, fewer points creates an inherently lower degree of statistical significance with respect to these trends.

From a management perspective, the development of regional relationships allows an understanding of channel morphology at a broad scale based on a limited number of field or gauging sites. Obviously, the more data points established, the more reliable the relationship. Moreover, watersheds that offer a more diverse set of geomorphic controls such as Etobicoke Creek clearly require a greater number of points than a system such as Mimico Creek which does not require the same intensity. Regardless, a scoped field program can provide efficiencies in establishing a baseline data set from which one can identify potential sites requiring restoration (outliers from the regional average) and guide restoration efforts by providing guidance with respect to channel geometry and meander geometry based on limited data (i.e., drainage area as a minimum).

From a statistical perspective, the regional relationships between drainage area and bankfull width, cross-sectional area and bankfull discharge are all strong for Etobicoke Creek. This information would provide vital insight from a design perspective in establishing a design discharge and channel dimensions for a proposed restoration project. Moreover, the reduced strength in relationships pertaining to bankfull depth and velocity emphasize the need to incorporate underlying geomorphic controls such as historic modifications, geology, land use and hydrology into the ultimate solution. Similarly, the Mimico Creek database offers strong relationships between drainage area and bankfull width/ cross-sectional area based on considerably fewer data points. It is reasonable to assume that additional data points will provide even stronger relationships and greater confidence in developing management solutions.

## 7.6 SUMMARY OF FINDINGS

There exist two types of watercourses, natural and altered. Natural watercourses respond to changes in the flow regime and sediment supply by adjusting channel position and changing shape through erosion and deposition, which allows the average channel morphology to remain relatively stable over time. An altered watercourse is one that has over time undergone changes in landuse which affect geomorphic processes on a scale that transcends natural impacts with an effect likened to a major global climate change (Knighton, 1998) or land use changes such as deforestation, farming and urbanization. When changes in flow regime and sediment supply from land clearing and urbanization exceed the thresholds for self-regulation in receiving watercourses, the dynamic equilibrium will be upset causing the channel to become unstable. In such circumstances the watercourse adjusts with physical changes such as bank erosion, lowering of the bed level of the stream, or major changes to the path of the channel itself. The watersheds of Etobicoke and Mimico Creek can be generally defined as altered watercourses.

This section has introduced very preliminary technical findings of the Etobicoke and Mimico Creeks fluvial geomorphology; and technical staff have only begun to establish an understanding of this complex altered and urbanized system. In an effort to improve the level of understanding and to enhance the utility of the technical data, TRCA will continue to monitor conditions at RWMP sites and will expand the network, where feasible, to ensure an accurate representation of reach conditions is understood.

Results of the erosion threshold analysis found that in the upper part of the watershed, the critical discharge values were well above bankfull given the very low gradients and the dominance of coarse materials provided by the Halton Till, which often behaves in ways similar to bedrock. Whereas, analysis showed that critical discharges in the lower more urbanized reaches of the watershed represented erosive flow conditions much more frequently (within bankfull). This, coupled with the typical characteristic of lower reaches to be more incised (or channelized) constrains flow within the channel, reduces its connection to the floodplain, and therefore further increases erosion potential.

The cross-sectional assessment identified ten sites in Etobicoke Creek and one site in Mimico Creek with greater than 5 % change from 2001, which is considered to represent a state of active adjustment. The majority of channel enlargement noted within Etobicoke Creek, and to a lesser extent Mimico Creek, was noted within the headwaters and mid-waters of the watersheds, zones typically responsible for sediment production and transport. However, the detailed assessments at each of these sites indicate that the dominant processes at play at the reach scale may not be consistent with the site-level findings. Bedrock controlled sites in the lower portion of the watershed tended to be wider and shallower than other sites of comparable drainage area within Etobicoke Creek. These sites were also associated with the highest critical discharge targets.

Within Etobicoke Creek, the strongest relationships identified through the regional curve analysis were with respect to upstream drainage area and the following parameters: bankfull discharge, cross-sectional area and bankfull width. Within Mimico Creek the strongest relationships identified through the regional curve analysis were with respect to upstream drainage area and the following parameters: bankfull width and cross-sectional area. Relationships developed through the regional curve analysis can be used to establish estimates of stable channel dimensions for portions of the watercourse lacking detailed geomorphic information or flow data.

However, it should be recognized that these regional curves are based on limited data, and also do not meet the standard assumptions, such as sites sharing consistent topography, geology, flow regimes and land use. Therefore, it is necessary to continue monitoring and collecting data to strengthen the regional curves. This data needs to be supplemented with detailed analysis and consideration of the fact that these relationships are also based on altered watercourses.

Results of the riparian assessment concluded that only 45 per cent of the riparian zone in the Etobicoke Creek and 49 per cent of the riparian zone in the Mimico Creek has natural cover. Channels in the headwaters of the basin are lower gradient, well vegetated channels flowing over Halton Till.

In general, much of the instability associated with the headwater reaches is due to natural causes, such as wood debris jams and beaver dams. The channels with these disturbances tended to be highly unstable. Most of the remaining headwater reaches were moderately unstable or in transition. Reaches around the Lester B. Pearson Airport, both on Etobicoke Creek and the lower reaches of Spring Creek have seen substantial alteration. Many of these reaches have been relocated and hardened. Much of the realignment works have reduced channel length, resulting in an increase in gradient and stream energy. The additional stream energy increases the potential for sediment transport and channel erosion, providing the possibility of increased rates of planform adjustment. These changes, along with the other effects of urbanization, have caused substantial instability in these channels, which tend to be sensitive or unstable. Within the City of Toronto, Etobicoke Creek meanders through a bedrock valley for much of its length. These channels have the greatest alteration/engineering, confinement and prominence of bedrock exposure and control. Many of the channels in this area were sensitive or moderately sensitive.

A summary of the preliminary technical findings by subwatershed are detailed as follows:

*Etobicoke Headwaters*

- Migration rates of 0.11 to 0.3 established for one site, GET 8
- Bankfull channel gradient calculated for 13 sites (range from 0.02 – 0.96 per cent)
- Erosion thresholds established for six sites
- Cross-sectional area analysis undertaken at seven sites of which six showing signs of aggradation and one site, GET10 is eroding
- GET10 identified as one of the top three sites in terms of erosion rates based on control cross-section; however, based on original ten transects, dominant reach-based process is toward aggradation
- Erosion sensitivity ratings for six sites ranged from moderate to highly sensitive

*Etobicoke West Branch*

- Migration rates were calculated for four sites; rates ranged from 0.12 m/yr to 0.28 m/yr
- Bankfull channel gradient calculated for eight sites (range from 0.1 to 0.77 per cent)
- Erosion thresholds established for three sites

- Erosion exceedence duration calculated for two sites, GET4 and GET6 – results show exceedence levels increasing from 2004 to 2006 at both sites with a drop in exceedence levels in 2007 likely due to dry weather conditions
- Cross-sectional area analysis undertaken at two sites of which one showing signs of aggradation and one, GET6 showing signs of erosion
- GET6 identified as one of the top three sites in terms of erosion rates based on control cross-section; original ten transects also indicate that dominant reach-based process is also toward erosion
- Erosion sensitivity ratings for six sites of which five sites rated as moderately sensitive and one site rated as highly sensitive

*Spring Creek*

- Migration rates were calculated for two sites; rates ranged from 0.24 m/yr to 0.6 m/yr
- Migration rate at GET 5 increase from 0.11 m/yr in 2002 to 0.6 m/yr in 2008
- Bankfull channel gradient calculated for ten sites (range from 0.21 to 0.89 per cent)
- Erosion thresholds established for three sites
- Erosion exceedence duration calculated for one site, GET5 – results show exceedence levels declining from 2004 to 2007
- Cross-sectional area analysis undertaken at two sites of which one showing signs of aggradation and one, GET5 showing signs of erosion
- GET5 identified as one of the top three sites in terms of erosion rates based on control cross-section; however, based on original ten transects, dominant reach-based process is toward aggradation
- Erosion sensitivity ratings for seven sites of which four sites rated as moderately sensitive, two sites rated as highly sensitive and one site rated as low sensitivity

*Tributary 3*

- No sites where migration rates calculated
- Bankfull channel gradient calculated for one site (gradient of 0.92 per cent)
- No sites where erosion threshold values calculated
- No sites where cross-sectional analysis completed
- No sites where erosion sensitivity ratings established

*Etobicoke Main Branch*

- Migration rate of 0.16 m/yr established for one site, Palisade
- Bankfull channel gradient calculated for eight sites (range from 0.22 to 0.7 per cent)
- Erosion thresholds established for three sites
- Erosion exceedence duration calculated for one site, GET3 – results show exceedence levels increasing from 2005 to 2006 with a reduction in 2007
- Cross-sectional area analysis undertaken at one site which is showing signs of erosion
- Erosion sensitivity ratings for four sites of which two rated as highly sensitive, one as moderately sensitive and one as moderately/highly sensitive

*Little Etobicoke Creek*

- No sites where migration rates calculated
- Bankfull channel gradient calculated for two sites (range from 0.56 to 0.73 per cent)
- Erosion thresholds established for one site
- Cross-sectional area analysis undertaken at two sites which showed no change

- Erosion sensitivity rating established as moderately/highly sensitive for one site

<u>*Tributary 4*</u>

- No sites where migration rates calculated
- Bankfull channel gradient calculated for three sites (range from 0.57 to 1.39 per cent)
- Erosion thresholds established for one site
- Cross-sectional area analysis undertaken at two sites one of which showing signs of erosion and one showing signs of aggradation
- Erosion sensitivity rating established at three sites of which two received a rating of highly sensitive and one as moderately sensitive

<u>*Lower Etobicoke*</u>

- Migration rates were calculated for two sites; rates ranged from negligible to 0.21m/yr
- Bankfull channel gradient calculated for  eight sites (range from 0.21 to 0.68 per cent)
- Erosion thresholds established for one site
- Cross-sectional area analysis undertaken at three sites all of which are showing signs of aggradation
- Erosion sensitivity rating established at six sites of which two received a rating of highly sensitive and four as moderately sensitive

<u>*Mimico Creek*</u>

- Migration rates were calculated for three sites; rates ranged from negligible to 0.18 m/yr
- Bankfull channel gradient calculated for five sites (range from 0.09 to 0.68 per cent)
- Erosion threshold values established for five sites
- Cross-sectional area analysis undertaken at five sites of which three are showing signs of aggradation and two are showing signs of erosion
- Erosion exceedence duration calculated for two sites, GMI2 and GMI5 – results show exceedence levels increasing at both sites from  2004 to 2006
- Three active erosion sites currently being monitored by TRCA staff
- No sites where erosion sensitivity ratings established

An understanding of the evolution of channel form provides an important context for management of risk to public and private property associated with channel erosion.  Eighteen erosion hazard sites have been identified on Etobicoke Creek where infrastructure or property would be at risk if erosion is left to continue.  Three erosion hazard sites are identified on Mimico Creek, in the lower reaches.

A total of 1,947 structures have been inventories within 5 m of either side of the watercourse in the Etobicoke Creek watershed.  These structures have been assessed in terms of risks and maintenance needs.  A similar assessment is underway for Mimico Creek.

Continued monitoring and assessments at the regional and reach scales is needed to develop a full understanding of the fluvial geomorphology of these watersheds and provide the necessary basis for managing risk at erosion hazard sites and making decisions about the overall protection, management and regeneration of these watercourses.

## 7.7 MANAGEMENT RECOMMENDATIONS

The following management considerations are recommended:

*Further Study*

- Prioritize remedial works, based on a watershed wide risk assessment which has identified areas of erosion that currently pose a risk to property or infrastructure. Implement site-specific monitoring at these sensitive locations and utilize migration rates where possible to determine a critical timeline for implementation of remedial works.

*Monitoring*

- Repeat detailed field assessments at all of the RWMP to provide more meaningful data from which to track regional changes.
- Expand network of monitoring sites to track changing conditions at reach basis, in addition to Regional scale.

*Stormwater Management (new and retrofit)*

- Manage runoff volumes through stringent stormwater management controls that promote the maintenance of pre-development water balance targets (see also Stormwater Management and Streamflow Section).
- Utilize erosion threshold values as a guide for new development applications.
- Utilize erosion threshold values as a guide for design of stormwater retrofit opportunities.

*Regeneration*

- Promote reach-based design and management of erosion protection and channel works such that broader geomorphological processes are adequately understood and addressed.

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## 7.9 APPENDIX 7- A: OVERVIEW OF FACTORS INFLUENCING FLUVIAL GEOMORPHIC PROCESSES

A watercourse, by its very nature, is a dynamic system responding to a constant change in flow regime and sediment supply. The amount of flow in a natural watercourse is determined primarily by climate and geology. Climate controls the amount of water delivered to the surface of the watercourse and how, when and where it arrives. A changing climate with the possibility of more frequent weather extremes and shifts in annual precipitation and temperature patterns is likely to have implications for changes in the shape and form of watercourses.

Geology exerts a fundamental control on what happens to the water once it arrives at the ground surface. Geology establishes the volume and proportion of surface and groundwater available to flow through a drainage basin, given its effect on infiltration and the use of water by vegetation. Geology also determines the volume and properties of sediment supplied to the channel and the strength and erodibility of the surficial material through which the watercourse flows. A complex underlying geology and topography can result in considerable variation in channel character, as well as create areas of variable sensitivity within the same drainage system.

The surficial geology of the middle reaches of Etobicoke and Mimico Creeks is dominated by the Peel Plain, a physiographic unit consisting of thin clay soils. The Peel Plain is comprised of Halton Till (clay and silt) and fine-textured glaciolacustrine deposits of Quaternary age. The creeks have cut into, and reworked, these deposits since deglaciation, creating corridors of alluvial sediments within the flood plain (Karrow, 1991). The alluvium is typically coarser-grained than the surrounding till. South of Dundas Street in both watersheds is the Iroquois Shoreline where deltaic-lacustrine sediment dominates the surficial geology. These Creeks have carved a deep valley through these deposits and, in many places, have exposed the dolostone and grey shale of the Georgian Bay Formation.

Natural watercourses respond to changes in the flow regime and sediment supply by adjusting channel position (migrating back and forth) and changing shape through erosion and deposition. This self-regulating ability is an inherent characteristic of natural watercourses that allows the average channel morphology to remain relatively stable over time. The state in which the flow regime and sediment supply are balanced to achieve this stable channel form is often referred to as *dynamic equilibrium*. In a condition of dynamic equilibrium, channel morphology is stable but not static, since it changes gradually as sediment is deposited and re-mobilized throughout the watercourse. For example, in many natural watercourses the outside of channel bends tend to erode. To offset this erosion, there is generally a corresponding deposition of material on the insides of bends. This gives the channel the appearance of 'migrating' across the floodplain or in a downstream direction. This kind of erosion and deposition is natural and is essential to maintaining the balance between flow and sediment supply in the system. Dynamic equilibrium is also critical for riparian and aquatic biota which are adapted to the habitat provided by this constantly evolving but stable condition.

Over the centuries or even decades, landuse changes through human activities can affect geomorphic processes on a scale that transcends natural impacts with an effect likened to a major global climate change (Knighton, 1998). Deforestation reduces evapo-transpiration and infiltration and increases runoff and sediment supply to watercourses. Farming introduces tile drainage and watercourse re-direction through ditches, which reduces stream length and alters flow and habitat potential. Urban development typically results in the extensive compression and paving of land surfaces, which significantly reduces infiltration and dramatically increases runoff to watercourses. When changes in flow regime and sediment supply from land clearing and urbanization exceed the thresholds for self-regulation in receiving watercourses, the dynamic equilibrium will be upset causing the channel to become unstable. In such circumstances the watercourse adjusts with physical changes that occur much more rapidly than the controlled adjustments of the natural dynamic equilibrium. These changes are rapid, extensive and often catastrophic and may include severe bank erosion, a lowering of the bed level of the stream, or major changes to the path of the channel itself. Such changes can result in destruction of aquatic and riparian habitat, damage to infrastructure and property, and risks to public safety.

Protecting, managing and restoring the shape and form of watercourses requires a thorough understanding of fluvial geomorphology and the effects of urbanization on geomorphic processes. Management of the potential impacts of urbanization should be addressed through watershed scale and neighbourhood scale land use planning and the application of best management practices in urban developments, as experience has shown that it is extremely difficult to repair watercourses after damage from urbanization has occurred.

**Effects of Urbanization on Channel Form**

Research into the effects of urbanization on watercourses has indicated that the critical threshold, at which channel destabilization begins, typically corresponds to a total drainage basin imperviousness of three to five percent (Hammer, 1972; Booth, 1990). Significant enlargement of the channel cross-section begins once the drainage basin reaches five to ten percent imperviousness. It is estimated that the channel will continue to enlarge, in response to urbanization, for a period of 35 to 65 years after the end of development in the watershed. Once adjustment of the channel to urbanization is complete, the cross-sectional area may be up to 6 times greater than that of the channel prior to disturbance (e.g., Hammer, 1972). This enlargement can occur by erosion of the channel banks and incision of the channel bed, the degree of each being determined by the channels' relative resistance to erosion.

In addition to cross-section enlargement, urban watercourses also experience adjustment of their plan form as the channel attempts to evolve a new meander pattern that is compatible with the new flow regime and sediment supply. The time frame for this adjustment process is thought to take an order of magnitude longer than cross-section change, resulting in a total period of instability as a result of urbanization that may be measured in centuries. It is theorized that urban watercourses will eventually achieve a new form of dynamic equilibrium through these adjustments, but even if this should occur, experience suggests that the ultimate form of an urban watercourse will bear little resemblance to a natural watercourse and will not possess the stability or structure required to support diverse aquatic ecosystems (Booth and Jackson, 1997; Fuerstenberg, 1997).

**Direct modification of watercourses**
In addition to the effects of land use change, human induced change can also include activities that result in direct modification to watercourse channels themselves. Agricultural practices can sometimes result in the realignment and channelization of watercourses resulting in loss of natural channel forms and habitats. Tillage immediately adjacent to watercourses causes channel instability as bank vegetation that would normally control erosion rates is lost. In the past, channels were realigned and straightened to facilitate development, changing aquatic habitat and intensifying channel instability as the resulting artificial channel forms lacked natural adjustment mechanisms. Furthermore, historic approaches to flood control have emphasized the rapid removal of water from the landscape, generally via the realignment, enlargement, and hardening of river and stream networks. The resultant increase in flow velocities and reduction in flow attenuation from the disconnection of channelized watercourses from their floodplain has amplified the increase in flows caused by urban land uses and exacerbated the resultant erosion.

**Engineered erosion protection**
Historically, the management of channel instability and increased erosion in impacted urban watercourses has been addressed using engineered erosion protection. This has involved a variety of modifications to river and stream channels including hardening of bed and/or banks with concrete, riprap, gabion baskets or armour stone as well as the installation of weirs and other grade control measures. However, in many cases such works have failed because they are undermined or circumvented by the watercourse channel as it adjusts either to maintain its natural evolutionary path or to respond to continued urbanization. Such works also affect aquatic and riparian habitat within and adjacent to the watercourse. Hardening of the channel increases velocities and decreases natural attenuation of flows, exaggerating the urban land use impacts on physical channel form. As a result, these conventional engineering approaches have typically resulted in a cycle of failure of the installed protection and ongoing channel degradation, leading to regular repair and extension of existing works and to the need for constructing new protection works elsewhere.

**Natural channel design**
In recognition of the negative outcomes of past erosion management approaches, current approaches include consideration of geomorphic and ecological processes, as well as potential impacts on upstream and downstream areas when designing and constructing erosion protection works. In some cases, large sections of watercourse are reconstructed in an attempt to restore equilibrium conditions through a practice referred to as “natural channel design”. However, the complexity of geomorphic processes in urban watercourses and the constraints created by infrastructure and private property make it difficult to truly recreate natural channels, and the performance of such projects in restoring natural physical and ecological function of watercourses is still unknown.

**Conventional erosion protection for “at risk” sites**
Further, conventional erosion protection works continue to be constructed for sites or areas immediately at risk where there is insufficient time, space or funding to examine more comprehensive process-based solutions.

**Stormwater management measures**
In addition, over the past two decades, development has increasingly incorporated stormwater management measures in an attempt to mitigate the imbalance between the urban hydrologic regime and the natural channel form. By far the most popular and widely-used approach is the design of end-of-pipe stormwater ponds or wetlands to detain the excess runoff from urban developments and release it slowly at a rate that is considered to be safe to the stability of the receiving watercourse. The design of such facilities is typically predicated on the assumption that flows in the watercourse below the level required to initiate sediment transport (i.e. erosion threshold) of the median substrate particle size will not result in erosion.

Currently, there is increasing evidence that these stormwater detention facilities may not be protecting receiving watercourses downstream of new developments (Booth and Jackson, 1997). It is speculated that this may be due to an oversimplification of complex mechanisms of erosion and sediment transport in current design practices in that the release of flows at low rates may not be sufficient to mitigate their impacts (Aquafor Beech Limited, 2007). In addition, there is evidence to suggest that these facilities may not be performing as designed such that the level of flow detention may not be sufficient in real-world conditions (Bengtsson and Westerstrom, 1992). Such results suggest that stormwater management approaches based on detention may not be sufficient to manage the watercourse impacts from increases in runoff and flow volume in urban areas.

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## 7.10 APPENDIX 7- B: MIGRATION RATE ASSESSMENT

Historic Analysis for all sites investigated within the Etobicoke Creek and Mimico Creek watersheds.

| Site | Land-Use | Channel Alterations and Modifications | General Site Measurements | | |
|---|---|---|---|---|---|
| | | | Channel Width (m) | Stability | Migration Rates (m/yr) |
| **GET-1** | 1954= Urban residential/Urban Golf Course<br>1978= Urban residential/Urban Golf Course<br>2006= Urban residential/Urban Golf Course | Channel length has not changed. | 1954= 19<br>1978= 18.3<br>1999= 23.1<br>2008= 18.5 | 2001=Moderate | No change |
| **GET-2** | 1954= Rural agriculture/residential<br>1978= Urban rural/golf course<br>2006= Urban residential, urban golf course | No significant changes observed in areas not obscured by tree cover. | 2008= 7.2 | 2001=Moderate | Obscured by trees |
| **GET-3** | 1954= Rural agriculture<br>1978= Rural residential/Rural vacant<br>1999= Urban mix of commercial and residential, Urban golf course<br>2006= Urban mix of commercial and residential, Urban golf course | Altered between 1954 and 1978; channel length has decreased; valley wall erosion has increased. | 1954= 10.3<br>1978= 13.9<br>1999= 14.5<br>2008= 24.8 | 2001= Moderate | Altered channel |
| **GET-4** | 1954= Airport property<br>1978= Airport property<br>2006= Airport property | Between 1954 to 1999 -4.6% change in length.<br><br>Since 1954 sections were relocated and hardened to accommodate runway expansion for the airport. | 44.9% change between 1964 and 1999<br>2008= 13.1 | 2001= Moderate | 0.28m/yr 1954-1999 |
| **GET-5** | 1954= Agriculture with few commercial buildings<br>1978= Agriculture with commercial buildings<br>2006= Agriculture with commercial buildings | Between 1954 to 1999 -21% change in length.<br><br>Top portion of the reach is straight and unchanged since 1954, bottom half of reach was realigned since 1978. | 78.5% change from 1964 and 1999<br>2008= 12.4 | 2001= High | 0.11 m/yr 1954 to 1999 |
| **GET-6** | 1954= n/a<br>1978= n/a<br>2006= Urban residential, urban park | Channel section has been completely concrete lined in upstream end south of Queen St. | 2008= 12.1 | 2001= Moderate | Not available |
| **GET-7** | 1954= n/a<br>1978= n/a<br>2006= Urban residential, urban park, SWM pond | Sections of channel have been hardened at unknown times.<br><br>It is also highly probable that the entire section of channel has been modified to a smooth meander pattern. | 2008= 5.0 | 2001=High | Not available |
| **GET-8** | 1978= Agriculture<br>1995= Residential areas<br>2006= Residential and agriculture | Slight shift in channel has occurred due to the presence or meander cut-off and oxbow in a meander depression on the floodplain. | 2008= 7.2 | 2001=High | 0.11 to 0.3m/yr from 1978 to 1995 |
| **GET-9** | 1954= n/a<br>1978= n/a<br>2006= Rural agriculture | No significant changes have occurred. | 2008= 8.2 | 2001= Moderate | Not available |
| **GET-10** | 1954= n/a<br>1978= n/a<br>2006= Rural agriculture | Large meander scar present.<br><br>No significant changes have occurred. | 2008= 3.5 | 2001=High | No change |
| **GMI-1** | 1954= Urban<br>1978= Urban<br>2006= Urban, urban park | Planform remains similar; some bank protection.<br><br>Concrete weir regulates flow upstream of site. | 2008= 14.2 | 2001= Low | No change |
| **GMI-2** | 1954= Urban residential<br>1978= Urban mix of commercial and residential<br>1999= Urban mix of commercial and residential<br>2006= Urban mix of commercial and residential | Historically the channel has not been altered.<br><br>Right bank has eroded significantly. | 1954= 9.6<br>1978= 8.0<br>1999= 9.8<br>2008= 15.5 | 2001= Low | Poor aerial imagery, therefore not possible. |
| **GMI-3** | 1954= Rural agriculture<br>1978= Urban residential, Urban park<br>1999= Urban residential, Urban park | Channel has been straightened since 1954 and length has decreased by 26.2% by 1978 due to construction of Hwy 401. | 1954= 8.7<br>1978= 9.0<br>1999= 8.8 | 2001= Low | Altered channel |

Historic Analysis for all sites investigated within the Etobicoke Creek and Mimico Creek watersheds.

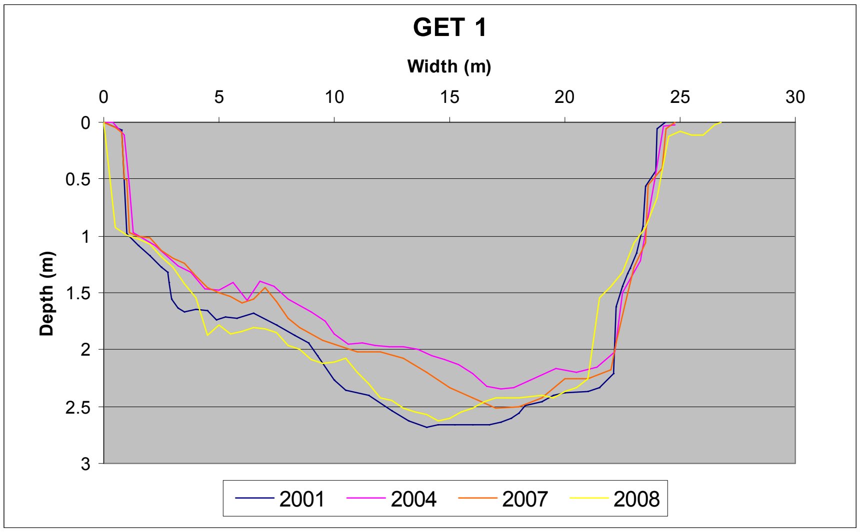
| Site | Land-Use | Channel Alterations and Modifications | General Site Measurements | | |
|---|---|---|---|---|---|
| | | | Channel Width (m) | Stability | Migration Rates (m/yr) |
| | 2006= Urban residential, Urban park | | 2008= 11.2 | | |
| **GMI-4** | 1954= Rural agriculture<br>1978= Urban commercial, Urban vacant<br>1999= Urban commercial, Urban golf course<br>2006= Urban commercial, Urban golf course | Alteration has occurred to accommodate the building of Hwy 409. | 1954= 7.9<br>1978= 7.5<br>1999= 9.0<br>2008= 9.5 | 2001= Moderate | Between 1954 and 1978= 0.04m/yr |
| **GMI-5** | 1954= Rural commercial, Rural vacant-parkland<br>1978= Urban commercial, Urban parkland<br>1999= Urban parkland<br>2006= Urban parkland | Slight planform change since 1954;, much of channel is obscured by tree cover. | 1954= 10.0<br>1978= 8.6<br>1999= Covered by trees<br>2008= 9.6 | 2001= Moderate | Not available |
| **Creekbank Rd Extension** | 1954= All rural land with agricultural fields, airport.<br>1968= Significant road development yet mainly agricultural, airport expansion.<br>1976= Commercial expansion, airport.<br>1988= Mainly commercial/industrial.<br>2006= Mainly commercial/industrial. | Channel was completely constructed by 1976 to drain local area.<br>Much of channel is piped and runs under developments. | 2006 avg= 8.37 | 2006=In adjustment | Not possible |
| **East Etobicoke Study** | 1954= Mainly agricultural.<br>2006= Commercial/industrial. | Downstream of Bramalea Rd. the channel has been aligned for a bridge crossing,<br>In 1970 the channel downstream was altered during airport expansion. | 2002= 8.55 | 2001= In adjustment | 0.24m/yr |
| **Peel Sanitary Sewer** | 1954= Mainly commercial with some open grass fields.<br>1978= Mainly commercial with some open grass fields.<br>2006= Mainly commercial with some open grass fields. | Multiple bank stabilization attempts.<br>Trunk sewer constructed in the 1970's. | 2007= 20.0 | 2007= In adjustment | Avg=0.21m/yr |
| **Winter Greck on Etobicoke Creek** | 1954= Mainly commercial with some open grass fields.<br>1978= Mainly commercial with some open grass fields.<br>2006= Mainly commercial with some open grass fields. | Multiple bank stabilization attempts.<br>Trunk sewer constructed in the 1970's. | 2001= 16.0 | Not available | Not available |
| **Derry-Dixie Road** | 1954= Mainly agricultural.<br>1975= Mainly agricultural.<br>2000= Commercial/ industrial.<br>2006= Mainly commercial with some open grass fields. | Based on air photos, channel widening has occurred due to increased input from surrounding areas. | 2008 avg = 11.34 | Not available | Not available |
| **Courtney Park Dr Extension** | 1954= Completely agricultural.<br>1966= Completely agricultural.<br>1985= Residential to the west, agricultural to the east.<br>1995= Residential to the west, agricultural to the east. | Based on air photos, channel has widened slightly due to increased input from residential area. | 1997= 21.05 | Not available | Not available |
| **Centennial Park Etobicoke Creek** | 1994= Meadow, park trails, residential buildings.<br>1998= Meadow, park trails, residential buildings. | Not available | 1998=11.2 | Not available | Not available |
| **Mimico-Parklawn Cut and Fill operation** | 1954= Primarily residential.<br>1978= Mainly commercial/industrial with some residential.<br>2006= Mainly commercial/industrial. | Channel straightened and hardened just upstream of Bonar Creek confluence by 1954. | 1954= 14.8<br>1978= 13.5<br>2006= 13.97 | Not available | Avg=0.018m/yr |
| **Etobicoke Creek Site B** | 1954= Mainly agricultural, some residential areas in the north.<br>1970= Commercial buildings constructed<br>2006= Primarily commercial/industrial. | Channel sections have been straightened multiple times from 1968 to 1988. | 1999= 15.50 | Not available | 0.14m/yr |
| **Etobicoke Creek Site A** | 1954= Mainly agricultural.<br>1978=Commercial development.<br>2006= Mainly commercial/industrial. | Elongation of channel due to flooding from Hurricane Hazel.<br>Increase in channel width since 1954. | Increased since 1954 to 1999 at 0.072m/yr.<br><br>1999= 14.12 | Not available | Usual= 0.13m/yr<br>Max= 0.41m/yr |
| **Little Etobicoke Creek** | 1954= Primarily agricultural, with some major road construction.<br>1975= Minor agriculture, mainly commercial/industrial.<br>2006= Completely commercial/industrial. | Channelized in the 1970's.<br>Complete re-alignment of channel by 1985. | 2008= 3.9 | 2008= Transitional | Not available |
| **Bonar Creek** | 1954= Sparse commercial development. | Creek has been piped under the CNR and roads. | 2007= avg is 3.5 | 2007= In regime | Not available |

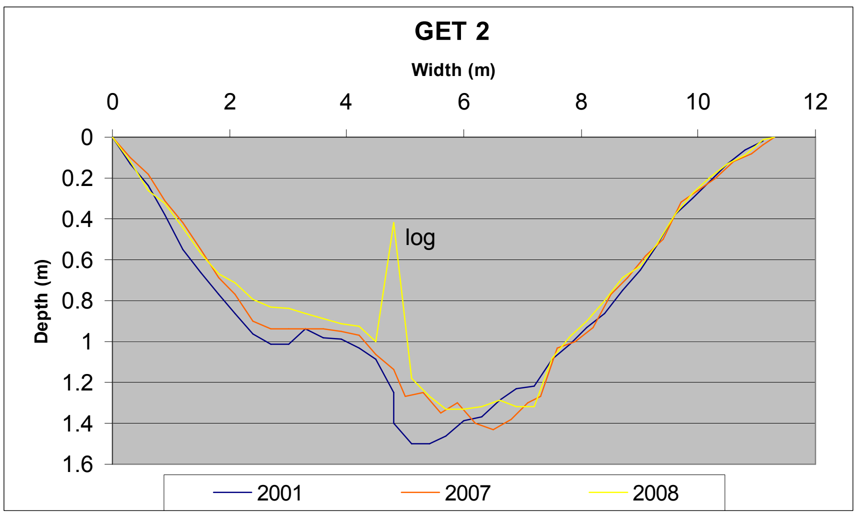
Historic Analysis for all sites investigated within the Etobicoke Creek and Mimico Creek watersheds.

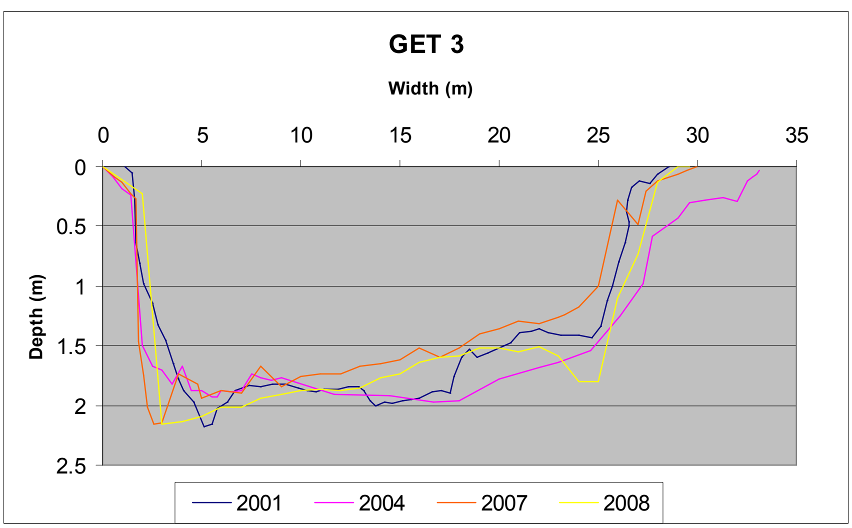
| Site | Land-Use | Channel Alterations and Modifications | General Site Measurements | | |
|---|---|---|---|---|---|
| | | | Channel Width (m) | Stability | Migration Rates (m/yr) |
| | 2006= Mainly commercial with some residential areas. | Much of channel has been straightened. | | (1 reach border line transitional) | |
| **Palisades Lane** | 1954= Mainly agriculture with tree corridors covering channel banks.<br>1978-= Encroachment of residential development and agricultural.<br>2006=Mainly residential, golf course upstream. | Slight enlargement of meanders downstream of Eglington Ave.<br>Slight section re-alignment after 1978 downstream of Rathburn Rd. | 2003=17.22 | Not available | Upstream= 0.16/yr<br>Downstream= 0.52m/yr |
| **Phase 1 Regeneration Etobicoke Creek** | 1954= Completely agricultural.<br>1966= Completely agricultural.<br>1985= Residential to the west, agricultural to the east.<br>1995= Residential to the west, agricultural to the east. | Channel has been straightened since 1954 and a meander has been removed downstream | 1999= 15.50<br>2005= 17.08 | Not available | Not available |
| **Phase 2 Regeneration Etobicoke Creek** | 1954= Mainly agricultural.<br>1975= Mainly agricultural.<br>2000= Commercial/ industrial.<br>2006= Mainly commercial with some open grass fields. | Based on air photos, channel widening has occurred due to increased input from surrounding areas. | 2005= 11.18 | 2005= In adjustment (1 reach border line transitional/adjustment) | Not available |
| **Mayfield West MEC-R1** | 1950= Mainly agricultural.<br>1988= Mainly agricultural.<br>2006= Mainly agricultural and residential buildings. | Increase in channel width since 1950. | 2008= 6.4 | 2008= Undefined | Not available |
| **Mayfield West MEC-R2** | 1950= Mainly agricultural.<br>1988= Mainly agricultural.<br>2006= Mainly agricultural. | Slight increase in channel definition since 1950. | 2008= 5.0 | 2008= Undefined | Not available |
| **Mayfield West MEC-R8** | 1950= Mainly agricultural.<br>1988= Mainly agricultural.<br>2006= Mainly agricultural. | Significant increase in channel width and definition since 1950. No major changes to channel planform. | 2008= 4.6 | 2008= Undefined | Not available |
| **Mayfield West MED-R25** | 1950= Mainly agricultural.<br>1988= Mainly agricultural.<br>2006= Mainly agricultural. | Slight increase in channel definition since 1950. Pond has been formed on right bank. | 2008= 5.2 | 2008= Regime | Not available |

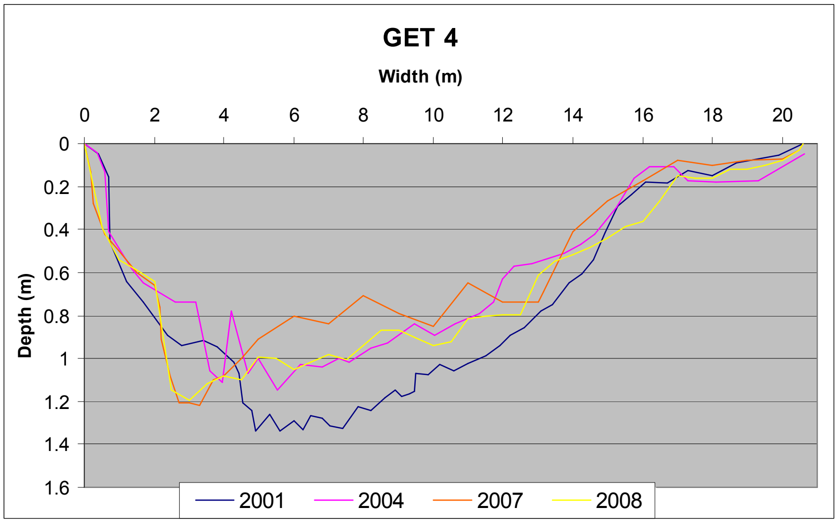
## 7.11 APPENDIX 7- C: CROSS-SECTIONAL ASSESSMENT RESULTS

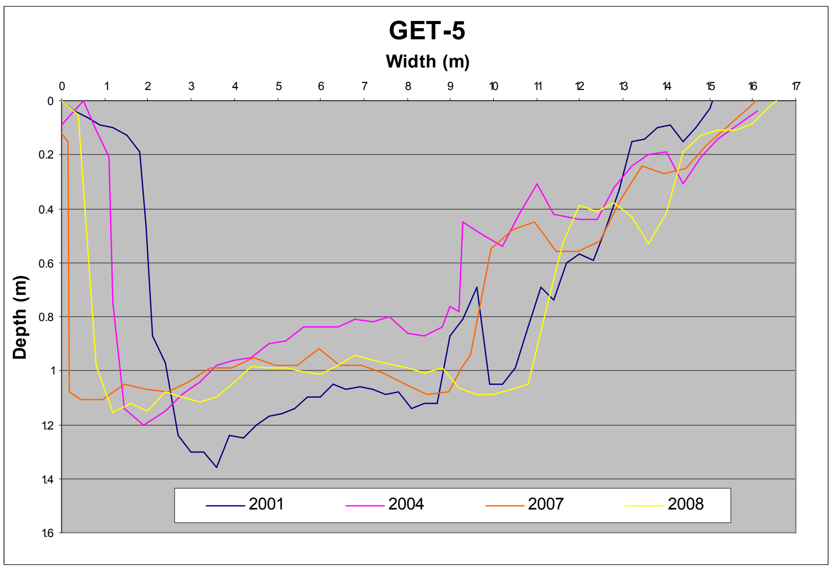
### Monitoring Cross-Sections (Etobicoke Creek)

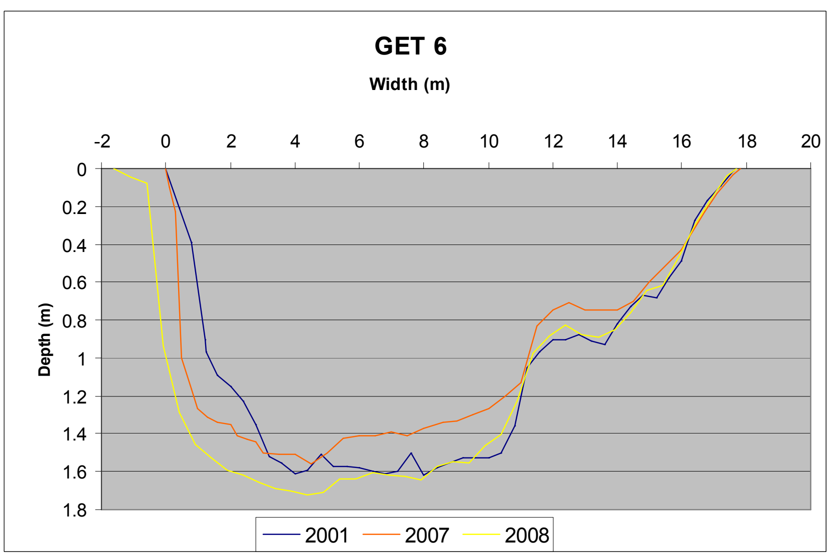


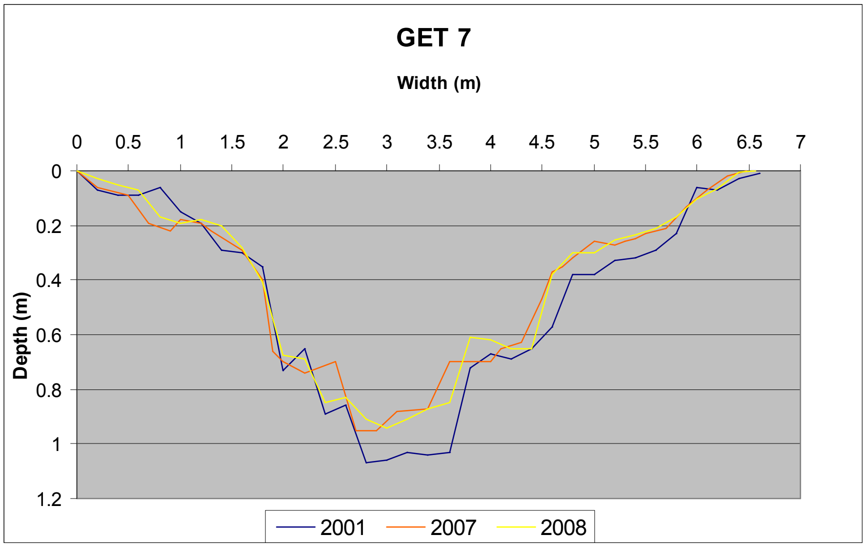



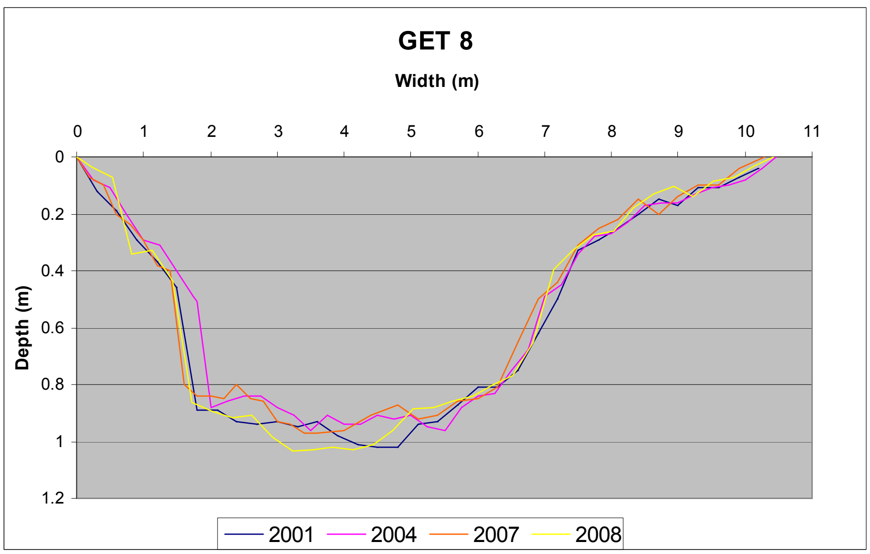



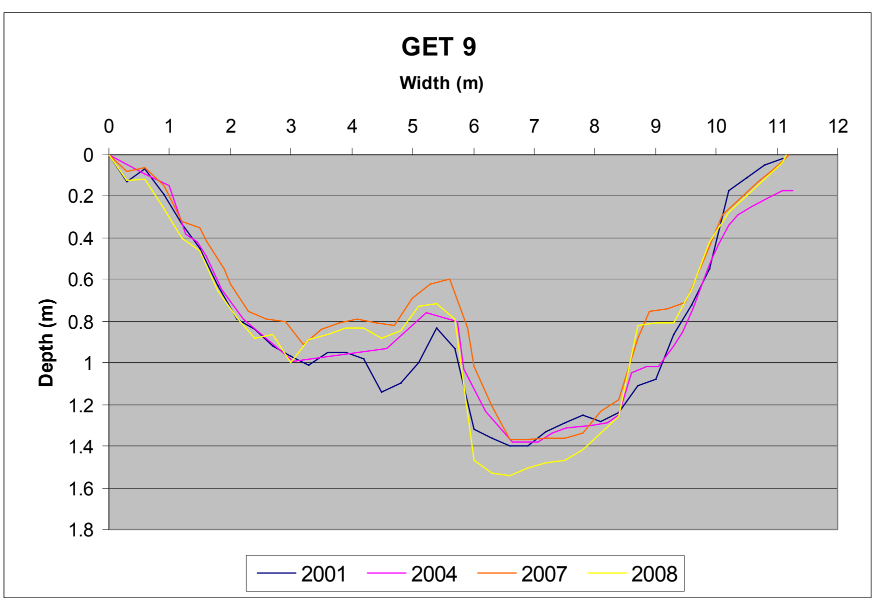

GET 4
Width (m)
Depth (m)
0
2
4
6
8
10
12
14
16
18
20
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
2001
2004
2007
2008

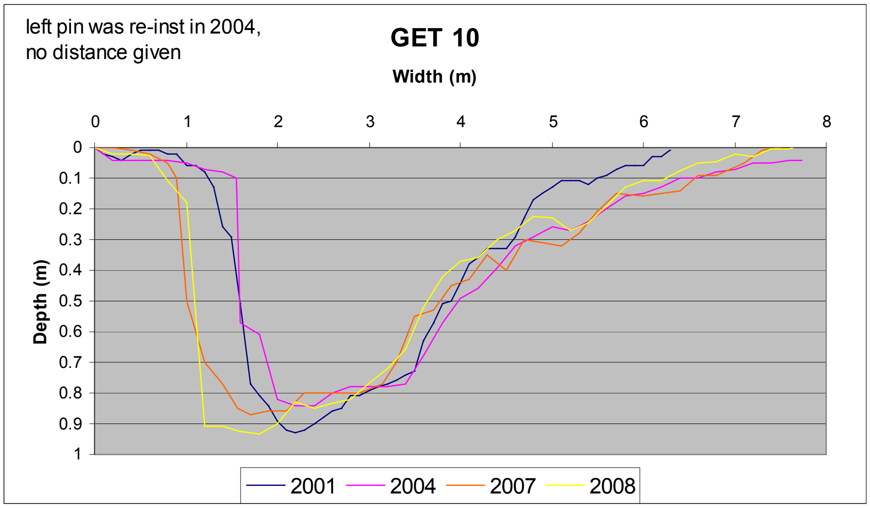

GET-5
Width (m)
Depth (m)
2001
2004
2007
2008

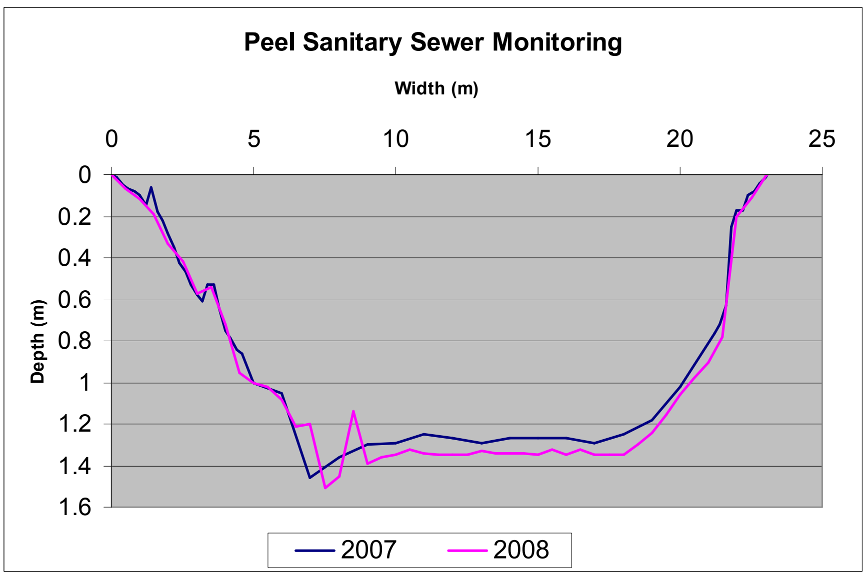

GET 6
Width (m)
Depth (m)
-2
0
2
4
6
8
10
12
14
16
18
20
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2001
2007
2008

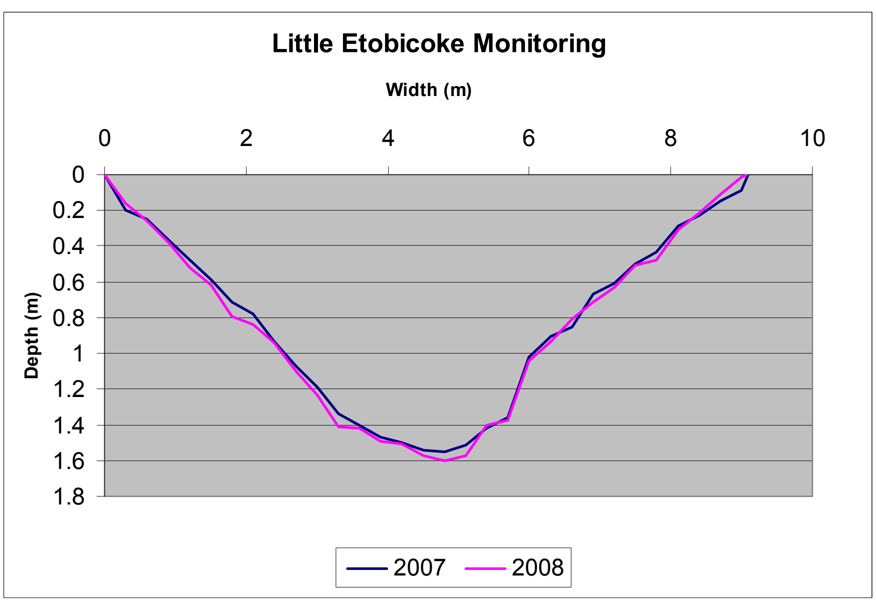

GET 7
Width (m)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
Depth (m)
0
0.2
0.4
0.6
0.8
1
1.2
2001
2007
2008

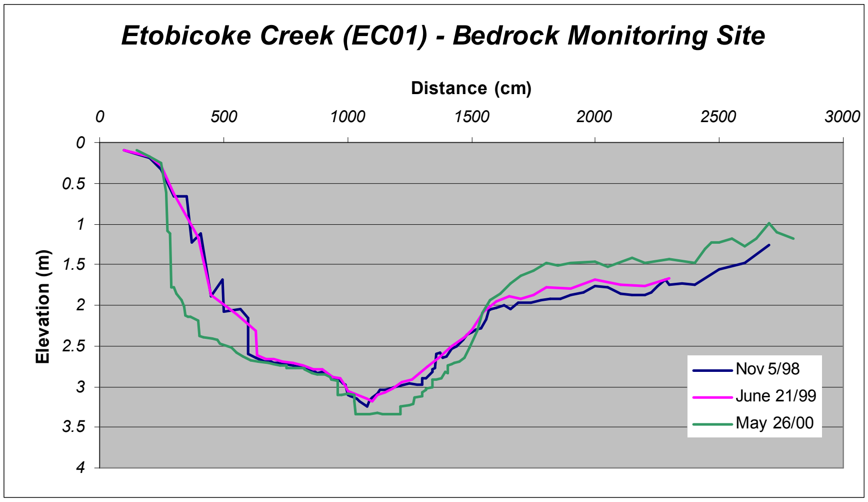

GET 8
Width (m)
0
1
2
3
4
5
6
7
8
9
10
11
Depth (m)
0
0.2
0.4
0.6
0.8
1
1.2
2001
2004
2007
2008

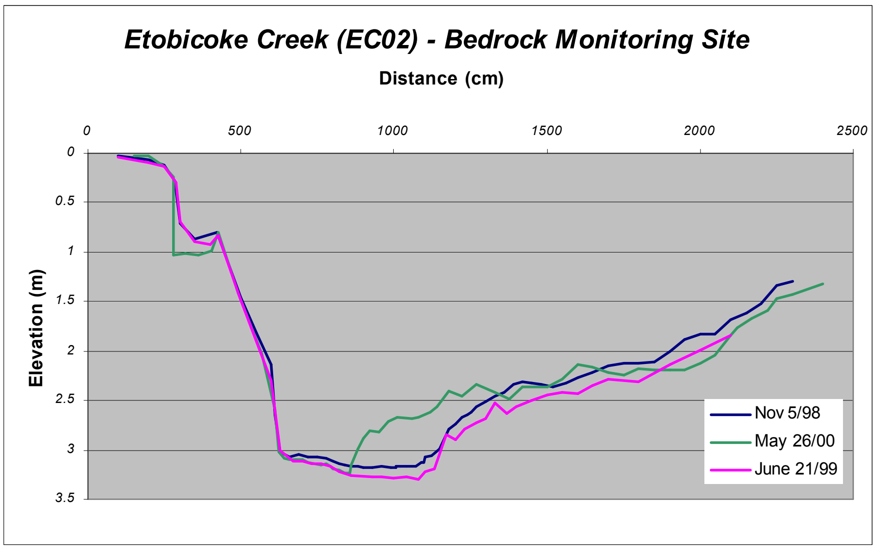

GET 9
Width (m)
0
1
2
3
4
5
6
7
8
9
10
11
12
Depth (m)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2001
2004
2007
2008

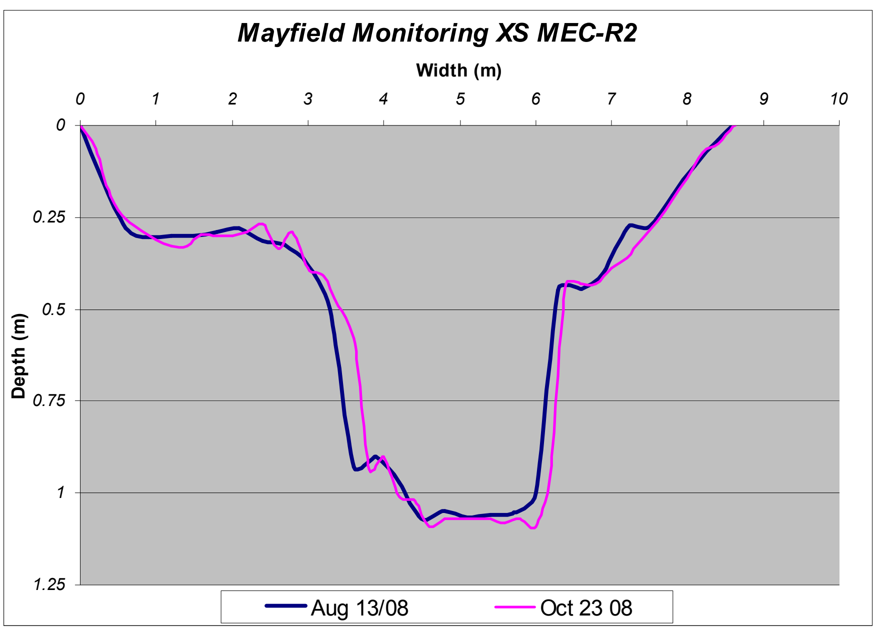

left pin was re-inst in 2004, no distance given
GET 10
Width (m)
0 1 2 3 4 5 6 7 8
Depth (m)
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
2001 2004 2007 2008

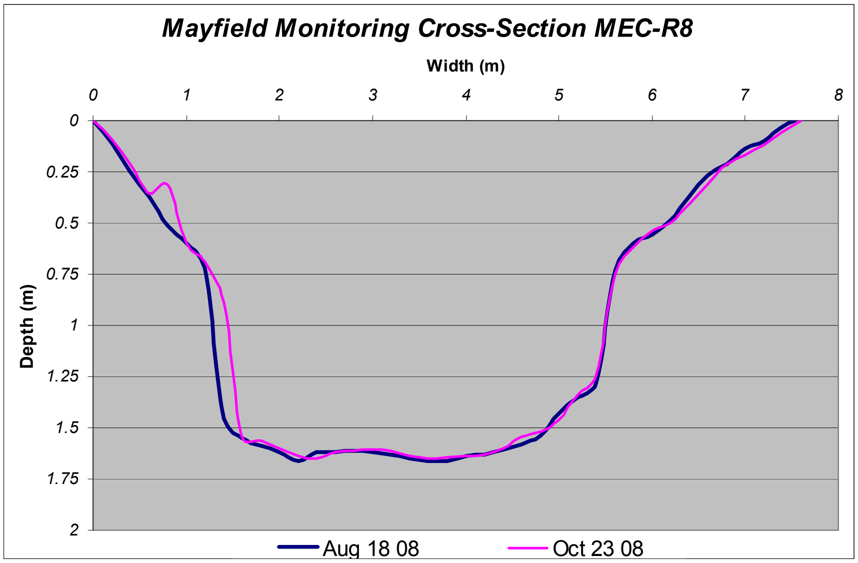

Peel Sanitary Sewer Monitoring
Width (m)
0 5 10 15 20 25
Depth (m)
0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6
2007 2008

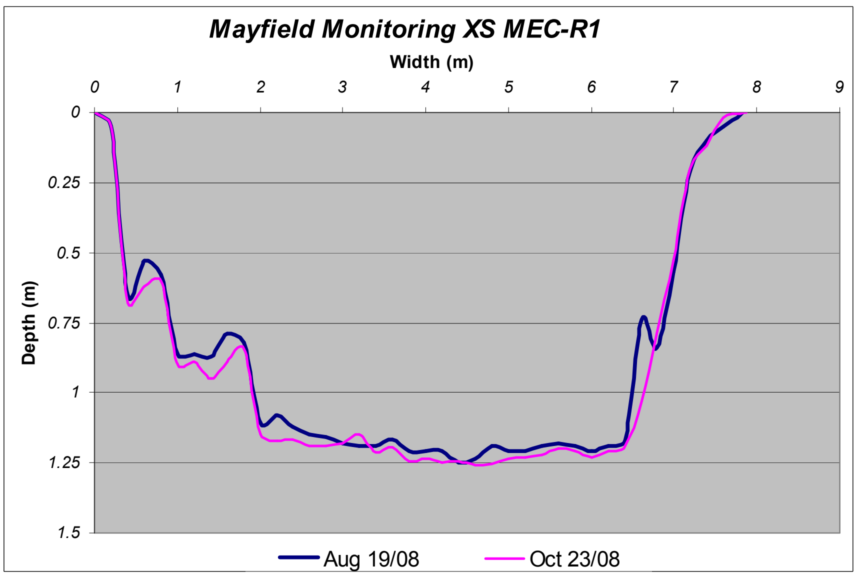

Little Etobicoke Monitoring
Width (m)
0 2 4 6 8 10
Depth (m)
0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8
2007 2008

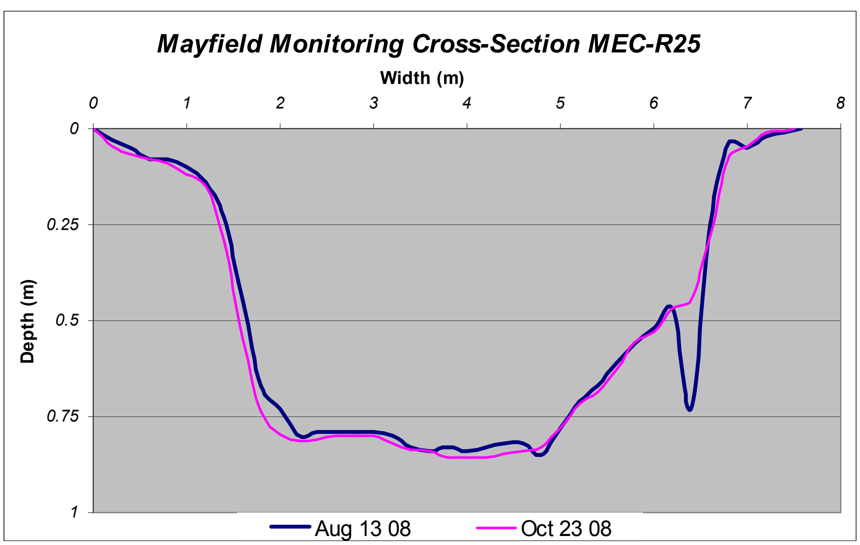

Etobicoke Creek (EC01) - Bedrock Monitoring Site
Distance (cm)
0
500
1000
1500
2000
2500
3000
Elevation (m)
0
0.5
1
1.5
2
2.5
3
3.5
4
Nov 5/98
June 21/99
May 26/00

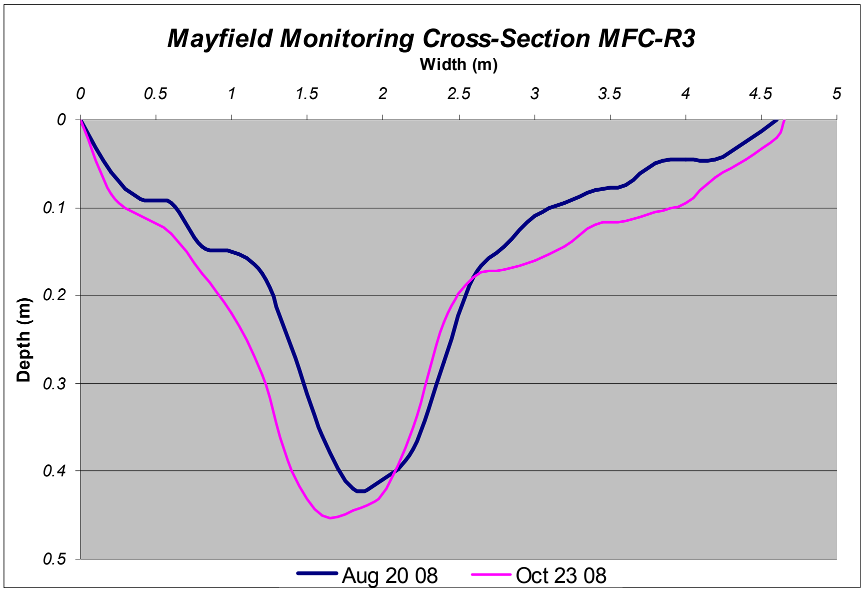

Etobicoke Creek (EC02) - Bedrock Monitoring Site
Distance (cm)
0
500
1000
1500
2000
2500
Elevation (m)
0
0.5
1
1.5
2
2.5
3
3.5
Nov 5/98
May 26/00
June 21/99


Mayfield Monitoring XS MEC-R2
Width (m)
0
1
2
3
4
5
6
7
8
9
10
Depth (m)
0
0.25
0.5
0.75
1
1.25
Aug 13/08
Oct 23 08

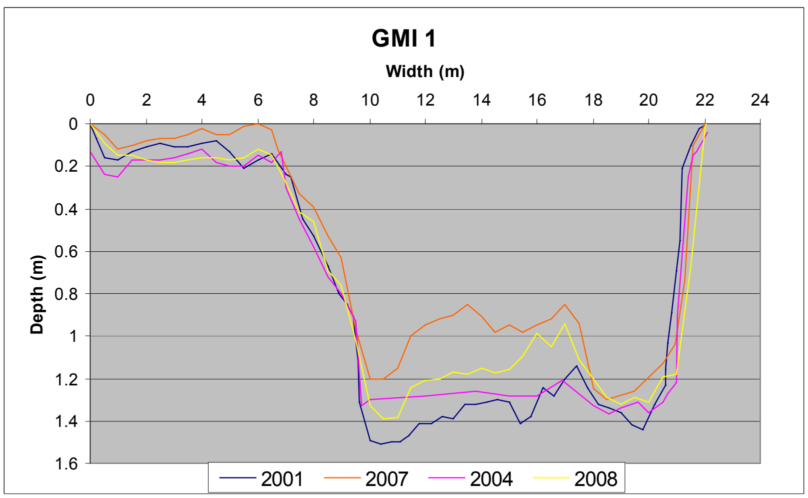

Mayfield Monitoring Cross-Section MEC-R8
Width (m)
0
1
2
3
4
5
6
7
8
0
0.25
0.5
0.75
1
1.25
1.5
1.75
2
Depth (m)
Aug 18 08
Oct 23 08

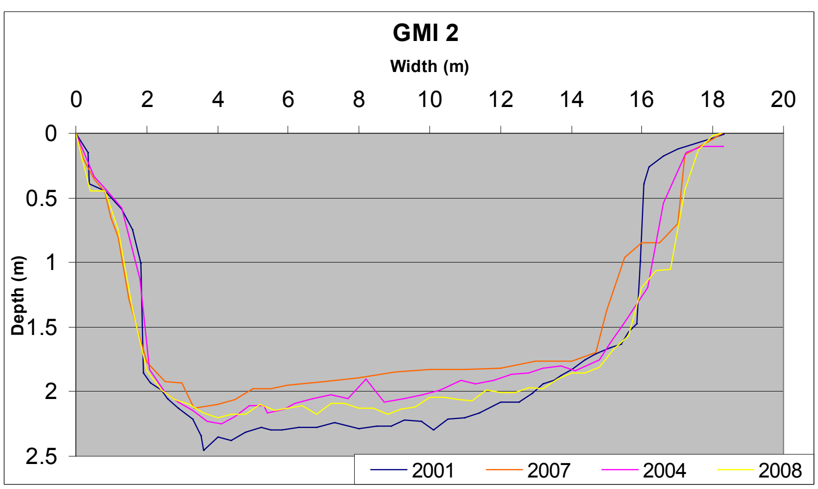

Mayfield Monitoring XS MEC-R1
Width (m)
0
1
2
3
4
5
6
7
8
9
0
0.25
0.5
0.75
1
1.25
1.5
Depth (m)
Aug 19/08
Oct 23/08

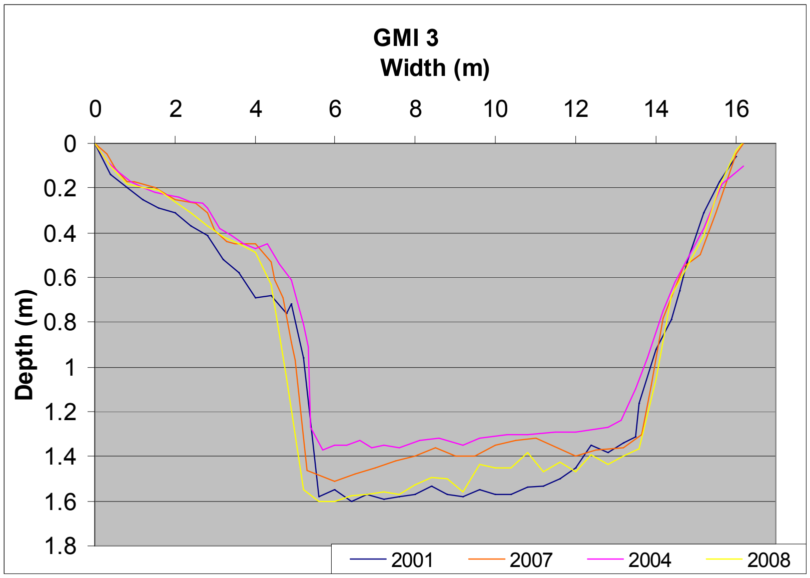

Mayfield Monitoring Cross-Section MEC-R25
Width (m)
0
1
2
3
4
5
6
7
8
0
0.25
0.5
0.75
1
Depth (m)
Aug 13 08
Oct 23 08



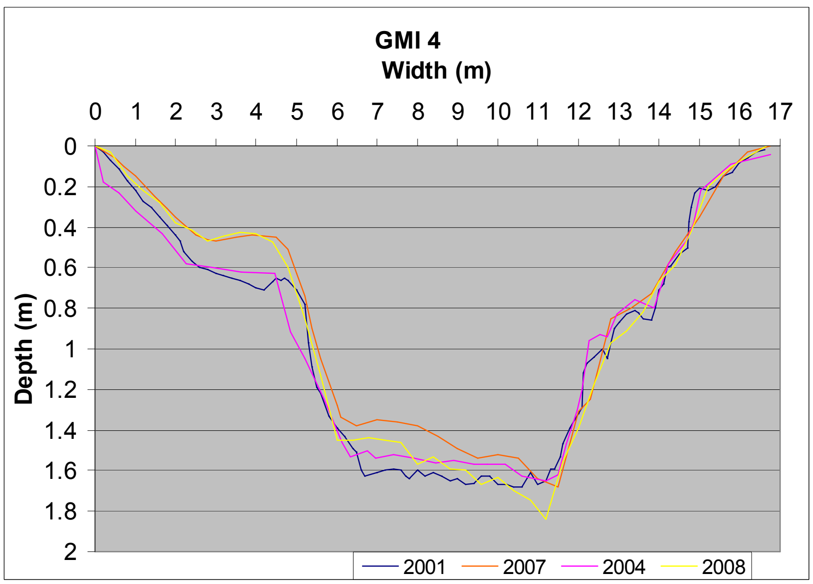

## Monitoring Cross-Sections (Mimico Creek)



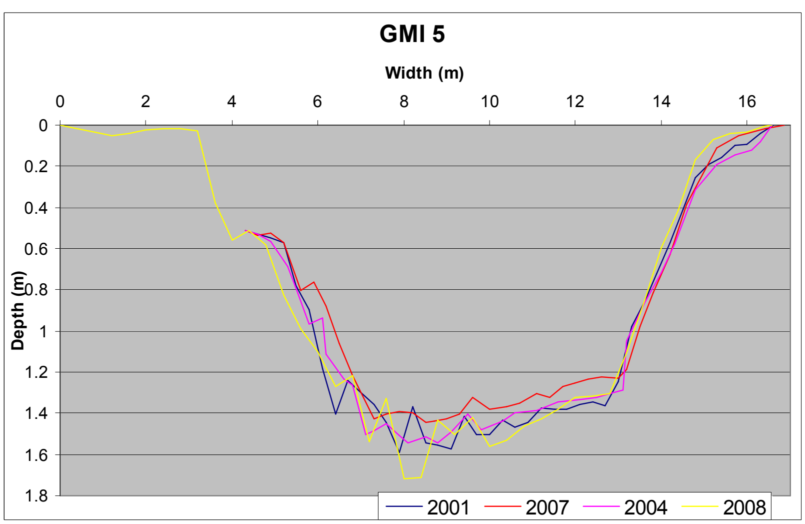





GMI 3
Width (m)
0
2
4
6
8
10
12
14
16
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
Depth (m)
2001
2007
2004
2008

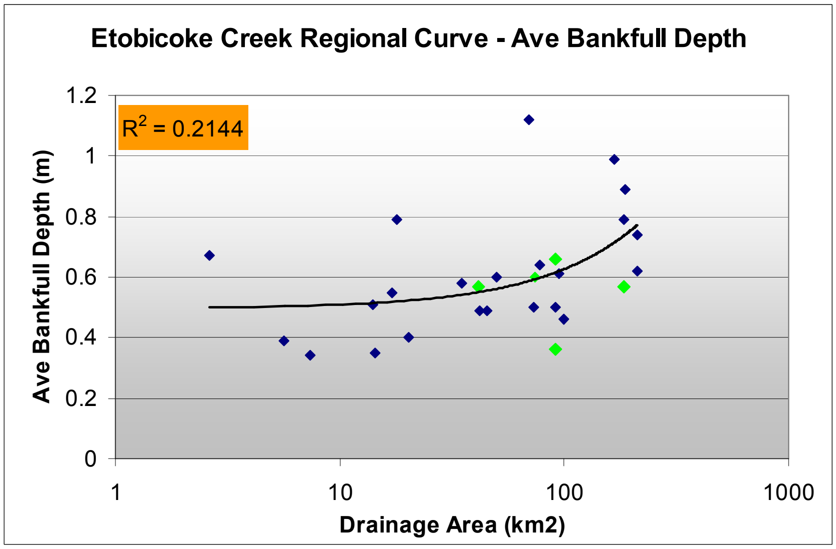
GMI 4
Width (m)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth (m)
2001
2007
2004
2008

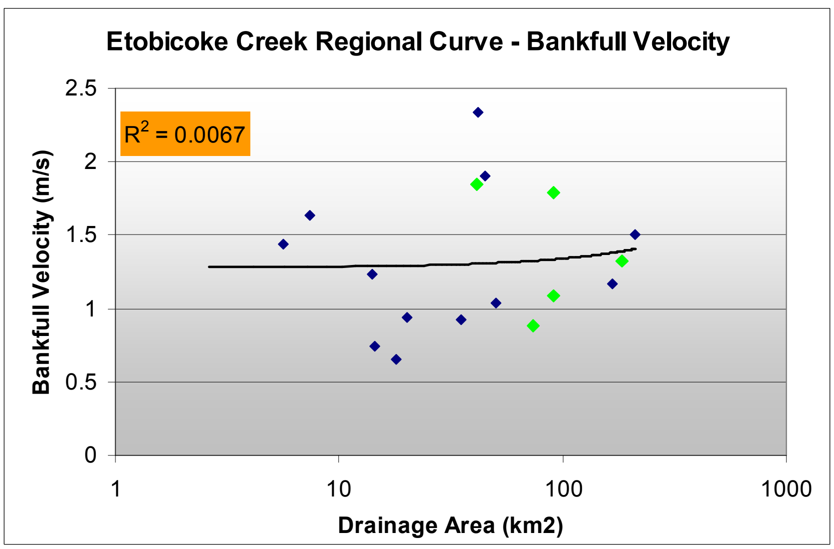



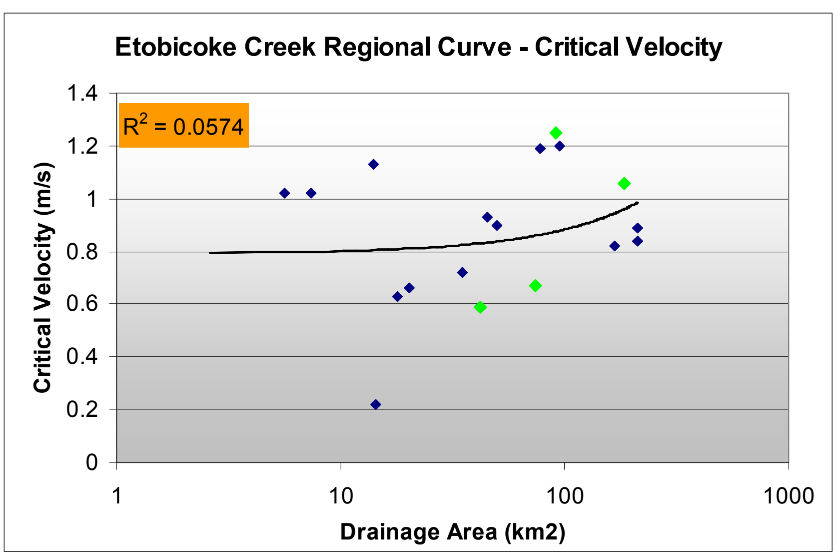
GMI 5
Width (m)
0
2
4
6
8
10
12
14
16
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
Depth (m)
2001
2007
2004
2008

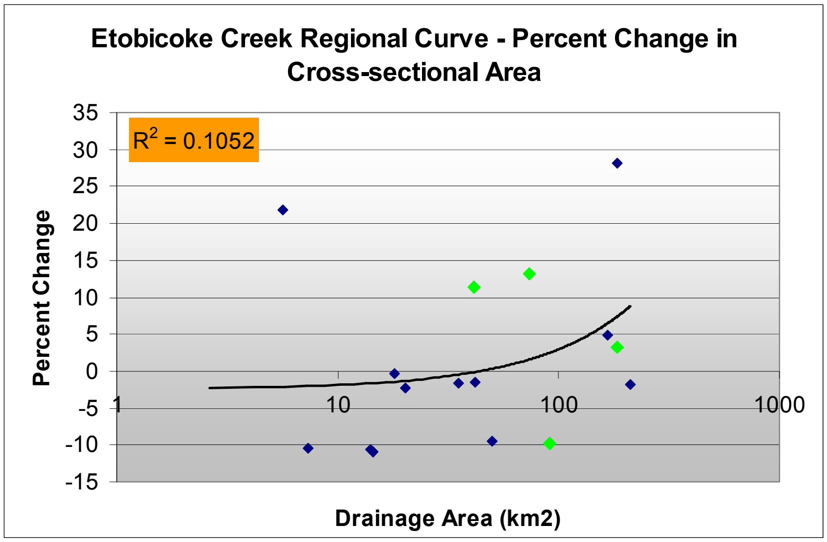
## 7.12 APPENDIX 7- D: REGIONAL CURVE RESULTS

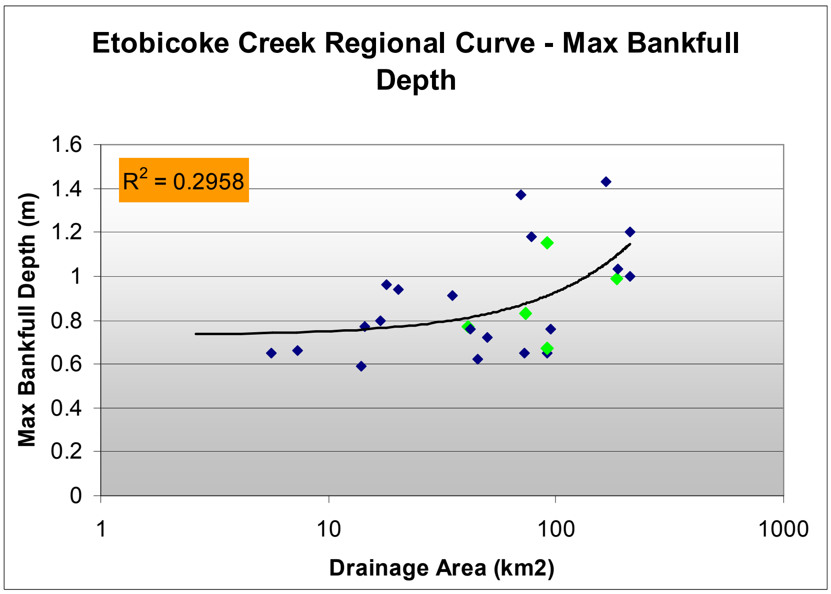
### Etobicoke Creek – Regional Curves

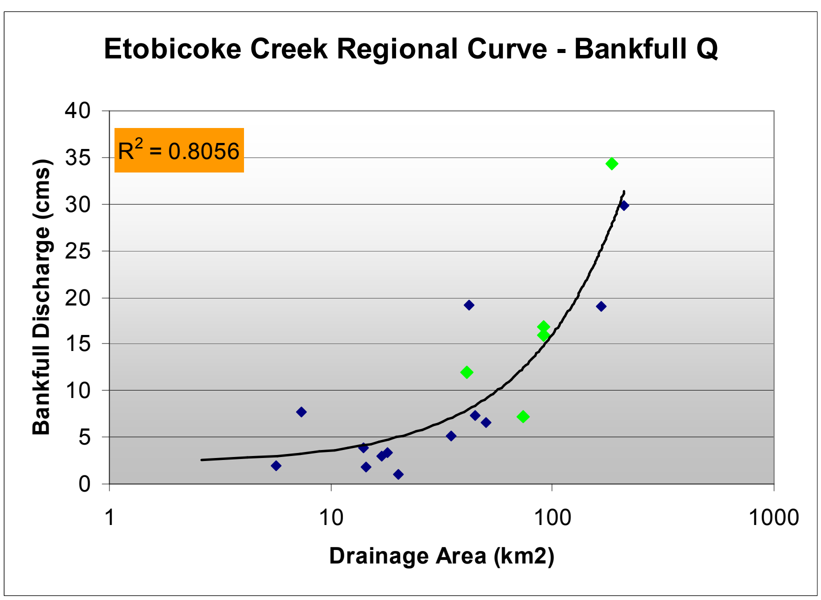


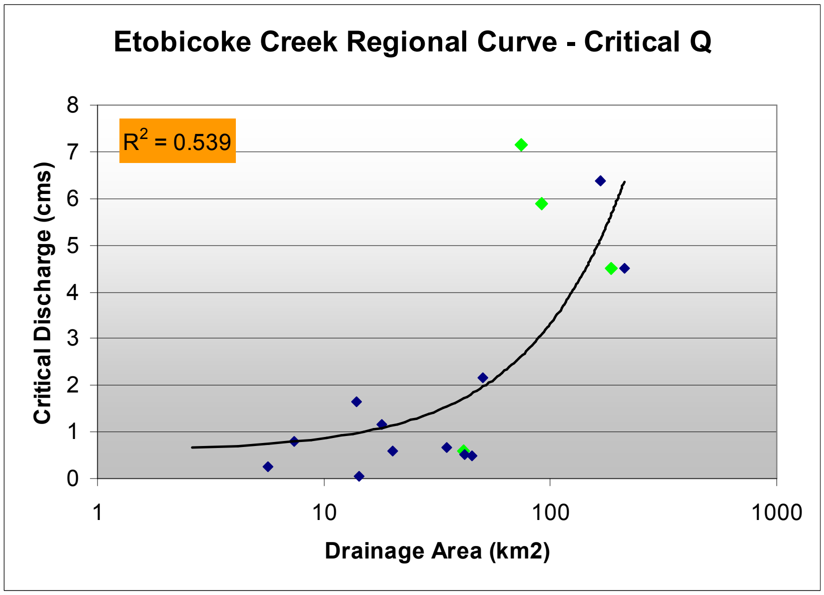



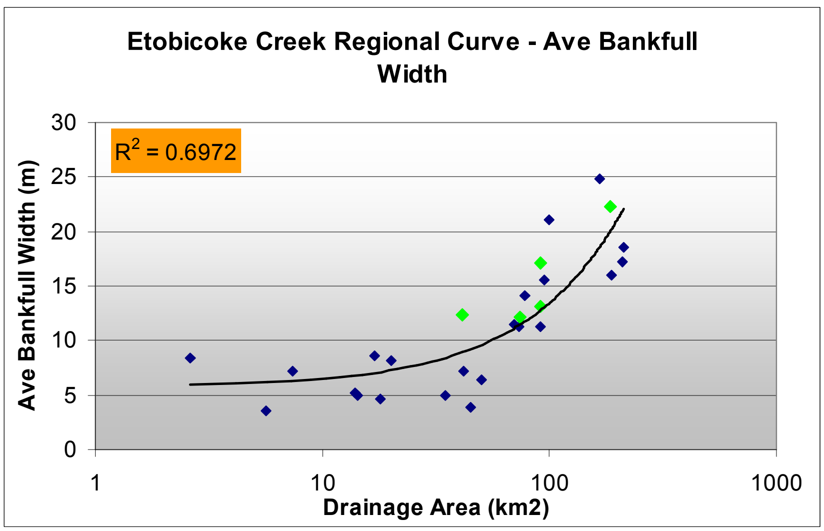



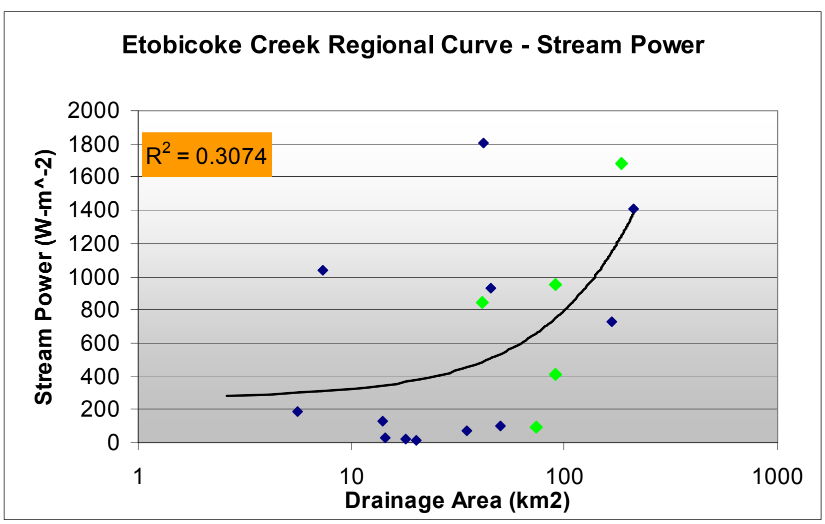

Etobicoke Creek Regional Curve - Percent Change in Cross-sectional Area
$R^2 = 0.1052$
Percent Change
Drainage Area (km2)
35
30
25
20
15
10
5
0
-5
-10
-15
1
10
100
1000

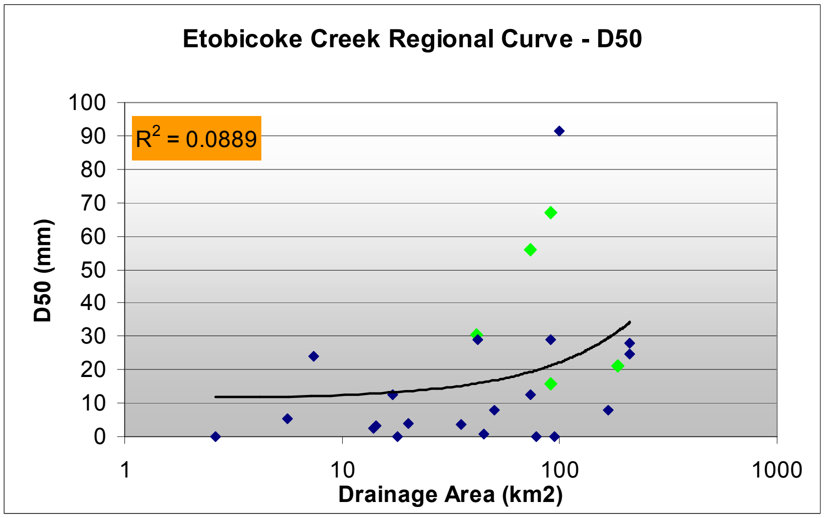

Etobicoke Creek Regional Curve - Max Bankfull Depth
$R^2 = 0.2958$
Max Bankfull Depth (m)
Drainage Area (km2)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
10
100
1000

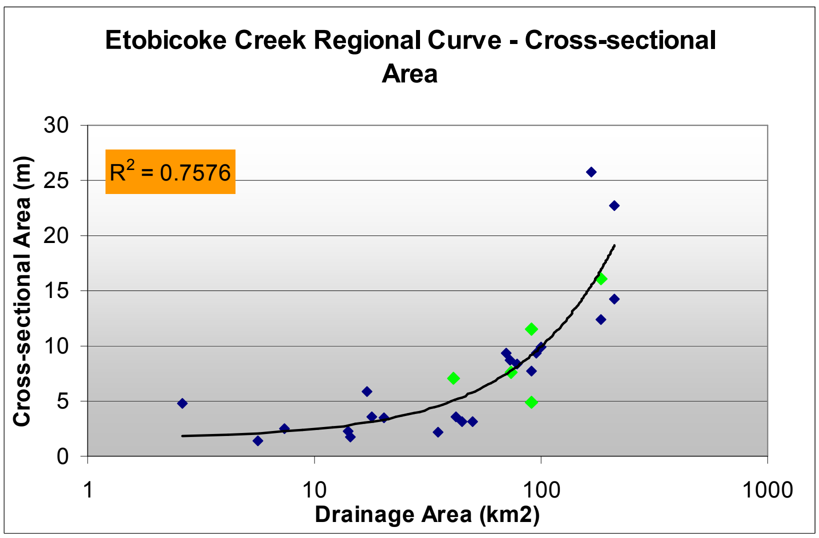

Etobicoke Creek Regional Curve - Bankfull Q
$R^2 = 0.8056$
Bankfull Discharge (cms)
Drainage Area (km2)
40
35
30
25
20
15
10
5
0
1
10
100
1000

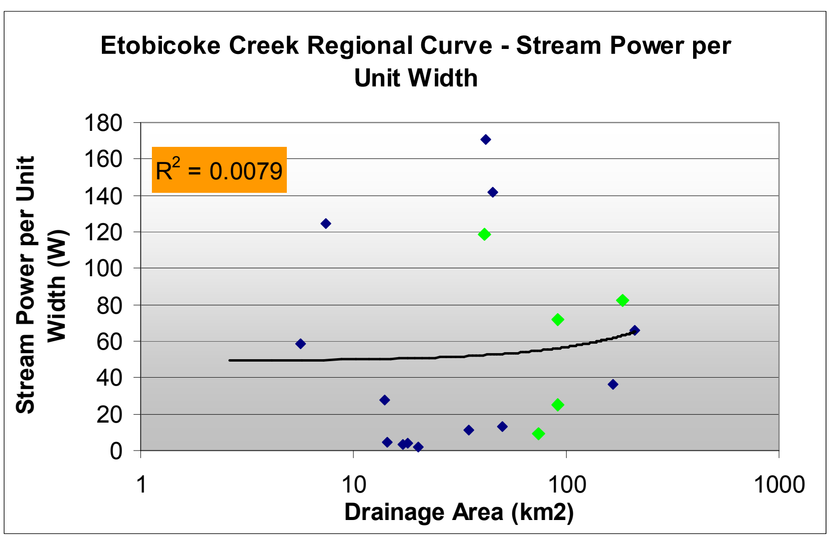

Etobicoke Creek Regional Curve - Critical Q
$R^2$ = 0.539
Critical Discharge (cms)
Drainage Area (km2)
0
1
2
3
4
5
6
7
8
1
10
100
1000

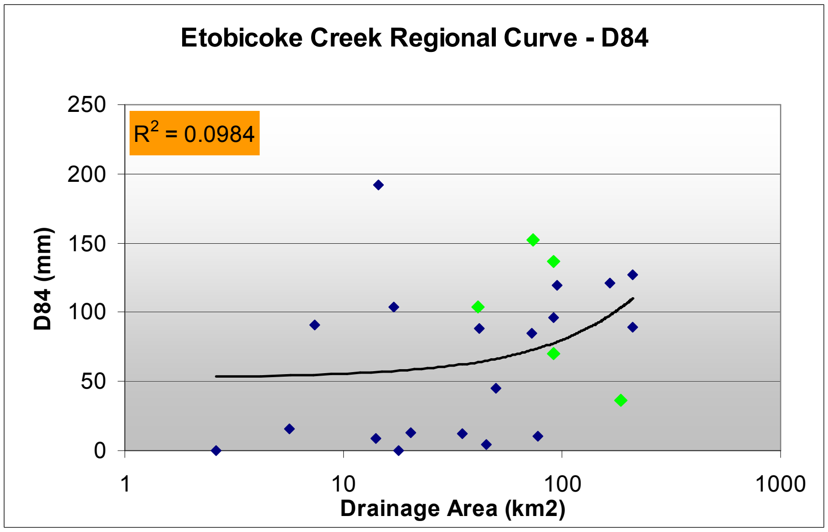

Etobicoke Creek Regional Curve - Ave Bankfull Width
$R^2$ = 0.6972
Ave Bankfull Width (m)
Drainage Area (km2)
0
5
10
15
20
25
30
1
10
100
1000


Etobicoke Creek Regional Curve - Stream Power
$R^2$ = 0.3074
Stream Power (W-m^-2)
Drainage Area (km2)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
1
10
100
1000

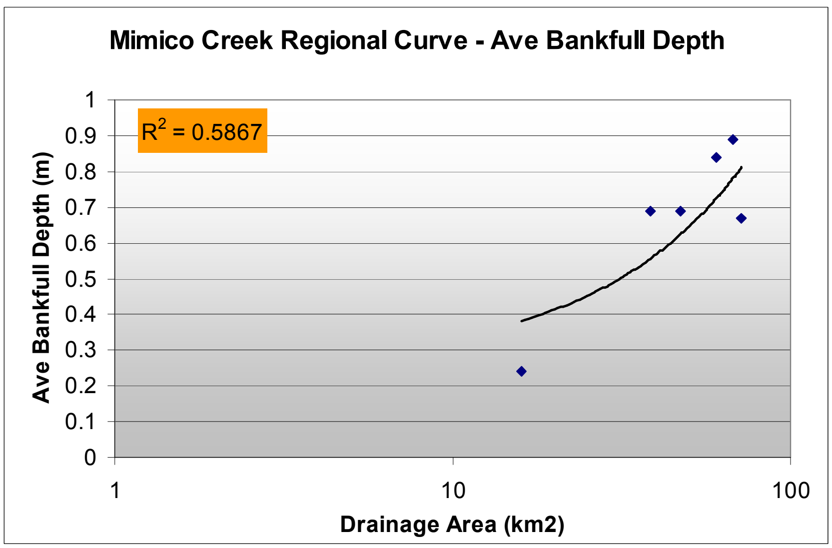

Etobicoke Creek Regional Curve - D50
$R^2$ = 0.0889
D50 (mm)
0
10
20
30
40
50
60
70
80
90
100
1
10
100
1000
Drainage Area (km2)

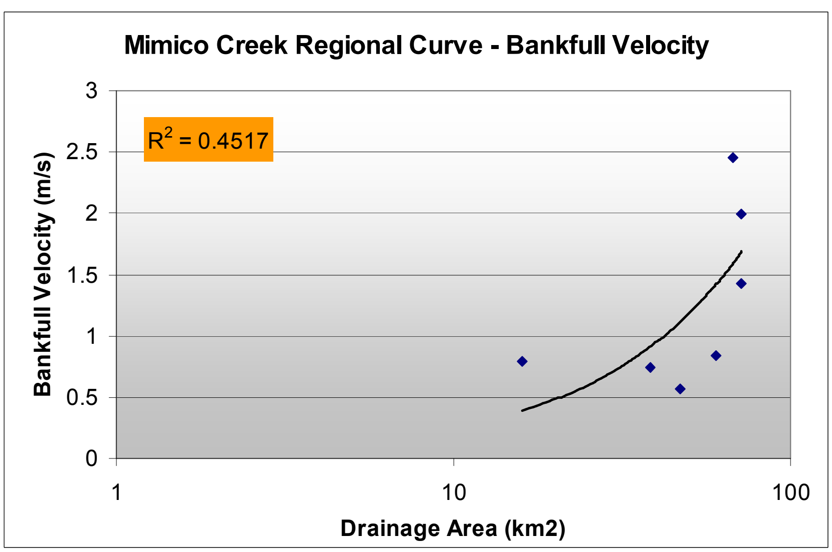

Etobicoke Creek Regional Curve - Cross-sectional Area
$R^2$ = 0.7576
Cross-sectional Area (m)
0
5
10
15
20
25
30
1
10
100
1000
Drainage Area (km2)

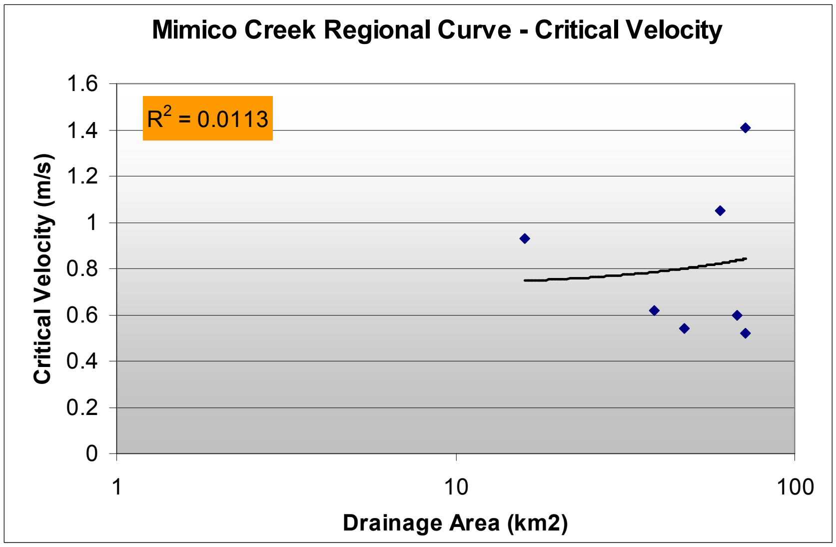

Etobicoke Creek Regional Curve - Stream Power per Unit Width
$R^2$ = 0.0079
Stream Power per Unit Width (W)
0
20
40
60
80
100
120
140
160
180
1
10
100
1000
Drainage Area (km2)

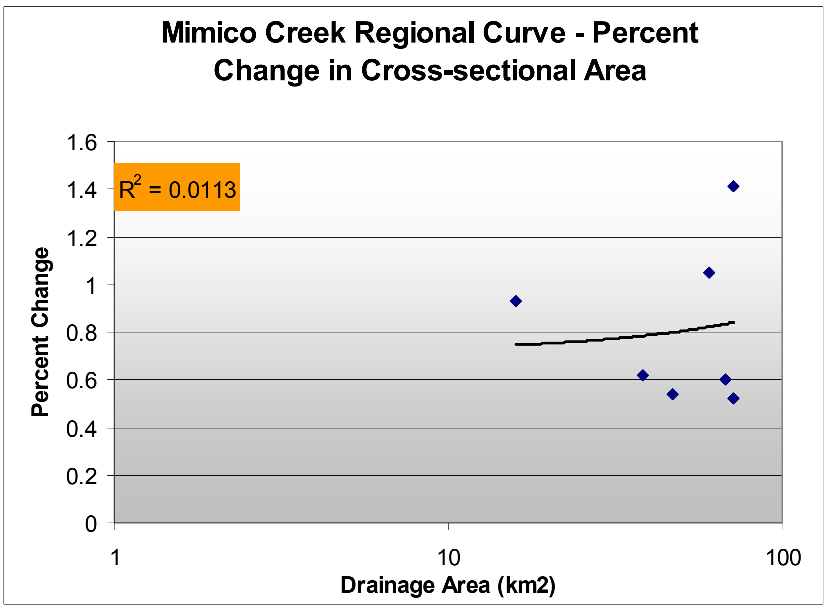


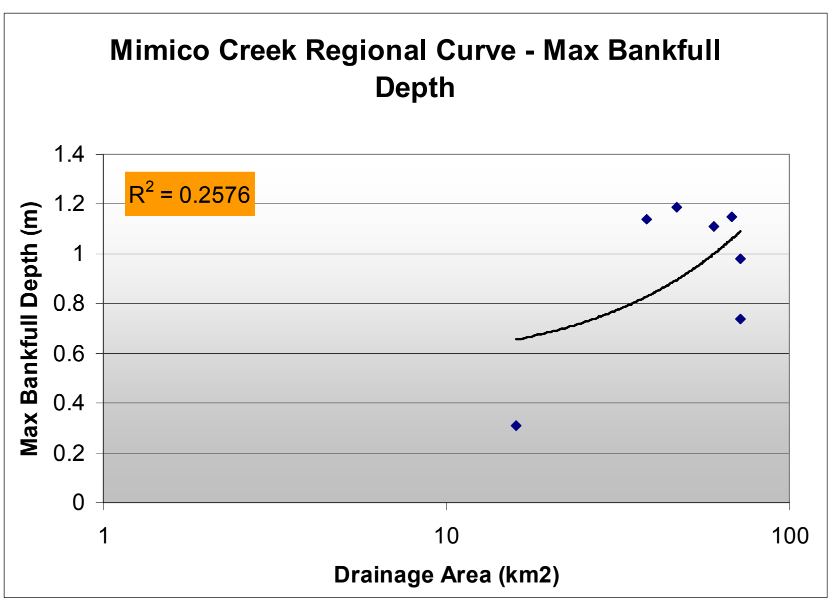

## Mimico Creek – Regional Curves

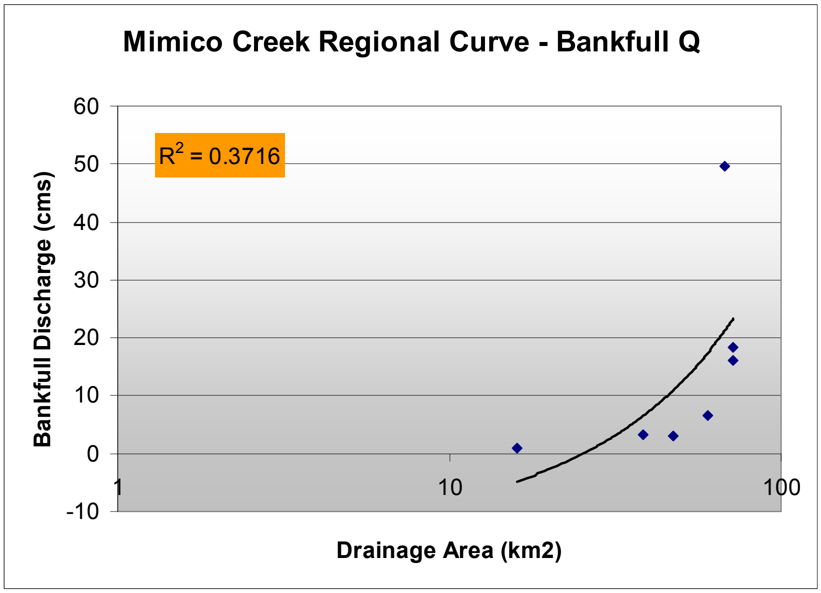


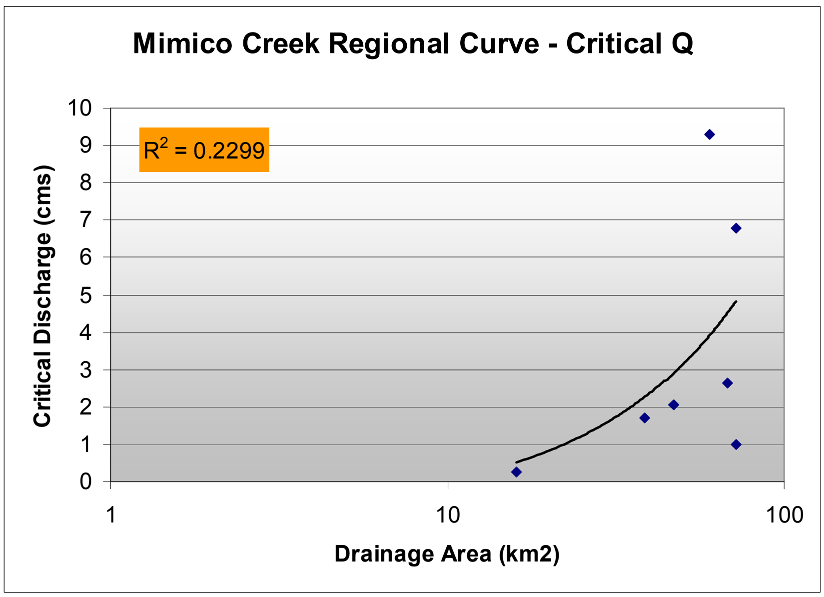



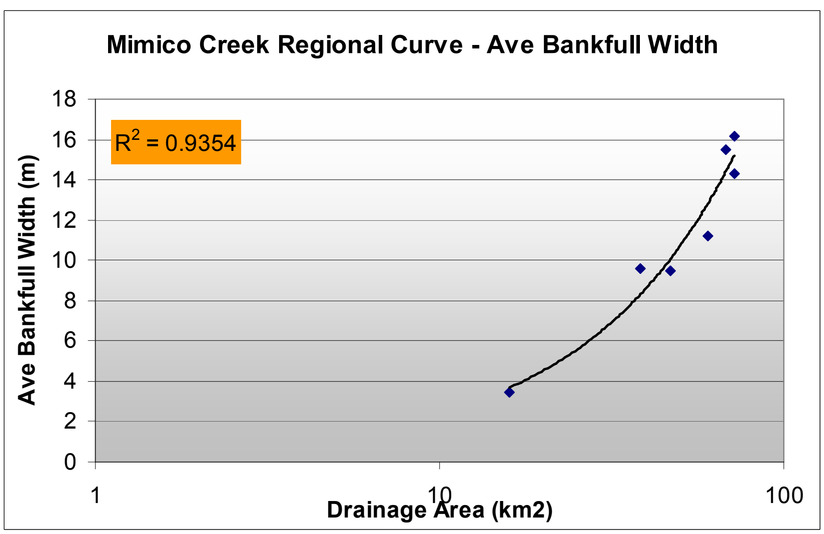

Mimico Creek Regional Curve - Critical Velocity
$R^2$ = 0.0113
Critical Velocity (m/s)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
10
100
Drainage Area (km2)

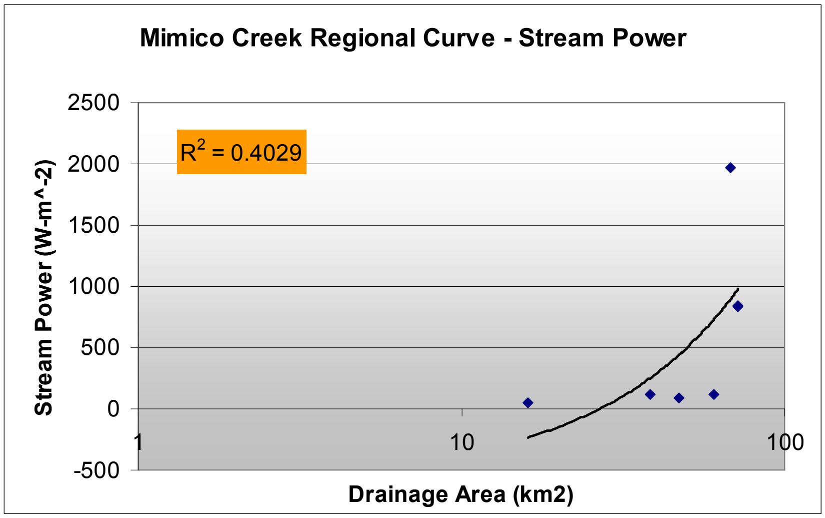

Mimico Creek Regional Curve - Percent Change in Cross-sectional Area
$R^2$ = 0.0113
Percent Change
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
10
100
Drainage Area (km2)

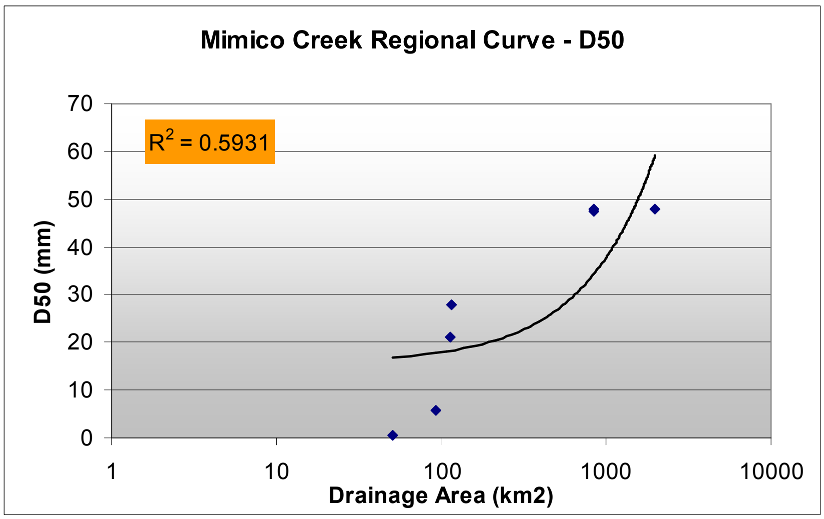

Mimico Creek Regional Curve - Max Bankfull Depth
$R^2$ = 0.2576
Max Bankfull Depth (m)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
10
100
Drainage Area (km2)

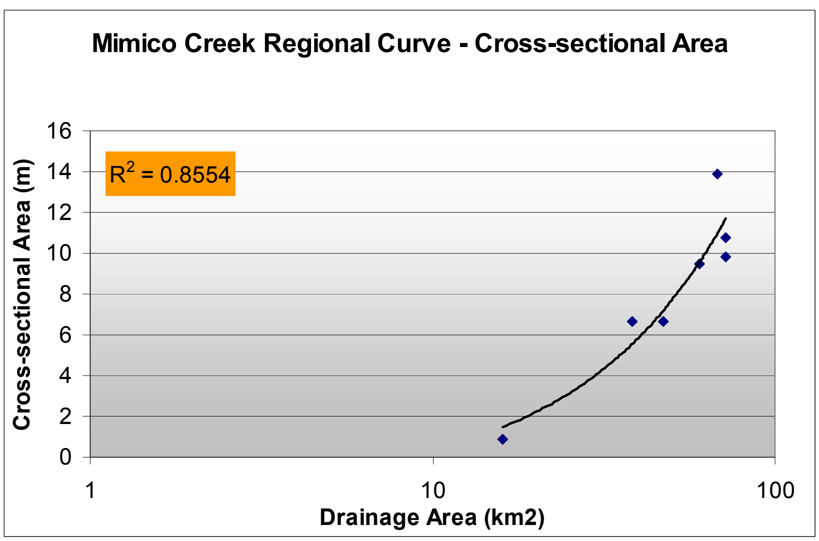

Mimico Creek Regional Curve - Bankfull Q
R2 = 0.3716
Bankfull Discharge (cms)
60
50
40
30
20
10
0
-10
1
10
100
Drainage Area (km2)

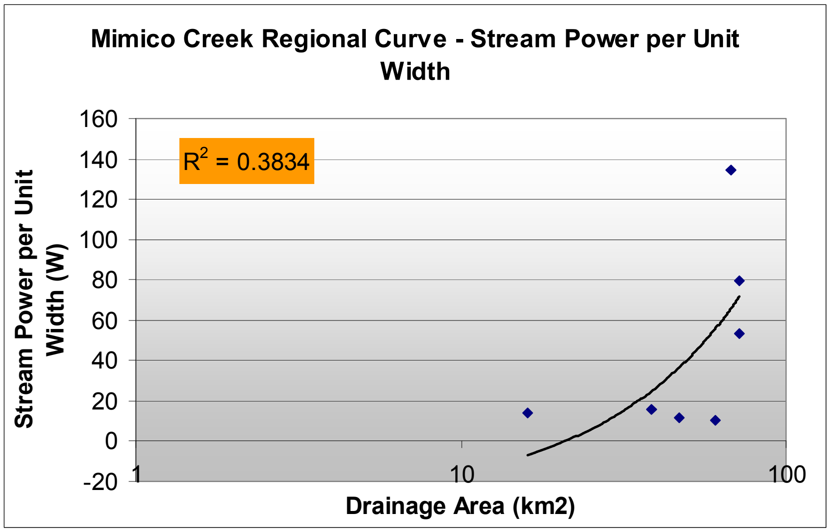

Mimico Creek Regional Curve - Critical Q
R2 = 0.2299
Critical Discharge (cms)
10
9
8
7
6
5
4
3
2
1
0
1
10
100
Drainage Area (km2)


Mimico Creek Regional Curve - Ave Bankfull Width
R2 = 0.9354
Ave Bankfull Width (m)
18
16
14
12
10
8
6
4
2
0
1
10
100
Drainage Area (km2)

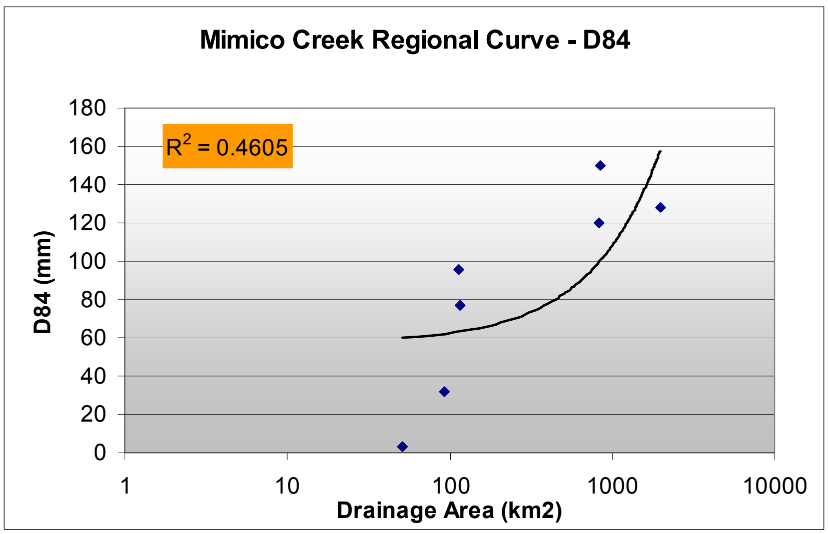

Mimico Creek Regional Curve - Stream Power
$R^2$ = 0.4029
Stream Power (W-m^-2)
2500
2000
1500
1000
500
0
-500
1
10
100
Drainage Area (km2)


Mimico Creek Regional Curve - D50
$R^2$ = 0.5931
D50 (mm)
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Drainage Area (km2)


Mimico Creek Regional Curve - Cross-sectional Area
$R^2$ = 0.8554
Cross-sectional Area (m)
16
14
12
10
8
6
4
2
0
1
10
100
Drainage Area (km2)



Mimico Creek Regional Curve - Stream Power per Unit Width
R² = 0.3834
Stream Power per Unit Width (W)
160
140
120
100
80
60
40
20
0
-20
1
10
100
Drainage Area (km2)

Mimico Creek Regional Curve - D84
R² = 0.4605
D84 (mm)
180
160
140
120
100
80
60
40
20
0
1
10
100
1000
10000
Drainage Area (km2)