Toronto and Region Conservation Authority

Carruthers Creek Watershed Plan
Fluvial Geomorphic Assessment

Prepared for the Region of Durham

October, 2019

FOREWORD

The Region of Durham recognizes watershed plans as an effective tool to inform the management of Durham's water resources, natural heritage, and natural hazards, such as flooding. In 2015, the Region retained the Toronto and Region Conservation Authority (TRCA) to update the watershed plan for Carruthers Creek.

This four-year study will build upon the goals, objectives, and management recommendations established in the 2003 *Watershed Plan for Duffins Creek and Carruthers Creek*.

The following report is one of a series of scenario analysis technical reports that follow the watershed characterization studies (completed in 2017). Information contained in these technical reports will examine potential impacts of future growth and land use changes in combination with other influences such as climate change. Additionally, these technical reports provide the knowledge base necessary to develop the plan's management recommendations. Any recommendations contained in the scenario analysis technical reports are consolidated in the Carruthers Creek Watershed Plan's management framework. The Watershed Plan is the final source for goals, objectives, indicators and management recommendations related to Carruthers Creek. Readers are encouraged to refer to the technical reports for more detailed implementation suggestions.

The following report was prepared by Matrix Solutions Inc. under the direction of TRCA. Given the specialized expertise and experience of the engineers at Matrix Solutions Inc., TRCA commissioned the fluvial geomorphic assessment as one of the series of technical reports that were prepared as part of the scenario analysis for the Carruthers Creek Watershed Plan.

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

CARRUTHERS CREEK

FLUVIAL GEOMORPHIC ASSESSMENT OF REGIONAL WATERSHED MONITORING PROGRAM DATA 2003-2016

Report Prepared for:
TORONTO AND REGION CONSERVATION AUTHORITY

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Report prepared for the Toronto and Region Conservation Authority, Revised October 2019

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EXECUTIVE SUMMARY

The Carruthers Creek watershed lies to the west of Toronto, draining into Lake Ontario. The Carruthers Creek watershed plan has been updated using full monitoring data sets provided from the Toronto and Region Conservation Authority (TRCA) and Matrix Solutions Inc. (formerly PARISH Geomorphic Ltd.). Monitoring data was collected in three-year intervals encompassing the years 2003, 2006, 2009, 2012, and 2016. This work is in support of a Watershed Plan initiative sought out by TRCA to prepare and develop watershed management strategies for each of the nine watersheds within its jurisdiction (TRCA, 2003). Additionally, the Regional Watershed Monitoring Program (RWMP) was established by TRCA to continue monitoring the progress of the objectives and goals of the watershed plan, as well as contribute additional information to monitoring data sets.

Most streams in Southern Ontario have been historically altered, and as a result have undergone various forms of adjustment. As the Carruthers Creek watershed becomes more developed, it is crucial to evaluate potential impacts to the watershed related to urbanization, and identify management actions to minimize these impacts. Ten valley segments of Carruthers Creek were selected for monitoring; two segments in Tributary A, three segments in Tributary B, and five segments within the Main Branch. Valley segments were selected for continued monitoring as part of the RWMN program, and to remain consistent with data collected in previous years by PARISH and TRCA.

Field data including cross-sections, pebble counts, erosion pin measurements, and a photographic inventory was collected once every three years, and summary tables were compiled. Benchmarks at each of the cross-section locations were established using nails, allowing for consistent data comparison within the study period. The percent change of cross-sectional area was calculated at cross-sections to evaluate changes in channel bed erosion or deposition. Additionally, the change in exposure of erosion pins was measured to determine an approximate channel migration rate per year, based on whether sediment had been deposited or eroded around the pins. A table summarizing these changes is provided below (Table 1).

TABLE 1 Summary of Geomorphic Conditions over the Monitoring Period for Carruthers Creek

Monitoring Station	Erosion Pin Measurement				Cross Sectional Area		RGA Stability Index
	Avg. Migration Rate cm/year	Level of Significance	Trend Over Time	Reason for Change	Total Change (%)	Trend Over Time	
Tributary A							
GTCC-11	1.6	Moderate	Erosion	Channel Widening and Deepening	48	Erosion	In Regime
GTCC-9	3.9	Moderate	Erosion	Channel Migration Along Right Bank	35	Erosion	In Regime
Tributary B							
GTCC-6	7.1	High	Erosion	Channel Deepening/ Migration Along Right Bank	26	Erosion	In Regime
GTCC-5	4.9	High	Erosion	Channel Incision	98	Erosion	Transitional
GTCC-4	5.1	Moderate	Erosion	Debris Jam/Erosion Along Left Bank	25	Erosion	Transitional
Main Branch							
GCC-12	3.0	Moderate	Erosion	Challenges Due to Ongoing Erosion of Right Bank	N/A	N/A	In Regime
GCC-7	3.7	Moderate	Erosion	Challenges Due to Proximity to Golf Course	N/A	N/A	In Regime
GCC-6	10.9	High	Erosion	Active Channel Widening/Bank Erosion	4.9	Erosion	Transitional
GCC-4	5.8	Moderate	Erosion	Erosion Along Right Bank (Confined Valley)	18	Deposition	In Regime
GCC-2	5.1	High	Erosion	Nearby Stormwater Ponds	1.4	Deposition	Transitional

Based on the monitoring results, the highest average rate of migration measured from change in exposure of the erosion pins occurred in the Main Branch in GCC-6. This is attributed to the large amount of erosion observed between each three-year monitoring period (i.e. > 10 cm/year). Two of the cross-sections located in the Main Branch also contain a change in cross-sectional area in the form of deposition resulting from naturally accumulating coarse material across riffles. This valley segment is located within a developed area of the watershed, where stormwater management ponds are located on either side of GCC-6. Bank undercutting and erosion was noted within this segment, as well as slumped banks which are indicative of channel widening. As a result, some erosion pins were lost, making it difficult to accurately determine exact rates of erosion. This monitoring site is considered high priority due to the large amount of active erosion occurring. Additionally, valley segments GTCC-5 and GCC-2 are considered high priority sites due to ongoing channel incision (GTCC-5) that has caused channel deepening as well as large deep scour pools that have formed (GCC-2) and are attributed to nearby stormwater management ponds.

The lowest average rate of migration occurs at GTCC-11 in Tributary A. This valley segment is the most northern-located of the segments assessed in the monitoring program, and is not as heavily influenced by the impacts of urbanization. Cross-sectional area has steadily increased each year over the monitoring period, where the channel transitioned from a narrow “V” shape to a “U” shape as a result of channel deepening and widening. Low migration rates measured from the change in exposure of erosion pins are attributed to deposition occurring over one monitoring time periods, followed by an erosive period.

Monitoring data collected for the Carruthers Creek watershed over a 13-year time period has revealed that overall, the watercourse is very active and there have been significant changes to channel morphology governed by erosion and deposition. In this study, the ten valley segments chosen for monitoring were assessed approximately every three years at various times of the year.

It is recommended that the geomorphic monitoring program be extended beyond the current time period, and certain components of the monitoring process be increased to twice per year to capture inter-seasonality which will pinpoint when ongoing deposition and/or erosion are occurring. Data obtained from flow monitoring stations (i.e. hydrographs) provided by TRCA were reviewed to determine if the hydrologic regime of the watercourse was contributing to the overall adjustment of the channel, but gaps in the data made it difficult to do so for all but one cross-section. As a result, it is recommended that hydrologic data be obtained for the entire watershed across the monitoring period to allow for better comparison. This will aid in accurately determining if there is a relationship between channel adjustment and flow regime, as well as provide better insight into seasonal hydrologic variations. Additionally, in areas of the watershed where land development is being proposed, geomorphic monitoring should continue during and post-construction to ensure channel health and stability is maintained.

Specifically, the following modifications to the monitoring program are recommended:

- More frequent (i.e., at least twice a year and every year) characterization of bed substrate to understand why some areas contain a build-up of coarse sediment, while in others, there is increased erosion of the channel bed.

- Hydrologic data collected over a larger area across the watershed, to ensure that seasonal variability in hydrologic regime is captured, as well as determining whether a relationship between channel adjustment and flow regime exists.

- Continued geomorphic monitoring during and following construction to ensure channel health and stability is maintained.

It would also be beneficial in areas where land development is proposed, if the monitoring program was continued in conjunction with other geomorphic studies such as meander belt width/erosion hazard corridor assessments and erosion thresholds. Meander belt width and erosion hazard corridor assessments will help determine the extent within which all associated natural channel processes occur and help forecast the future planform extent to assist in the siting of infrastructure. Erosion thresholds are necessary where changes in the intensity and/or frequency of flows are anticipated in areas of development and will help ensure changes to the flow regime do not result in excessive changes to channel morphology. Where changes to the flow regime are expected, channel enhancement or increased bank protection may be required as preventative measures in addition to implementing stormwater management practices outlined in the TRCA (2012) Stormwater Management Criteria.

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1 INTRODUCTION

Toronto and Region Conservation Authority (TRCA) has undertaken the process to update the watershed plan for Carruthers Creek. The original watershed plan was prepared in 2003, at a time when minimal supporting field data was available for the fluvial geomorphology component. It was identified that as the Carruthers Creek watershed becomes more developed, it will be critical to establish baseline conditions to assess potential impacts. As part of this work, the Regional Watershed Monitoring Program (RWMP) was established by TRCA. Matrix Solutions Inc. (formerly PARISH Geomorphic Ltd.) established the ten monitoring stations along Carruthers Creek in 2003 (Appendix A). These stations were updated every three years through 2012.

To provide support for the updated Carruthers Creek watershed plan, Matrix was retained by TRCA to complete a 2016 update of the monitoring stations and prepare a report analyzing the full monitoring data set which includes years 2003, 2006, 2009, and 2012. This analysis will provide an understanding of channel morphology, which can be employed to guide policy recommendations and assess future development scenarios in the watershed. The following report is intended to be the final version based on four rounds of comments between 2017 and present. This report addresses the most recent round of comments received in August 2019 from TRCA and CVC. It has been concluded that several comments are considered out of scope based on email correspondence with TRCA received September 19, 2019, and therefore report updates have only been provided on comments within the original scope.

2 BACKGROUND REVIEW

The following sections provide an overview of completed reports, studies, and plans that have informed this report and provided baseline understanding of key insights, characteristics, and findings.

2.1 Carruthers Creek State of the Watershed Report - Fluvial Geomorphology

The State of the Watershed (SOW) report (TRCA, 2002) was developed as a reference document for the companion document, the Watershed Plan (TRCA, 2003). A number of technical experts contributed to the document, producing chapters focusing on various aspects of the watershed including physical properties and processes, and cultural characteristics. The chapter focusing on fluvial geomorphology was reviewed to provide background for the current Carruthers Creek report.

The fluvial geomorphology chapter provided a broad overview of the general form and function of the Carruthers Creek watershed. The report discussed the underlying geology, drainage density, and shape of the watershed. The watershed is a narrow elongated basin which is concave in shape, with steeper headwaters and generally flattens progressing downstream toward Lake Ontario. The channel planform reflects this; the channel is straighter in the upstream and becomes more sinuous south of Highway 401. Fine-grained substrates are common as a result of the underlying geology, which is predominantly from the glacial Lake Iroquois. It was noted in the reporting that there was very little field data available for

Carruthers Creek and was recommended that broader scale studies will need to be undertaken to provide the information necessary to inform management decisions. The report cautioned that as development of the area progresses, more local-scale studies will likely be completed and it will be necessary to have a holistic understanding of the watershed.

2.2 A Watershed Plan for Duffins Creek and Carruthers Creek

The Watershed Plan for Duffins Creek and Carruthers Creek was developed as part of an initiative by TRCA to guide the preparation of a watershed management strategy for each of the nine watersheds in its jurisdiction (TRCA, 2003). This particular planning initiative represented the sixth and seventh management plan to be completed out of the nine watersheds. The purpose of the watershed plan was to complete a thorough study of natural features and functions, human heritage, public use, and the interdependence of these elements. This was completed through the SOW Reports. The Watershed Plans then focused on evaluating the potential effects of current and future watershed activities and identifying management actions to minimize effects and enhance existing features.

The report identified that the key management issues facing the Carruthers Creek watershed are those that challenge all urbanizing creek systems; urban growth, ongoing stewardship of existing agricultural and urban land uses, and firm protection of existing natural areas. Technical studies indicated that protecting and enhancing terrestrial natural heritage cover is critical to achieving management goals. For Carruthers Creek, it was noted that there is a less robust terrestrial Natural Heritage System and that within the development process there are very few opportunities to grow the area of natural cover. Without protection of these areas and changes to development planning it is likely that as urban growth continues the health of Carruthers Creek will decline. The report also highlighted the importance of improving areas with existing development through reforestation, streambank management, and changing cultural practices through community engagement initiatives. The Regional Watershed Monitoring Program (RWMP) is a key component of continuing to monitor progress of these goals and objectives under the watershed plan. It would also address information gaps by contributing additional data to establish baseline conditions in lesser studied areas. This would be critical for Carruthers Creek considering the lack of available data to support the SOW fluvial geomorphology assessment.

2.3 Valley Segments, Carruthers, Petticoat, Duffins Creek Watersheds

PARISH was retained to establish the fluvial geomorphology stations as part of the RWMP for TRCA (PARISH, 2003). As part of this process, a valley segment report was produced delineating the Carruthers, Petticoat, and Duffins Creek watersheds into distinct segments. Valley segments are considered to be relatively homogenous sections of a watercourse that exhibit distinct physical characteristics. These characteristics are determined by governing factors such as topography, geology, climate, and hydrography. The valley segments were delineated based on differences in stream order, catchment size, slope, and surficial geology. Locations for the RWMP sites were then selected based on representative coverage of the valley segments.

Carruthers Creek was divided into 26 valley segments with 12 segments on the Main Branch. Based on stream length and types of valley segments, ten monitoring sites were selected for Carruthers Creek, five on the tributaries and five on the Main Branch (Figure 1).

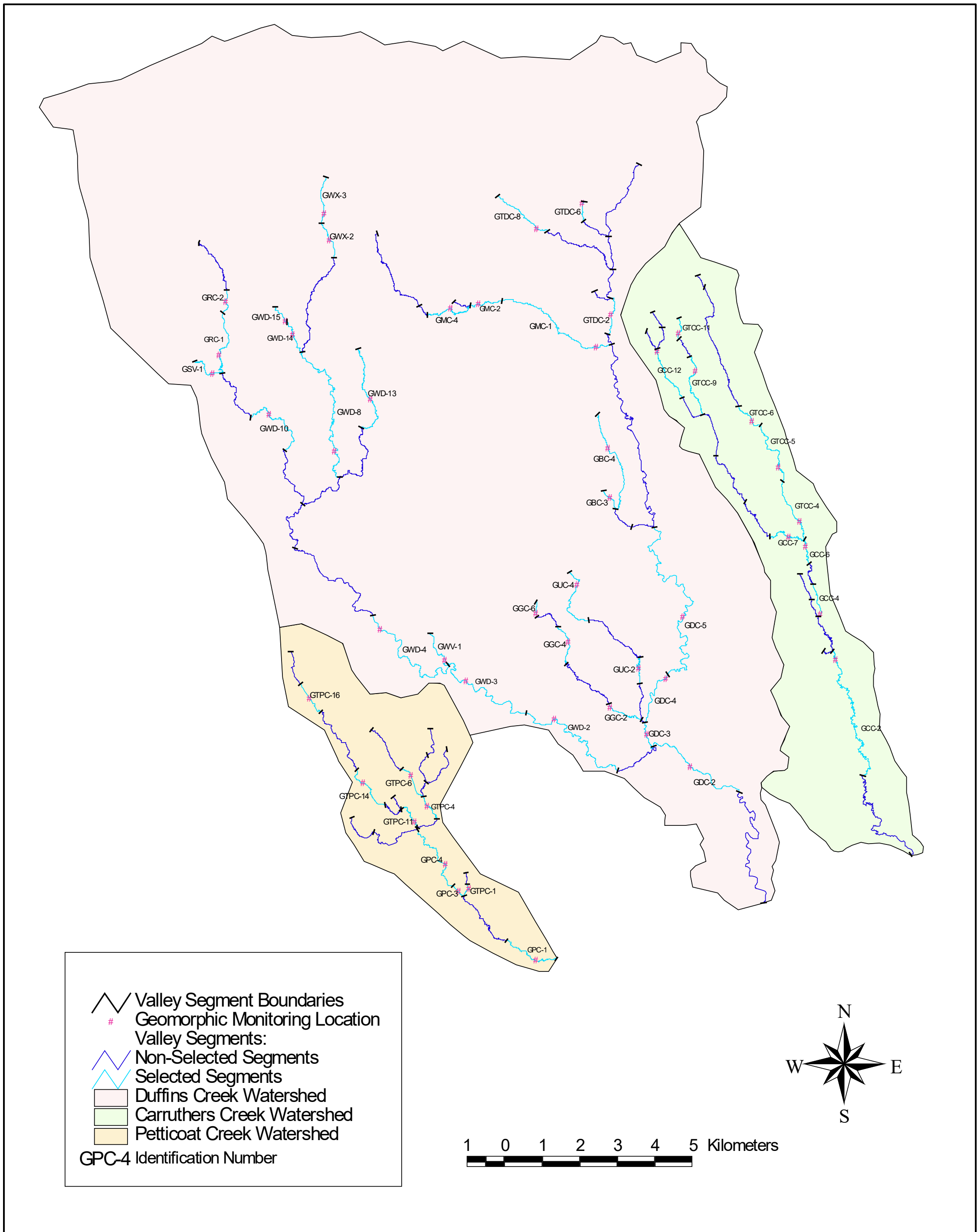

Figure 3: Geomorphic monitoring site locations within the Petticoat Creek, Duffins Creek, and Carruthers Creek Watershed.

FIGURE 1 Geomorphic Monitoring Site Locations and Valley Segments (PARISH 2003a)

2.4 Regional Monitoring Program - Fluvial Geomorphology Component: Petticoat Creek, Carruthers Creek, Duffins Creek, and Highland Creek Watersheds

The RWMP was established to track changes in physical habitat. A fluvial geomorphology component was included because the physical form and function of a watercourse are key elements of aquatic habitat (PARISH 2004). The TRCA established 150 geomorphic monitoring sites across their jurisdiction as part of this program. In 2003, fluvial geomorphology sites were set up in the final three watersheds, Petticoat, Carruthers, and Duffins (additional sites were established for Highland Creek). For the three watersheds, 50 monitoring sites were allotted. The number of field sites in each watershed was dictated by the number of valley segments within it. Several sites were linked to fisheries monitoring sites to allow for integration between disciplines.

Setting up the fluvial geomorphology monitoring sites involved additional data collection beyond what was recommended to maintain the monitoring program. This was to provide a larger baseline condition dataset. At each site the following took place:

- 10 bankfull cross-sections were completed, this included establishment of the control cross-section for the monitoring program.
- Up to five erosion pins were installed through the length of the field site. Generally, at least one to two erosion pins were located in close proximity to the control cross-section.
- A long profile survey was completed through the length of the field site. A benchmark was established to allow future surveys to tie-into the original survey.
- Photographs were taken at documented vantage points so they could be repeated in the future.
- A GPS reading was taken to document the location of the control cross-section.

A historical assessment was completed based on the 1999 aerial photographs for the area and floodline mapping from 1964 and 1987. The assessment was relatively high-level, providing general observations of the watercourse and the surrounding area.

A Rapid Geomorphic Assessment (RGA) and Rapid Stream Assessment Technique (RSAT) were completed at each site to evaluate channel stability. It is important to note that rapid assessment results may vary between years based on the time of year they are taken. In general, they are taken to assess channel health and stability and to identify the dominant geomorphic processes occurring in a watercourse. Large variations in rapid assessment results can be expected given that the watershed has undergone accelerated urbanization within the monitoring time period.

For Carruthers Creek, two valley segments were considered in regime (stable), two were in adjustment (unstable), and six were transitional. The RGA and RSAT scores are summarized in Table 1 and illustrated in Figures 2 and 3. The dominant geomorphic processes acting in valley segments that were in adjustment were widening and aggradation. Evidence included the presence of abundant woody debris within the channel and on banks, in addition to exposed tree roots. Basal scouring was prevalent through greater than 50% of the reach and widening of the channel often resulted in bank slumping. Signs of aggradation were evidenced by siltation in pools and accretion on point bars. Transitional segments often contained minor signs of channel widening, in addition to aggradation. A comparison of the rapid assessment results from 2004 and those in the current study are provided in Section 3.4.

TABLE 1 Stability Rankings for Carruthers Creek

Valley Segments	RGA	Stability Index	RSAT	Stability Index
GTCC-11	0.03	In Regime	23	Moderate
GCC-12	0.15	In Regime	23	Moderate
GTCC-9	0.29	Transitional	25	Moderate
GTCC-6	0.22	Transitional	28	Moderate
GTCC-5	0.57	In Adjustment	21.5	Moderate
GTCC-4	0.22	Transitional	20	Moderate
GCC-7	0.30	Transitional	19	Low
GCC-6	0.36	Transitional	20	Moderate
GCC-4	0.38	Transitional	23	Moderate
GCC-2	0.44	In Adjustment	18	Low

PARISH (2004)

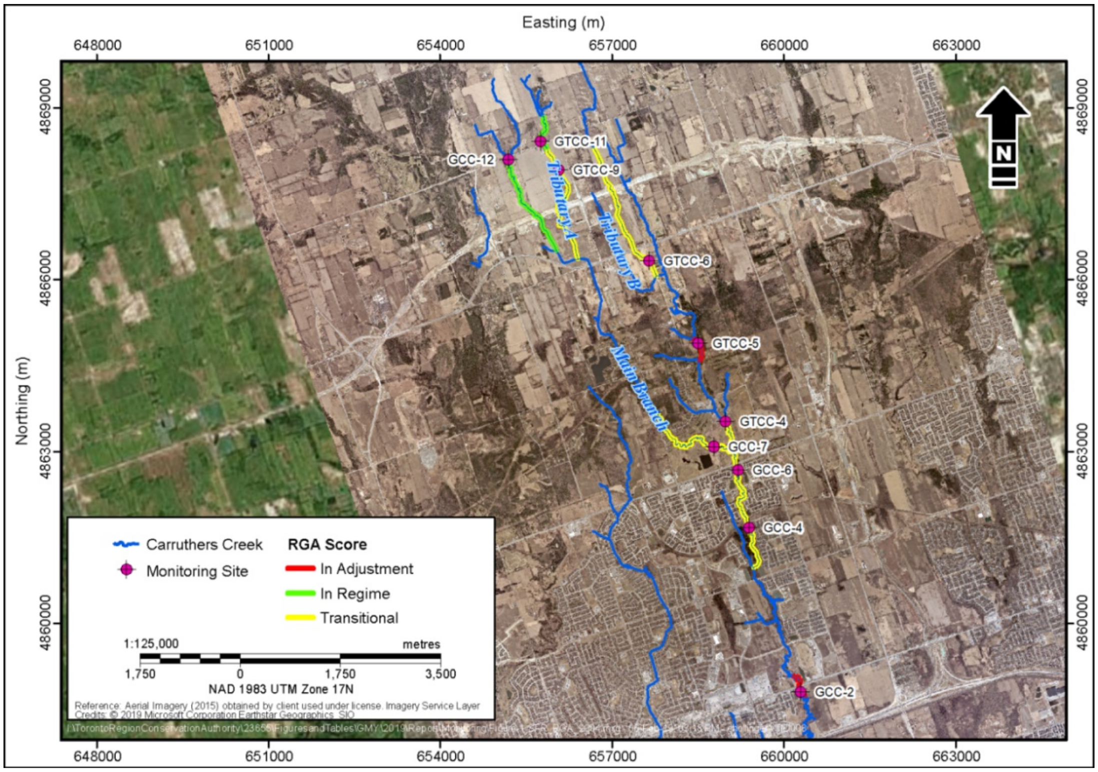

FIGURE 2 Rapid Geomorphic Assessment (RGA) Results for Each Valley Segment (Results from PARISH 2004)

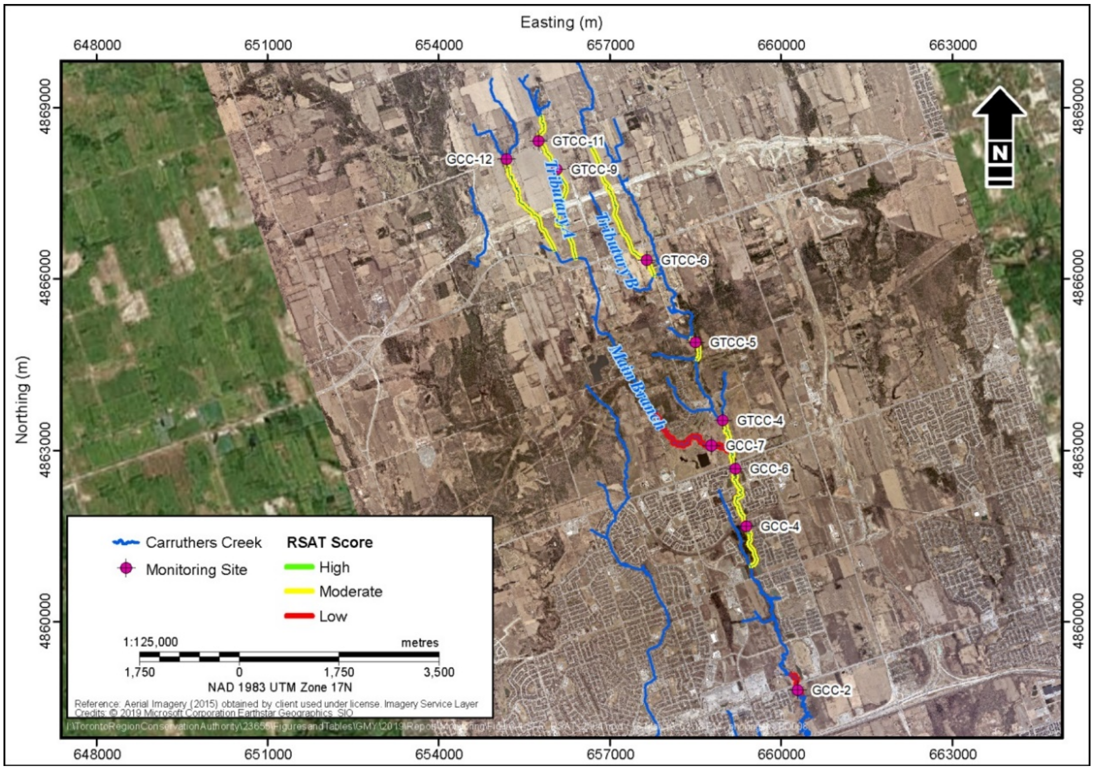

FIGURE 3 Rapid Stream Assessment Technique (RSAT) Results for Each Valley Segment (Results from PARISH 2004)

3 FIELDWORK AND ANALYSIS METHODS

Field data collection to update the monitoring stations was completed over four days in October 2016. During this time, cross-sections, pebble counts, erosion pin measurement, and monumented photographs were completed. RGA and RSAT rapid assessments were also completed for each valley segment to compare with results from 2004. The updated 2016 data was then compiled with the preceding datasets in a consistent format for comparison and analysis. The integration of the various datasets allows for comparison between monitoring years and analysis of the overall monitoring period. Summary tables were compiled with the results of these analyses for cross-sections, erosion pins, and substrate gradations. Additionally, summary sheets for each site with cross-section graph overlays and corresponding photographs for each monitoring year are located in Appendix B to facilitate interpretation.

3.1 Cross-sectional Shape and Area

Each of the ten established cross-sections is benchmarked with nails, which were originally located well beyond bankfull for detailed topographic data collection between the points. The measuring tape can then be tied to the pins each time re-measurement is completed. The start of the cross-section (zero end of the tape) is always at the left bank pin and terminates at the right bank pin.

To compare the cross-section data, the various years are overlaid on a graph to provide direct comparison. This comparison is done qualitatively, identifying which areas of the cross-section expanded or contracted, which relate to overall channel processes. Quantitatively, cross-sectional area and percent change of cross-sectional area are calculated (Table 2). To provide additional detail on where the change within the cross-section is occurring, it is often useful to compare the maximum depth, bottom width, bankfull width, and wetted width. This aids in revealing how the cross-section is changing and if the overall shape is transitioning. Using bottom width or bankfull width is particularly useful because the width of the monitoring cross-section must remain static to allow for comparison. The width of the monitoring cross-section should also be well beyond bankfull to allow for documentation of changes in bankfull.

TABLE 2 Summary of Cross-sectional Area and Percent Change for all Monitoring Stations 2003-2016

Monitoring Station	Cross Sectional Area (m^2)**					Percent Change				Total Change (%)
	2003 (Fall)	2006 (Fall)	2009 (Spring)	2012 (Spring)	2016 (Fall)	2003 2006	2006 2009	2009 2012	2012 2016	
GTCC-11	0.41	0.48	0.51	0.52	0.61	17	7.0	0.5	18	48
GTCC-9	0.83	0.99	1.0	0.99	1.1	19	2.0	-1.6	13	35
GTCC-6*	2.0	3.0	3.4	4.1	4.2	NA	NA	21	4.6	26
GTCC-5	2.6	2.5	3.0	4.3	5.1	-4.4	21	42	20	98
GTCC-4	1.6	1.8	1.9	2.1	2.1	9.0	6.9	7.9	-0.25	25
GCC-12*	1.2	1.1	1.4	1.6	1.6	-11	NA	11	NA	NA
GCC-7*	1.8	1.5	2.8	2.4	NA	-14	NA	NA	NA	NA
GCC-6	5.4	5.2	5.5	5.7	5.7	-4.1	6.7	2.3	0.16	4.9
GCC-4	7.8	7.1	7.4	6.7	6.4	-9.8	4.7	-8.8	-4.8	-18
GCC-2	3.3	2.8	3.4	3.6	3.3	-13	19	7.0	-7.9	-1.4

Notes: All reaches: A negative value in the percent change field indicates deposition, while a positive value indicates erosion.

** Cross-sectional area values were rounded to two significant figures; any discrepancy between the results shown and the percent changes are due to this rounding.

GCC-12: Cross-section width increased in 2009, pin moved back.
2016 bank pins could not be found, cross-section reinstalled at a larger width in the same location as approximated based on erosion pin.

GTCC-6: 2006 cross-section width increased from 3.60 m to 6.00 m Bank pin could not be found from original 2003 installation.
2009 cross-section width increased by 0.85 m.
Total change is calculated for 2009-2016.

GCC-7: 2009 cross-section width inceased from 4.00 m to 5.52 m.
2012 told that the right cross-section pin was removed by golf course maintenance staff. Reinstalled flush to bank at 5.52 m.
2016 no pins or indicators of cross-section location could be found, cross-section not reinstalled due to challenges with maintaining.

Generally, the cross-section is considered the most reliable technique for monitoring. When the bank pins are established sufficiently far from the top of bank, the risk that they will be lost to erosion is minimized. However, if a bank pin must be moved due to erosion risk, a number of issues can arise and it is very difficult to ensure the accuracy of future cross-section comparisons. If a bank pin cannot be found and must be re-established, it is highly unlikely that comparisons will be accurate. It is difficult to properly align the re-established pin with the original pin even when the original width is known. When a bank pin is moved back from the known original pin to protect is from erosion, it must be properly documented otherwise it is difficult to make accurate comparisons. Even when the bank pin is moved and properly documented, moving one bank pin further into the floodplain generally moves the pin to ground that is slightly higher than the original location. Then when the cross-section is measured, the measuring tape cannot be properly levelled impacting the cross-section graph by artificially deepening a portion of the cross-section. This can be compensated for using the water surface to determine the difference in elevation. If the channel is dry, the error cannot be quantified or addressed. This is why it is critical to establish long-term monitoring cross-section bank pins far beyond the top of bank.

3.2 Substrate Size Distribution

To characterize the substrates at each cross-section, pebble counts were completed. A total of 50 random particles are selected and measured along the median axis. Particle size distributions are tabulated accordingly to produce the representative grain sizes: D_{16}, D_{50}, and D_{84}. These values are compared between monitoring periods to identify changes in the overall substrate distribution (Table 3).

TABLE 3 Summary of Grain Size Distribution for all Monitoring Stations 2003-2016

Monitoring Station (listed in upstream to downstream)		2003 (Fall)	2006 (Fall)	2009 (Spring)	2012 (Spring)	2016 (Fall)
	Data displayed in cm					
GTCC-11	D_{16}	si	si	si	cl	si
	D_{50}	si	si	si	vfs	si
	D_{84}	fs	si	1.0	0.13	0.01
GTCC-9	D_{16}	cs	0.50	0.19	0.49	si
	D_{50}	0.6	2.0	1.5	0.5	0.52
	D_{84}	2.3	6.1	5.0	1.5	3.2
GTCC-6	D_{16}	si	si	si	cl	si
	D_{50}	si	0.50	0.49	fs	cs
	D_{84}	si	2.0	3.0	2.0	1.0
GTCC-5	D_{16}	ms	0.49	si	0.49	1.8
	D_{50}	0.59	1.0	cs	1.5	3.4
	D_{84}	2.5	1.8	2.0	4.0	6.8
GTCC-4	D_{16}	0.11	0.49	0.23	cs	0.81
	D_{50}	1.0	1.5	2.5	1.5	1.9
	D_{84}	4.0	4.5	4.8	3.0	4.1
GCC-12	D_{16}	fs	cl	cs	1.7	1.7
	D_{50}	1.5	1.0	2.5	4.0	4.8
	D_{84}	5.6	3.3	6.0	8.3	8.5

Monitoring Station (listed in upstream to downstream)		2003 (Fall)	2006 (Fall)	2009 (Spring)	2012 (Spring)	2016 (Fall)
		Data displayed in cm				
GCC-7	D_{16}	0.50	cs	0.19	0.49	NA
	D_{50}	3.0	2.5	3.0	1.5	NA
	D_{84}	9.0	12	6.8	8.0	NA
GCC-6	D_{16}	si	cs	0.11	0.50	0.52
	D_{50}	0.59	1.0	0.49	1.0	2.0
	D_{84}	3.5	1.8	2.3	2.8	3.4
GCC-4	D_{16}	0.11	0.50	0.49	1.0	1.6
	D_{50}	2.5	1.5	3.0	3.5	9.9
	D_{84}	9.6	6.8	11	7.5	16
GCC-2	D_{16}	fs	si	si	vfs	0.16
	D_{50}	1.5	0.49	0.49	0.50	0.36
	D_{84}	5.6	1.0	1.5	1.8	0.50

*cl = clay (<2 µm)
Si = silt (2-9 µm)
vfs = very fine sand (10-49 µm)
fs = fine sand (50-190 µm)
ms = medium sand (0.02-0.049 cm)
cs = coarse sand (0.05-0.19 cm)

Substrate monitoring can be complicated by two different factors: fine material and seasonality. When a distribution is dominated by fine material (silt, sand, pebbles), it is very difficult to identify shifts and nuances in the grain size distribution and in this case sediment samples should be taken. Therefore, substrate monitoring in smaller tributaries or headwater generally only identifies change if there is a shift from fine material to gravel material. This would require a significant overall change to the system, such as incision to remove the upper layer of fine material revealing underlying coarser material. There are also seasonal changes to the grain size distribution that occur related to the different flow conditions. In the summer, grain size distributions are often finer due to the accumulation of fine material during low flow conditions. The spring and fall tend to be wetter, so monitoring during these seasons would identify coarser substrate due to fine materials being flushed out at higher flows. To account for this, when possible, monitoring should ideally be completed within the same time frame each monitoring year. Flow conditions should also be taken into account when planning the monitoring visit for the same reason. Data for this monitoring program was collected in September/October of 2003, November/December of 2006, April – June in 2009, April – June in 2012, and October of 2016. It is recognized that there is typically increased discharge associated with spring freshet and increased rainfall events in the fall. Therefore, comparable results would be expected even though the monitoring was not completed within the same time frame each year.

3.3 Lateral Channel Migration

Erosion pins are installed horizontally into the face of stream banks throughout the monitoring site to provide a means of quantifying channel migration at these locations. Each erosion pin is a one metre length of rebar installed below the bankfull elevation and above the baseflow level. A portion of the erosion pin is left exposed from the bank and measured (typically 20 cm), providing a reference length when re-measured in subsequent monitoring periods. The pins serve as a direct measure of bank recession/migration rate and are typically installed on the outside bank of pools or straight sections of channel to serve as controls. For each monitoring site, four to five pins were installed. This generally included two erosion pins at the monitoring cross-section to corroborate the cross-section results.

Change in pin exposure is re-measured during each monitoring year. The total change in exposure is then calculated for the entire monitoring period. Total change in exposure is divided by the time period to determine the migration rate in cm/year (Table 4). A negative change in exposure is indicative of deposition, while a positive change is exposure is indicative of erosion. The time period differs by erosion pin based on the available data; not all erosion pins have data for every monitoring period. This is because during a longer monitoring period, such as the 3-year cycle for the RWMP, it is more likely that an erosion pin may not be found on a subsequent visit. If the erosion pin is not found, there are a number of explanations: the erosion pin was eroded out of the bank, the erosion pin was covered by slumped material, or the erosion pin remained in the bank but could not be located by the practitioner (human error). Ideally, the practitioner should provide additional notes when a change in exposure is not measured. Often if an erosion pin has been eroded out of the bank, it may be found lying on the bed, noting this will provide qualitative data for the location. It would be uncertain when the pin was fully eroded out of the bank, but it can be concluded that the bank has eroded at least the one metre length of the erosion pin during the three year period. Similarly, there is often a general indication that an erosion pin may have been covered by slumped material if slumps are common in the monitoring reach. At minimum, if an erosion pin is not found, it generally suggests that a channel is relatively active. It is also important when interpreting the calculated migration rates and measured changes in exposures to consider that erosion is often an episodic process, rather than a occurring at a steady, consistent rate.

To provide a couple of examples from Table 4, in the case of GTCC-11, the erosion pin EP1 installed in the right bank experienced erosion over 2003-2006, 2006-2009, and 2009-2012, with the pin further exposed by 5.5 cm, 15 cm, and 3.0 cm, respectively for each time frame. However, deposition was occurring between 2012 and 2016, with a reduction in exposure of 6 cm noted. In contrast, the erosion pin EP1 installed in the right bank of GTCC-9 experienced erosion over the 2003-2006, 2006-2009, and 2009-2012 with an increase in exposure of 20 cm, 14 cm, and 50 cm noted, respectively. The erosion pin could not be located following the 2012-2016 period. As noted previously, this could be caused by: the erosion pin being eroded out of the bank, that it was covered by slumped material, or that it was not located by the practitioner. While it may be inferred in this case that it is likely that the erosion pin was eroded out based on past trends, a re-survey of the channel cross-section helps to confirm this inference. The erosion pin results are further explained in the existing conditions section of each reach.

TABLE 4 Summary of erosion pin data for all monitoring stations 2003-2016

Site	Location	ID	Change in exposure (cm)				Total (cm)	Time period for total	Migration rate m/year	Migration rate cm/year
			2003 2006	2006 2009	2009 2012	2012 2016				
GTCC-11	RB	EP 1	5.5	15	3.0	-6.0	17	2003-2016	0.013	1.3
	LB	EP 2	2.5	15	7.0	-6.5	18	2003-2016	0.014	1.4
	LB	EP 3	1.5	5.0	18	1.0	26	2003-2016	0.020	2.0
	RB	EP 4	0.5	5.5	25	11	42	2003-2016	0.032	3.2
	LB	EP 5	4.5	-3.5	4.5	-1.5	4	2003-2016	0.0031	0.3
GTCC-9	RB	EP 1	20	14	50		84	2003-2012	0.093	9.3
	LB	EP 2	3.0	-3.5	5.0		4.5	2003-2012	0.005	0.5
	LB	EP 3	5.0	-6.0	-1.0		-2.0	2003-2012	-0.002	-0.2
	RB	EP 4	16	17	2.0		35	2003-2012	0.038	3.8
	RB	EP 5	8.5	33	16		57	2003-2012	0.063	6.3
GTCC-6	LB	EP 1	23	-2.5	24		44	2003-2012	0.048	4.8
	LB	EP 2	-8.5	16			7	2003-2009	0.012	1.2
	LB	EP 3			45		45	2009-2012	0.150	15
	RB	EP 4		31	32	70	133	2006-2016	0.130	13
	LB	EP 5	-5.5	31	3.0	-8.0	20	2003-2016	0.015	1.5
GTCC-5	RB	EP 1	36			5	36	2003-2006	0.120	12
	LB	EP 2	-2.0	1.0	-0.5	0.5	-1.0	2003-2016	-0.001	-0.08
	RB	EP 3	20	19	7.5		46	2003-2012	0.051	5.1
	RB	EP 4		25			25	2006-2009	0.083	8.3
	LB	EP 5	-7.0	6.0	-5.5		-6.5	2003-2012	-0.007	-0.72
GTCC-4	LB	EP 1		18	34		52	2006-2012	0.087	8. 7
	LB	EP 2	16		14	6.0	20	2009-2016	0.029	2.9
	RB	EP 3	21	12	18	14	65	2003-2016	0.050	5.0
	RB	EP 4	-15	37	-20	7.5	10	2003-2016	0.008	0.77
	LB	EP 5		9.0	57	13	79	2006-2016	0.079	7.9
GCC-12	LB	EP 1	21	26	8.0		55	2003-2012	0.061	6.1
	LB	EP 2	34	6.5	5.5	43	46	2003-2016	0.035	3.5

Site	Location	ID	Change in exposure (cm)				Total (cm)	Time period for total	Migration rate m/year	Migration rate cm/year
			2003 2006	2006 2009	2009 2012	2012 2016				
	LB	EP 3	-35	7.5			-27	2003-2009	-0.045	-4.5
	RB	EP 4		30	20		50	2006-2012	0.083	8.3
	RB	EP 5	1.0	6.5	14	-5.0	22	2003-2016	0.017	1.7
GCC-7	RB	EP 1			6.5	8.5	15	2009-2016	0.021	2.1
	RB	EP 2	15	47	-24		38	2003-2012	0.042	4.2
	RB	EP 3	30		31		31	2009-2012	0.102	10
	LB	EP 4	3.5	-3.5	-7.5	-12	-19	2003-2016	-0.015	-1.5
GCC-6	LB	EP 1	87	31	69	26	213	2003-2016	0.164	16
	LB	EP 2	5.0	16	0.5	9.5	31	2003-2016	0.023	2.3
	RB	EP 3			48		48	2009-2012	0.160	16
	RB	EP 4		56	38		94	2006-2012	0.156	16
	RB	EP 5		13	14		27	2006-2012	0.044	4.4
GCC-4	LB	EP 1	7.0	11		44	44	2012-2016	0.110	11
	RB	EP 2	44		16	23	39	2009-2016	0.056	5.6
	RB	EP 3	45	8.0	2.0	14	69	2003-2016	0.053	5.3
	LB	EP 4	4.5	16	5.0	7.0	33	2003-2016	0.025	2.5
	RB	EP 5	28	1.0	23	10	61	2003-2016	0.047	4.7
GCC-2	LB	EP 1	11	5.0	5.0		21	2003-2012	0.023	2.3
	RB	EP 2	2.0	-0.5	-2.0	-2.5	-3.0	2003-2016	-0.002	-0.23
	RB	EP 3	-10		1.5	8.0	9.5	2009-2016	0.014	1.4
	RB	EP 4		40	21	42	103	2006-2016	0.100	10
	LB	EP 5	55	14	41		109	2003-2012	0.120	12

* erosion pins highlighted with yellow are those located at the monitoring cross-section

** vacant boxes in “change in exposure” indicate erosion pin was not found in that particular year

3.4 Rapid Assessment Results

A rapid assessment was completed for each valley segment in accordance with the RGA (MOE 2003) and RSAT (Galli 1996) stream assessment protocols. Rapid assessments were undertaken to investigate any significant changes in the geomorphic stability of each segment relative to previously reported results (PARISH 2004; Table 1). A summary of the 2016 RGA and RSAT results is presented Table 5, and illustrated in Figures 4 and 5. In general, 2016 RGA scores were slightly lower than those previously recorded in 2004 suggesting an improvement in channel stability (highlighted in red in Table 5). RSAT scores generally increased in comparison to the scores reported in 2004, indicating higher channel stability. Although the results suggest improved channel stability within the catchment, the rapid assessment protocols are very subjective and can often be misleading. Long-term monitoring of geomorphic parameters, as those discussed in previous subsections, provides a better method of assessing trends in channel form and function. A detailed description of each valley segment and comprehensive assessment of long-term monitoring results is provided in subsequent sections.

TABLE 5 Comparison of Rapid Assessment Results (2004 and 2016)

Valley Segments	RGA	Stability Index	RGA	Stability Index	RSAT	Stability Index	RSAT	Stability Index
	2004		**2016**		**2004**		**2016**	
GTCC-11	0.03	In Regime	0.09	In Regime	23	Moderate	24	Moderate
GTCC-9	0.15	In Regime	0.13	In Regime	23	Moderate	25	Moderate
GTCC-6	0.29	Transitional	0.16	In Regime	25	Moderate	26	Moderate
GTCC-5	0.22	Transitional	0.32	Transitional	28	Moderate	30	Moderate
GTCC-4	0.57	Adjustment	0.25	Transitional	21.5	Moderate	27	Moderate
GCC-12	0.22	Transitional	0.15	In Regime	20	Moderate	28	Moderate
GCC-7	0.30	Transitional	0.13	In Regime	19	Low	23	Moderate
GCC-6	0.36	Transitional	0.20	Transitional	20	Moderate	27	Moderate
GCC-4	0.38	Transitional	0.18	In Regime	23	Moderate	34	Moderate
GCC-2	0.44	Adjustment	0.28	Transitional	18	Low	27	Moderate

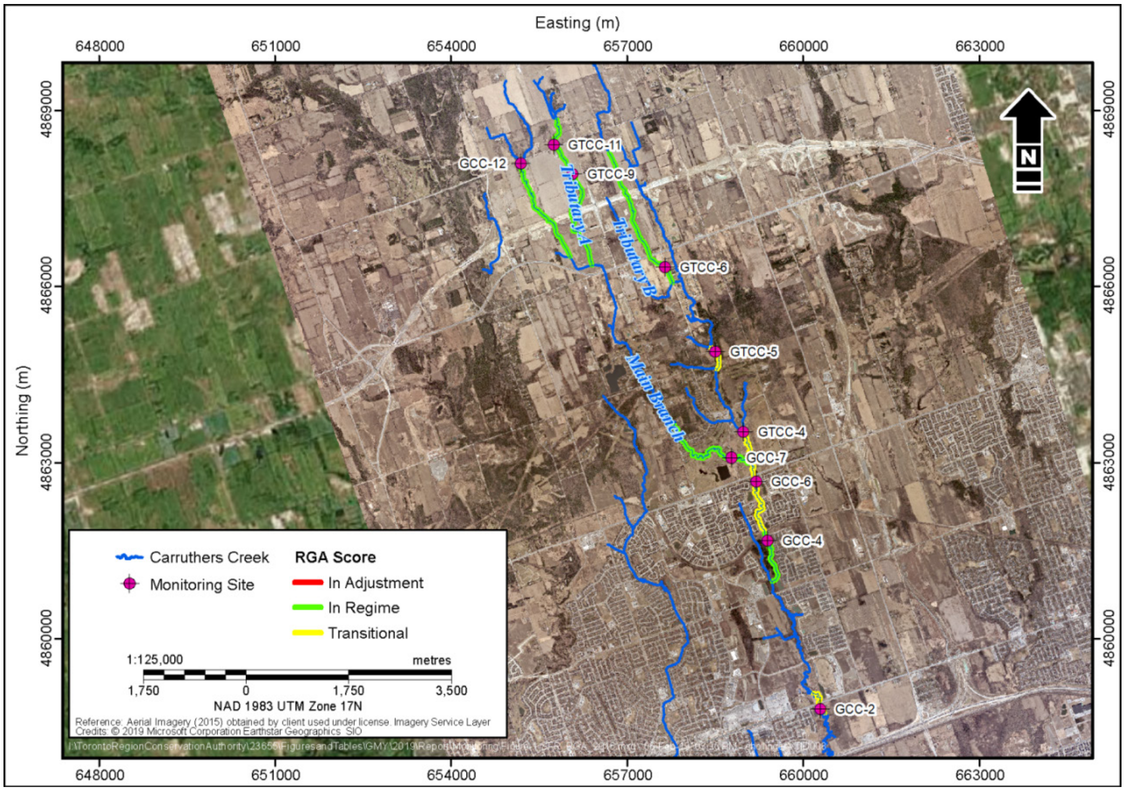

FIGURE 4 Rapid Geomorphic Assessment (RGA) Results for Each Valley Segment (2016)

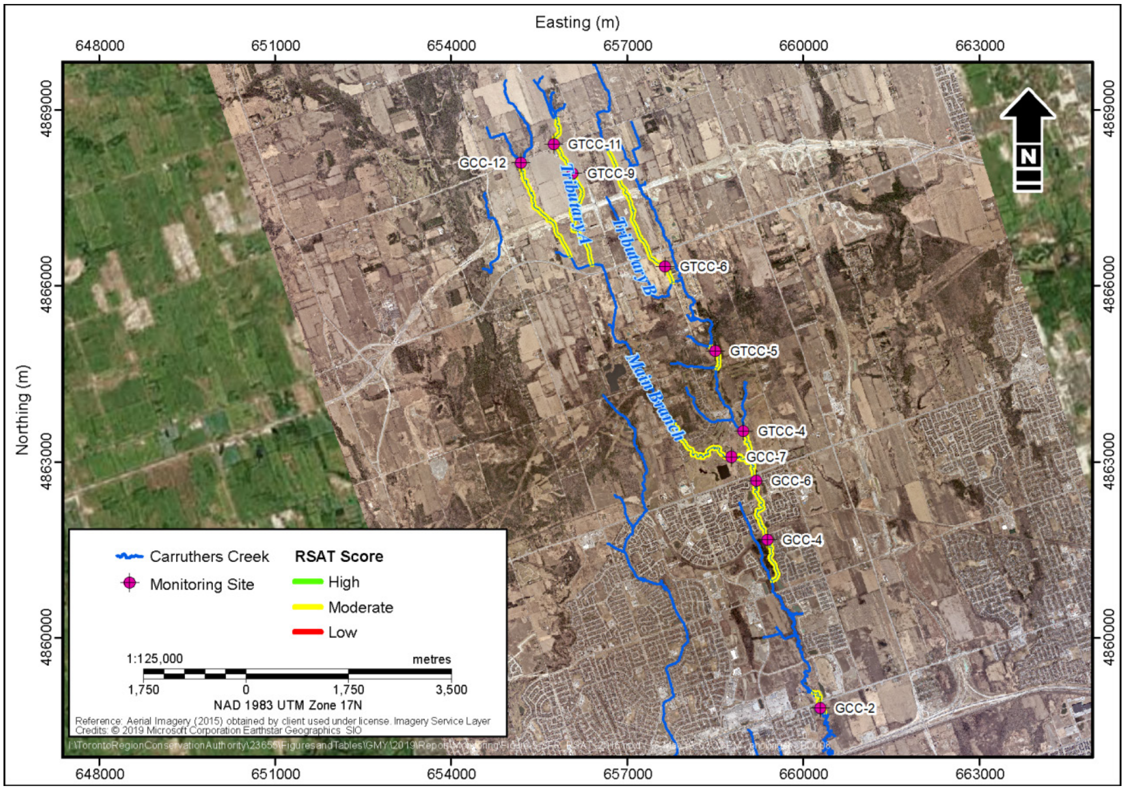

FIGURE 5 Rapid Stream Assessment Technique (RSAT) Results for Each Valley Segment (2016)

4 TRIBUTARY A

Tributary A is located at the upstream end of the watershed beginning north of Concession 7 and confluences with the Main Branch north of Highway 7 (Figure 6). The tributary is approximately 4 km in length and flows through rural area where the dominant surrounding land use is agricultural. The riparian corridor for the tributary is generally 40 to 100 m wide. Vegetation consisted of deciduous swamp, meadow marsh, buckthorn deciduous thicket, and a small area of hardwood deciduous forest downstream of Highway 407. Two monitoring stations were located on Tributary A: GTCC-11 and GTCC-9. The valley segment containing GTCC-11 was classified as 3M (PARISH 2003): small catchment and high slope. The valley segment containing GTCC-9 was classified as 2M: small catchment and moderate slope.

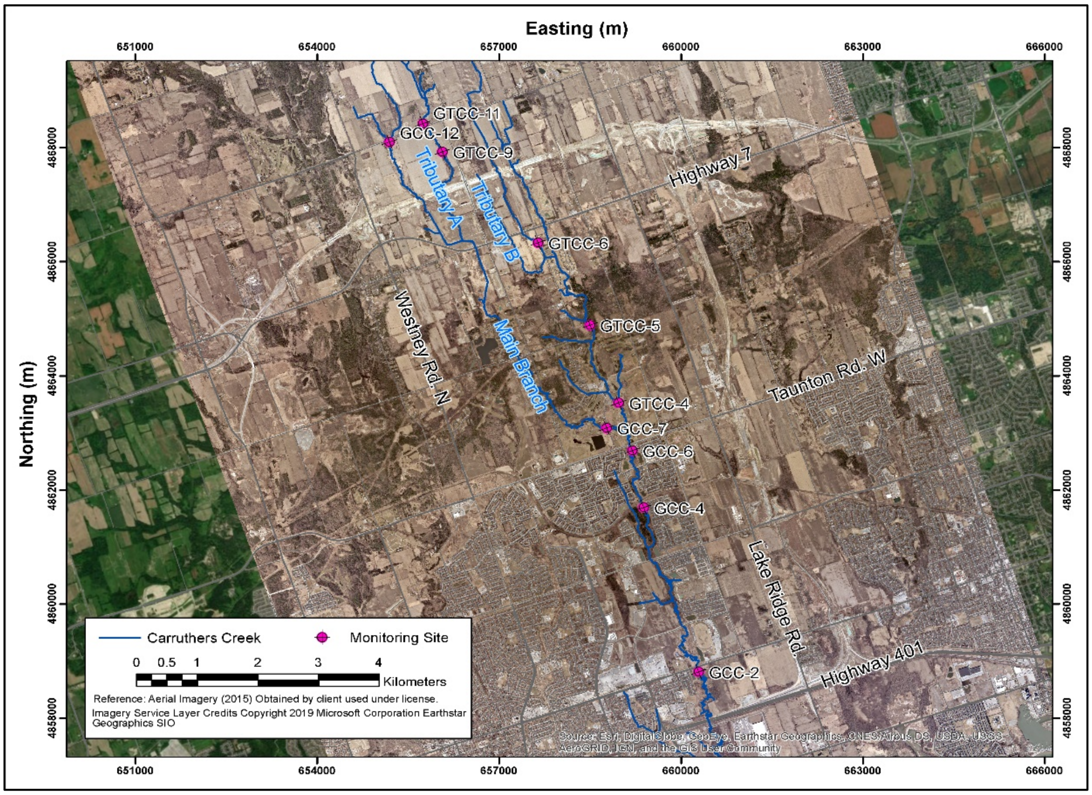

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FIGURE 6 Tributary and Monitoring Site Locations

4.1 GTCC-11

The GTCC-11 station is located approximately 200 m upstream of Highway 7. The channel is located in an area vegetated with shrubs, tall grasses, and deciduous trees. This vegetated area is approximately 60 m wide beyond which are agricultural fields. The eastern bank is vegetated with poplar trees and red osier dogwoods, while the western bank is vegetated with tall dense grasses.

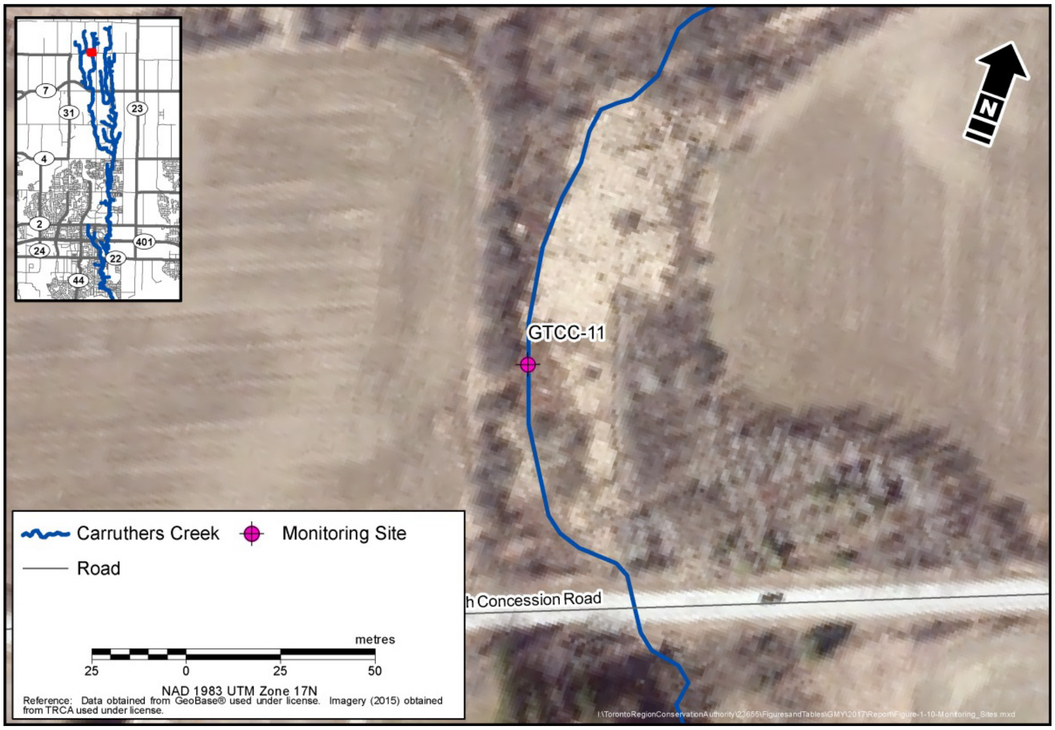

FIGURE 7 Location of GTCC-11 Monitoring Station

In 2003, the cross-sectional area for the monitoring cross-section was 0.41 m^2. The cross-section had a narrow “V” shape, typical of a small tributary. At the time of survey (October) the wetted width was 0.30 m. The bankfull width was approximately 0.71 m and the max depth was 0.36 m. Over the monitoring period, the cross-section exhibited a steadily increasing cross-sectional area. Between 2003 and 2016, the cross-sectional area increased by 0.10 m^2 or approximately 48%. The cross-section overlay indicates that this change corresponds to a deepening and widening of the thalweg, transitioning the cross-section from a “V” to a “U” shape. The 2006 and 2009 cross-sections show the cross-section deepening to a maximum depth of 0.43 m in 2009. The 2012 and 2016 cross-sections then show widening of the bed through ongoing toe erosion, while the maximum depth returns to a consistent 0.40 m. Comparing the 2016 cross-section to the other years also suggests deepening of the floodplain area. This could be a result of higher flows more frequently spilling onto the floodplain and establishing a larger bankfull cross-section. Shifts in floodplain topography can also be tied to growth and die-off of dense, tall grass vegetation. These changes in cross-sectional shape are a manifestation of typical channel processes in a small headwater channel.

The erosion pins generally exhibited increased exposure between monitoring periods. The maximum increase in exposure was 24.5 cm for EP4 between 2009 and 2012. In some cases (EP1 and EP2), the change in exposure between monitoring periods increased, while by the following monitoring period, the change in exposure decreased. This indicates that deposition was occurring during one time period, followed by erosion the next monitoring period. During this monitoring period there was also a large change in exposure (18 cm) for the erosion pin at the monitoring cross-section (EP3). Based on these exposures the erosion rates would be approximately 8 cm/year and 6 cm/year, respectively. The erosion rates based on the full monitoring period (13 years) ranged from 0.31 to 3.19 cm/year. The average erosion rate is 1.63 cm/year. In cases where no measurement for the change in exposure was recorded, the erosion pin was either not located or was eroded out.

The substrate at GTCC-11 is composed of fine-grained materials including sand, silt, and small pebbles. Over the monitoring period this was consistent with no noticeable coarsening.

4.2 GTCC-9

The GTCC-9 station is located approximately 700 m downstream of GTCC-11. It is approximately 2 km from the confluence with the main channel. At GTCC-9 the channel is located on the floor of a valley, which is approximately 20 to 40 m wide. The channel meanders across the valley floor, periodically contacting the valley walls. The valley floor is vegetated with meadow grasses and woody shrubs such as buckthorn and red osier dogwoods. The slopes are populated by deciduous trees. Beyond the top of the valley are agricultural fields. At the monitoring cross-section, the right bank (western) is vegetated with tall grasses and the left bank (eastern) is covered by a large red osier dogwood. The monitoring photographs indicate that the cross-section was originally installed immediately downstream of the dogwood. Over time the dogwood has grown sufficiently large that it encompasses the area where the left bank pin is located. This made it difficult to properly level the measuring tape along the left bank due to the dense woody vegetation that must be pushed down to allow the tape to lie flat.

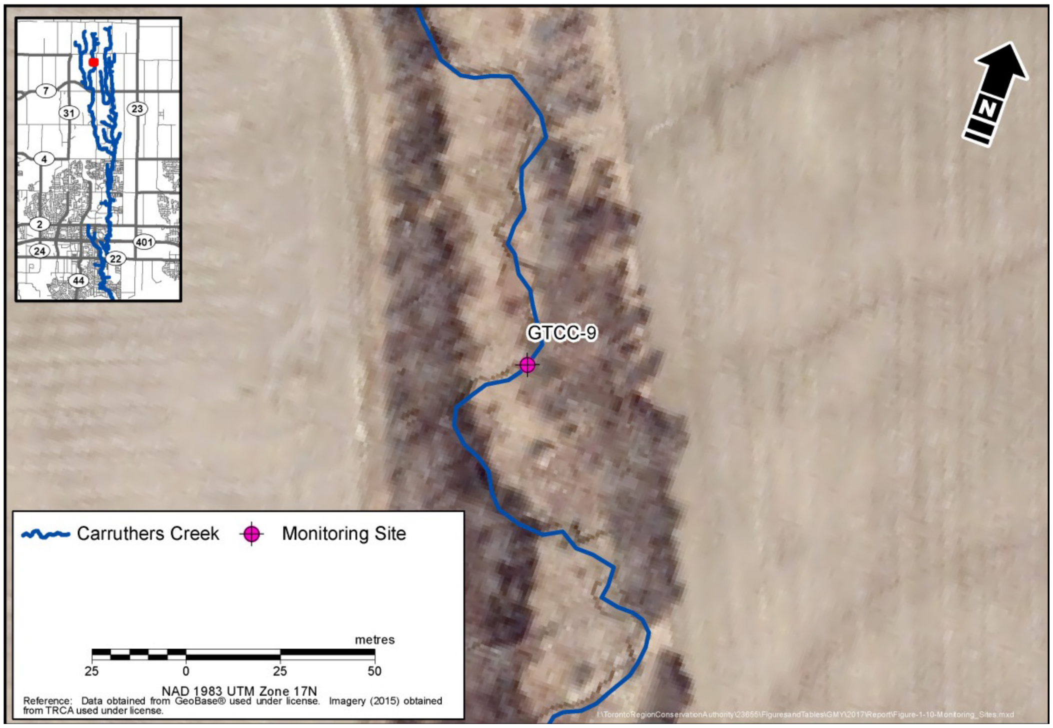

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FIGURE 8 Location of GTCC-9 Monitoring Station

In 2003, the cross-sectional area for the monitoring cross-section was 0.83 m^2. The cross-section had a notched low-flow channel in the center with a bottom width of approximately 0.50 m. The 2006 cross-section was distinctly different from all other monitoring years and appears to have captured a transitional period. The cross-section bottom width increased to approximately 0.77 m and no longer exhibited a defined low-flow area. Between 2003 and 2006, cross-sectional area increased by 0.16 m^2, the largest change during the 13-year period. Due to the transitional shape, it was difficult to define bankfull for the 2006 cross-section. The cross-sections for 2009, 2012, and 2016 all indicate that the channel is migrating toward the right bank. This is evidenced by the increasing elevation of the left bank profile and the consistent retreat of the right bank. The cross-section is also deepening along the right side. Over the 13-year monitoring period, the bed has deepened by approximately 0.10 m, based on comparison of the maximum depth values from 2016 and 2003. The overall cross-sectional area has increased by 0.30 m^2 or 35%. This overall increase in cross-sectional area is likely a result of the ongoing channel migration, as noted above. It is anticipated that this channel adjustment will ultimately stabilize, provided sediment and flow regimes remain generally consistent.

Two erosion pins are located at the monitoring cross-section, one in each bank. Both pins exhibited an increase in exposure between 2003 and 2006 when the cross-section shape widened. From 2006 to 2012, the right bank pin (EP4) exhibited continued increases in exposure while the left bank pin (EP3) exhibited small reductions in exposure. This is consistent with the migration of the channel toward the right bank. Based on the EP4 data, the average erosion rate for the right bank at the monitoring cross-section is 3.83 cm/year. During the monitoring period the largest changes in exposure were noted at EP1 and EP5. This was a result of their locations; both were located on the outer bank of a bend. The average migration rates based on the EP1 and EP5 data are 9.28 and 6.33 cm/year.

The substrate at GTCC-9 is composed of fine-grained material and medium-sized gravel. The substrate was relatively consistent over the monitoring period, with 2006 and 2009 considered coarser than other years based on the D_{50}. These years may have been coarser because the cross-section was actively enlarging and more of the fine material had been removed. Additionally, the 2009 cross-section was measured in April, when high flows are more frequent due to spring melt. This leads to seasonally coarse distributions as fine material is flushed away more regularly.

4.3 Summary

In general, valley segments in Tributary A are considered stable (*In Regime*) and contain moderate stream health. In comparison to the 2004 data, stability rankings of the channel at both monitoring stations have not changed. The cross-sectional area of the surveyed cross-sections for both segments increased between 2003 and 2016 and is attributed to the cross-section widening and deepening. Channel substrate was composed of a high proportion of fine-grained silt and sand. Additionally, small pebbles and gravel was common within the channel and channel substrate remained relatively consistent over the entire monitoring period. Based on erosion pin measurements, the average rate of erosion at sites GTCC-11 and

GTCC-9 was approximately 2.7 cm/year. The largest changes in erosion pin exposure were typically where pins were placed on the outer bank of a bend.

5 TRIBUTARY B

Tributary B begins northeast of Tributary A, south of Concession 8 (Figure 6). It is the larger of the two tributaries, approximately 9.4 km in length, more than double the length of Tributary A. North of Highway 7, the channel flows through rural, agricultural land with a riparian corridor ranging from approximately 10 m wide in the headwaters to approximately 80 m wide south of Highway 407. South of Highway 7, the channel flows through a small residential development where a channel design has been implemented. The channel then flows through a dense woodlot area before continuing through Deer Creek Golf Course. The confluence with the Main Branch is located near the south end of the golf course. There are three monitoring stations located on Tributary B, all of which are located downstream of Highway 7. The valley segment containing GTCC-6 is classified as 1H: small catchment and low slope. The valley segment containing GTCC-5 is classified as 3H: small catchment and high slope. The valley segment containing GTCC-4 is classified as 2H: small catchment and moderate slope.

5.1 GTCC-6

The GTCC-6 station is the most upstream station, located approximately 325 m downstream of Highway 7, near the crossing of Concession 4. On the south side of the channel is a small deciduous woodlot with meadow grasses. The north side is vegetated with tall, dense meadow grasses and shrubs. The monitoring cross-section is located in a highly active area of the channel where ongoing erosion of the right bank is occurring. As a result of this, there were challenges maintaining the cross-section bank pins. The 2003 cross-section was not considered as part of the results because the cross-section was reinstalled in 2006 after the right bank pin was completely lost. The 2006 cross-section is 2.3 m wider than the original 2003 cross-section. There also appeared to be an issue with the 2006 cross-section when compared to subsequent cross-sections. This is likely related to the movement of the right pin from 6.0 m (2006) to 6.85 m (2009). Therefore only the 2009, 2012, and 2016 cross-sections were evaluated. Flow in GTCC-6 is intermittent, as evidenced through the lack of flow observed during the field visits, completed at different times. However, the monitoring results demonstrate that this channel experiences sufficient flow during wetter periods, to result in toe erosion and undercutting.

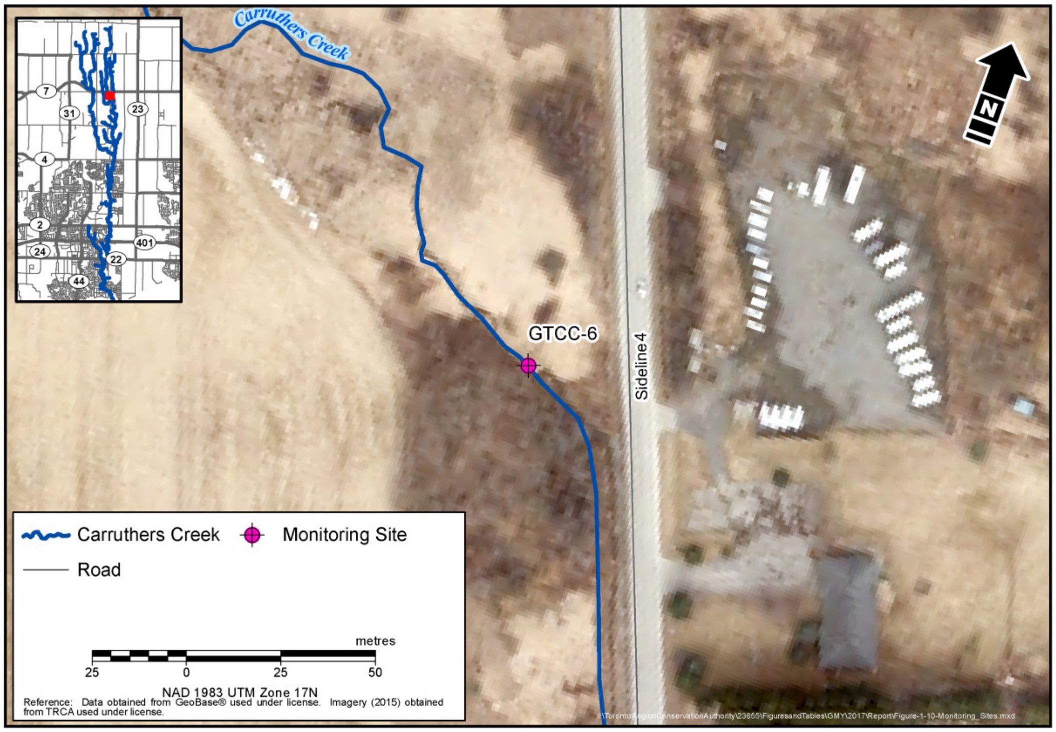


FIGURE 9 Location of GTCC-6 Monitoring Station

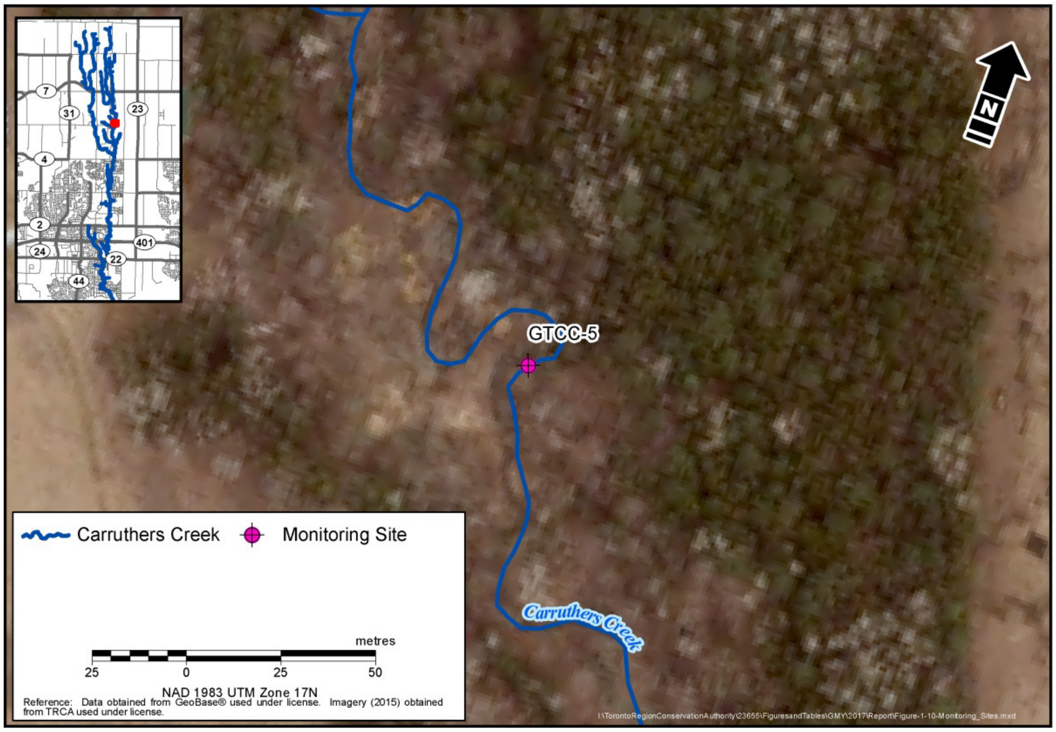
The three cross-sections indicate that the cross-section has deepened and also migrated further into the right bank. This is expected given the erosion and severe undercutting of the right bank seen in the monitoring photographs. Minimal change to the left bank profile has occurred. Between 2009 and 2012, the cross-section deepened with the maximum depth increasing from 1.00 m to 1.13 m. The 2016 cross-section exhibits aggradation along the left bank toe and erosion of the right bank toe. There were increases in cross-sectional area both in 2012 and 2016, indicating that the channel is not just migrating toward the right bank, but also enlarging. The cross-sectional area in 2009 was 3.35 m^2 and increased to 4.05 m^2 in 2012, and then 4.23 m^2 in 2016. Over the 7-year period, this was an increase of 0.88 m^2 or 26.2%.

Two erosion pins are located at the monitoring cross-section, one in each bank. The right bank pin (EP4) exhibited large increases in exposure every monitoring period. Based on the data from EP4, the migration rate of the right bank is approximately 13.3 cm/year. The left bank pin (EP5) exhibited changes in exposure ranging from -8 cm to 30.5 cm. This would suggest that there is erosion followed by periodic slumping of material along that bank. The other erosion pins indicated that toe erosion is widespread throughout the reach. For example, EP2 and EP3 were located in a bend that was actively eroding; both pins were found eroding out of the bank and lying on the bed at two of the monitoring visits. This type of severe toe erosion and undercutting often occurs in channels with grass dominated vegetation.

The substrate at GTCC-6 is composed of fine-grained materials including sand, silt, and small pebbles. Over the monitoring period, this was consistent with no noticeable coarsening.

5.2 GTCC-5

The GTCC-5 station is located in a large woodlot upstream of the Deer Creek Golf Course. Through this area the channel is quite sinuous with tight bends and steep eroding banks. Woody debris, such as branches and downed trees, was common, resulting in debris jams. The banks in this reach were higher than those upstream, ranging from 0.50 to 1.25 m. This is indicative of incision. The monitoring cross-section is located on the downstream straight section of an "S" bend. There is substantial erosion along the outer bank upstream of the cross-section; the bend has overwidened and formed a large pool. A large willow tree fell across the channel at the monitoring cross-section between 2009 and 2012; due to this, the measuring tape would not lie flat in 2012 and 2016. The impact on the cross-section graph could not be quantified; it is assumed that the cross-section shape is representative of field conditions. Specific depth measurements for 2012 and 2016 are likely to be slightly higher than in the field due to the tree pushing the tape higher in the center of the cross-section. The two cross-sections correlate well with each other signifying that the tree had a consistent impact on measuring tape and cross-section measurement.



Reference: Data obtained from GeoBase® used under license. Imagery (2015) obtained from TRCA used under license.

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FIGURE 10 Location of GTCC-5 Monitoring Station

The monitoring cross-section at GTCC-5 experienced the most significant change out of all the monitoring stations. The channel has substantially incised at this location as the result of a debris jam failure. Debris jams establish a sharp change in elevation on the channel profile. When a debris jam fails, the channel will incise to remove the difference in elevation and re-establish a consistently sloped profile. This process was well documented at the GTCC-5 cross-section. Based on the cross-section overlay and corroboration by the monitoring photographs, the channel began to incise between 2006 and 2009. The cross-section was stable between 2003 and 2006 with some accumulation of sediment, resulting in a small reduction in area. The material likely accumulated as a result of the small debris jam located immediately downstream of the cross-section (2003 photograph) creating a backwater. Between 2006 and 2009, the debris jam destabilized as seen in the 2009 photograph (Appendix B). The 2009 cross-section deepened and widened along the right bank; cross-sectional area increased by 0.53 m^2 or 21.3%. The maximum depth increased by 0.29 m between 2006 and 2009. Between 2009 and 2012, the large willow tree located on the left bank fell across the cross-section. It can be seen in the 2009 photograph on the left bank. The downed tree is an additional disturbance altering flow at the cross-section. The change in cross-sectional area between 2009 and 2012 was the most significant during the monitoring period, enlarging by 1.27 m^2 or 42.4%. The maximum depth increased by 0.36 m; this value could be inflated due to the measuring tape issue as a result of the downed tree. Between 2012 and 2016, the cross-section continued to enlarge, primarily through severe undercutting and subsequent retreat of the right bank. The bed appears to have stabilized as there was minimal change in the actual bed elevation. A mid-channel bar has also formed which supports this notion.

In total, the cross-section has incised approximately 0.62 m based on the difference in maximum depth between the 2003 and 2016 cross-sections. Over the 13-year monitoring period, the cross-sectional area has increased by 2.54 m^2 or 98%. The cross-section enlarged through incision and retreat of the right bank, while the left bank profile remained stable.

There are two erosion pins located at the monitoring cross-section, EP2 (left bank) and EP3 (right bank). The data for these two pins is consistent with the cross-section results; EP2 exhibited minimal change in exposure during the monitoring period, while EP3 exhibited large changes each monitoring year. Based on the data from EP3, the migration rate for the right bank is approximately 5 cm/year. The other three erosion pins were frequently lost during the monitoring, which suggests that they were fully eroded out of the banks due to the severity of erosion. For example, EP4 was only re-measured once during the monitoring period, in 2009, and had a change in exposure of 25 cm.

The substrate at GTCC-5 was dominated by finer material consisting of coarse sand, pebbles, and silt from 2003 to 2009. Medium and coarse gravel represented the coarser fraction. The distribution coarsened in 2012 and 2016, and is typical of an incising channel. When the debris jam no longer created a backwater, fine sediment would have been flushed out leaving coarser material behind. As the channel incised further, additional fine material would have been removed. The coarsening of the bed is also an indication that incision is slowing as the accumulation of coarse material acts to reduce bed erosion.

5.3 GTCC-4

The GTCC-4 station is located on the Deer Creek Golf Course in a small cedar woodlot downstream of a cart path bridge. The woodlot provides a small buffer from the adjacent manicured golf course. The monitoring cross-section is located between in a straight section between two successive bends, or an “S” bend. In the upstream bend, there was severe woody debris obstruction. Upstream of the bend, the channel flows adjacent to a valley wall along the right bank. The bend downstream of the cross-section has severe erosion of the outer bank. The bank is steep and elevated, with minimal vegetative buffer from the golf course, approximately less than 5 m.

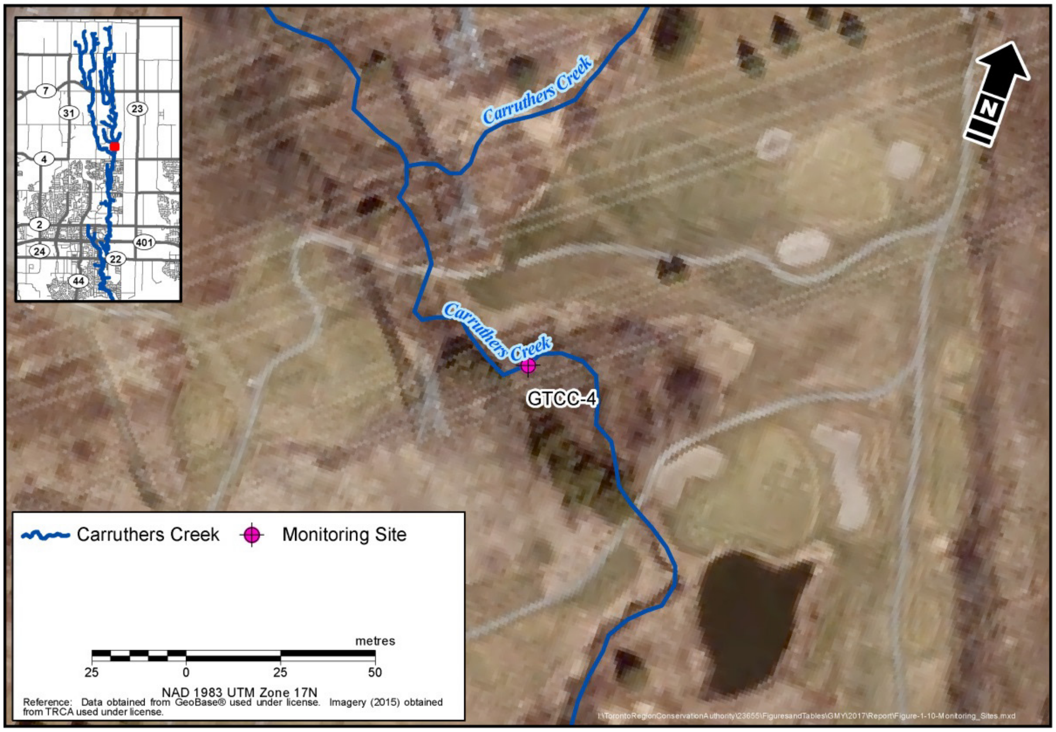

FIGURE 11 Location of GTCC-4 Monitoring Station

In 2003, the cross-sectional area for the monitoring cross-section was 1.64 m^2. The maximum depth was 0.81 m. The cross-section had a narrow low-flow area, with a bottom width of approximately 0.60 m. Between 2003 and 2009 the cross-sectional area steadily increased, primarily through erosion of the vertical left bank, widening the bottom width of the channel. The 2009 cross-section appears to be capturing a transition between the 2003/2006 cross-sections and the 2012/2016 cross-sections. In 2009, the cross-section incised to a maximum depth 0.87 m. This is the deepest measured cross-section during the monitoring period. The 2012 cross-section then exhibits a large loss of material from the lower portion of the right bank, where very little change was noted in the previous cross-sections. It is unclear from the monitoring photographs what may have caused this. The left bank also exhibited a noticeable retreat between 2009 and 2012. The change in cross-sectional area between these 2009 and 2012 was 0.15 m^2 or approximately 8%. The 2012 and 2016 cross-sections have a wider bottom width of approximately 1.4 m as compared to approximately 0.60 m in 2003. Visually comparing the cross-sections, the 2003/2006 cross-sections have a narrow defined low-flow area, while the 2012/2016 cross-sections have a larger general "U" shape. This change in cross-sectional shape is reflected by a 25% increase in cross-sectional area over the 13-year monitoring period.

One erosion pin is located at the monitoring cross-section in the left bank, EP2. The pin exhibited increases in exposure ranging from 6 to 15.5 cm. Based on this data, the average erosion rate for the left bank was approximately 2.86 cm/year. Erosion pin 4 exhibited variable results ranging from large increases in exposure (36.5) to large decreases in exposure (-19.5). This is indicative of an area which is eroding, destabilizing, and collapsing. Erosion pin 1 was located in the outer bank of the eroding bend downstream of the cross-section. It was found eroded out of the bank in 2016 and exhibited large increases in exposure in 2012 and 2009. Based on EP1, the average erosion rate in this bend is approximately 8.6 cm/year. Overall, based on all the erosion pin data for GTCC-4, the average erosion rate was 5.03 cm/year.

The channel substrate primarily consisted of medium to coarse gravels. As this material is relatively large, vertical erosion is likely to be low (i.e., flows in the channel are unlikely to exceed the critical threshold of these materials). Therefore, the primary mode of cross-sectional adjustment was lateral erosion. The substrate distribution was consistent over the 13-year monitoring period and exhibited no distinct shifts.

5.4 Summary

In general, two valley segments in Tributary B are *Transitional*, and one is *In Regime*. All segments contain moderate stream health and have generally become more stable in comparison to the stability rankings from 2004. The cross-sectional area of the surveyed cross-sections for all three segments increased between 2003 and 2016 and is attributed to the cross-section deepening from channel incision. There are signs of active erosion at all monitoring stations within this segment, mainly in the form of bank slumping, toe erosion, and channel incision. The highest amount of channel incision was recorded at GTCC-5, where debris jams formed from fallen trees have resulted in the channel incising up to 0.62 m over the entire monitoring period. Several erosion pins were lost and relocated at the various stations over the monitoring period, making it difficult to quantify exact erosion rates. The highest erosion rates measured were 12 – 15 cm/year, while average erosion rates are approximately 5.7 cm/year. Typically pins places on outer banks have been fully eroded out as this where most of the active erosion has occurred. Channel substrate dominantly consists of silt, sand, and small pebbles in GTCC-5 and GTCC-6. The substrate at GTCC-5 has coarsened over time due to channel incision. Substrate at GTCC-4 is dominated by medium and coarse gravel and is significantly coarser than other monitoring stations within this valley segment.

6 CARRUTHERS CREEK MAIN BRANCH

The Main Branch of Carruthers Creek originates to the west of Tributary A, north of Concession 7, and east of Westney Road (Figure 6). The Main Branch is approximately 27 km long and flows into Lake Ontario. The surrounding land use north of Taunton Road is primarily rural and agricultural. South of Taunton Road, the channel corridor is generally contained within residential development, particularly between Taunton Road and Rossland Road. Sinuosity also begins to increase noticeably south of Taunton Road, becoming highly sinuous south of Rossland Road. This increase in sinuosity corresponds to the reduced gradient progressing toward the Lake. There are five monitoring stations located on the Main Branch. One is located in the headwater area, GCC-12, while the other four are located south of Highway

7. There is a large area gap of approximately 9 km between GCC-12 and the next station (GCC-7). The furthest downstream station is GCC-2, located on the south side of Kingston Road. There are no stations located below Highway 401. The valley segment containing GCC-12 was classified as 2L: small catchment and moderate slope. The valley segment containing GCC-7 was classified as 5H: medium catchment and moderate slope. The valley segment containing GCC-6 was classified as 4H: medium catchment and low slope. The valley segment containing GCC-4 was classified as 5H: medium catchment and moderate slope. The valley segment containing GCC-2 was classified as 4H: medium catchment and low slope.

6.1 GCC-12

The GCC-12 station is the most upstream station on the Main Branch of Carruthers Creek. It is located approximately 100 m downstream of Concession 7. The channel flows adjacent to a rural residential property with agricultural fields surrounding the riparian corridor. The riparian corridor is relatively wide at the monitoring station approximately 80 to 100 m. The surrounding vegetation is predominantly tall meadow grasses and small willow woodlots. At the monitoring cross-section, both banks are vegetated with meadow grasses.

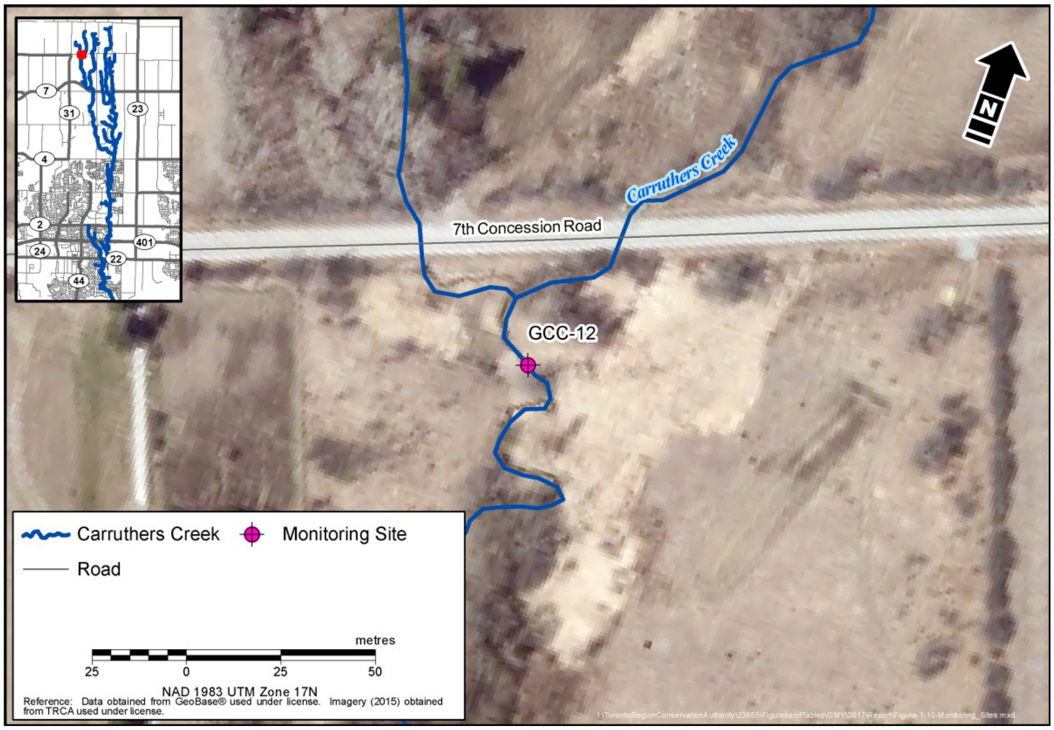

FIGURE 12 Location of GCC-12 Monitoring Station

There were challenges maintaining the monitoring cross-section at GCC-12 due to ongoing erosion of the right bank. Neither of the cross-section bank pins could be located in 2016. The cross-section was reinstalled based on an erosion pin that corresponded to the cross-section. Therefore, the 2016 cross-section should not be compared with other monitoring years. It was also noted during the 2016 measurement that the right bank was noticeably higher than the left bank, making it difficult to level the tape. Assuming the cross-section was reinstalled at the correct location, this difference in bank height could have impacted previous cross-section measurements. Notes from the 2009 cross-section measurement also indicated that the tape was not level. This may have been a result of moving the right pin back which occurred in 2009. The pin was moved from 4.3 m to 5.1 m, presumably to prevent loss due to erosion. The movement of the right bank pin in 2009 made comparisons to the earlier years, 2003 and 2006, difficult.

In general, the cross-section is migrating toward the right bank and steadily eroding it. It also appears that the cross-section has deepened based on the overlays and the photograph documentation.

Two erosion pins are located at the monitoring cross-section, EP3 (left bank) and EP4 (right bank). The erosion pins provide particularly useful data when there are issues maintaining a cross-section. The right bank erosion pin results indicated ongoing retreat of the right bank. Twice, EP4 was lost or eroded out of the bank (2006 and 2016). The change in exposure between 2006 and 2009 for EP4 was 30 cm. Between 2009 and 2012, the change in exposure was 20 cm. The average migration rate at EP4 was 8.33 cm/year based on this data. The left bank pin at the cross-section, EP3, could not be located twice during the monitoring period in 2012 and 2016. Two of the erosion pins were located in an actively eroding bend downstream of the monitoring cross-section, EP1 and EP2. Both EP1 and EP2 exhibited large increases in exposure between 2003 and 2006, 21 cm and 34 cm respectively.

The channel substrate at GCC-12 is primarily composed of medium to coarse gravels. There appears to be a coarsening of the distribution in 2012 and 2016. This is indicated by the higher D_{50} values, as well as D_{16} values that are comparable to the D_{50} values from previous monitoring years. The coarsening may be a result of deepening of the cross-section. When this occurs, finer material is removed while coarser material which is too large for the channel to transport remains on the bed. Additionally, this site is downstream of a road and it is possible that sediment transport is decreased downstream of the culvert crossing.

6.2 GCC-7

The GCC-7 monitoring station is located at the south end of the Deer Creek Golf Course. Specifically, it is located in a 50 m reach of channel between a cart path crossing and a golf course road (Squire Drive). The channel is surrounded by golf course fairway and has a minimal riparian buffer of less than 5 m. The close proximity to golf course operations led to challenges in maintaining the cross-section. The 2009 cross-section needed to be reinstalled after the right bank pin was found lying on the bank. The pin was reinstalled 1.5 m wider than the original cross-section. The right bank pin had to be reinstalled again in 2012 due to the removal by golf course maintenance staff. A cross-section was not completed in 2016 because neither of the bank pins could be located; due to previous issues it was not reinstalled. Based on these issues, only the 2003 and 2006 cross-sections could be compared.

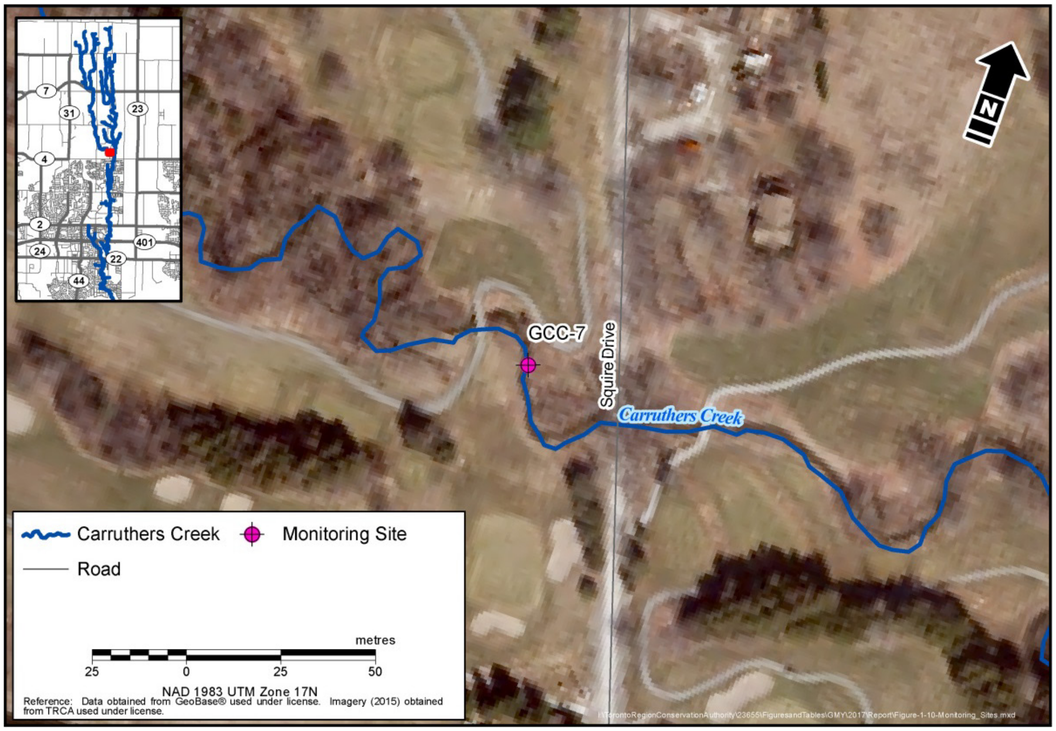

FIGURE 13 Location of GCC-7 Monitoring Station

Between 2003 and 2006, the cross-section exhibited evidence of erosion along the right side of the cross-section and right bank face. This was paired with an accumulation of material on the left side of the cross-section. The cross-sectional area was reduced from 1.75 m^2 to 1.5 m^2, approximately -14%. Based on these two years, the channel was migrating toward the right bank. Without subsequent years of data it is unclear if this process continues and if there is a general trend of reduction in cross-sectional area.

The two erosion pins located at the cross-section provide additional insight; EP3 was located in the right bank and EP4 was located in the left bank. The data from EP3 indicated that the right bank was continually eroding through the 13-year monitoring period. The pin could not be located in two of the monitoring years (2009 and 2016) presumably due to severe erosion. For both of the monitoring years that it was measured, the exposure increased by 30 cm. This suggests an erosion rate of 10 cm/year for the right bank based on the EP3 data. Data from EP4 exhibited decreases in exposure for each monitoring year between 2006 and 2016. The results ranged from -3.5 to -11.5 cm. Observations of the left bank in 2016 noted that the bank is slumping. The slumping and erosion is likely related to the lack of riparian buffer to provide additional support to the banks.

The channel substrate at GCC-7 is primarily composed of medium to coarse gravel with the largest material classified as cobbles. The grain size distribution was consistent over the 13-year monitoring period with no observable trends. Given that this section is located on the golf course, it is likely that the channel was previously armoured using substrate that would remain in place even at higher flows, which may explain the lack of observable trends in the substrate.

6.3 GCC-6

The GCC-6 monitoring station is located immediately south of Taunton Road in a riparian corridor between two residential areas. The residential area to the east was completed between 2005 and 2008, while the area to the west was completed shortly after. Stormwater management ponds are located on either side of the channel corridor, as well as a paved trail to the east. This is the first of three stations located in the southern developed portion of the watershed. The channel is situated within a woodland area approximately 125 m wide. Vegetation consisted of deciduous trees, woody shrubs, and tall grasses. The channel is quite sinuous with tight eroding bends. Eroding and undercutting banks were common throughout the reach resulting in frequent slumped vegetated blocks. The monitoring cross-section is located in a straight section of a large bend. The left bank at the monitoring cross-section corresponds with the outer bank of the bend and is vertical, while there is a vegetated point bar located along the right side of the cross-section. The wetted width is narrowed by the point bar and flow is focused along the toe of the left bank. This encourages erosion and undercutting.

Reference: Data obtained from GeoBase® used under license. Imagery (2015) obtained from TRCA used under license.

FIGURE 14 Location of GCC-6 Monitoring Station

Out of all the monitoring sites, the cross-section at GCC-6 was the most consistent, exhibiting minimal change over the 13-year monitoring period. The cross-sectional area in 2003 was 5.42 m^2 with a maximum depth of 1.37 m. Maximum depth was extremely consistent at 1.34 m in both 2006 and 2009 and 1.33 m in 2012. This indicates that the channel bed has not changed. The only change in the cross-section was retreat of the left bank. The most significant change during the monitoring period was noted between 2006 and 2009; cross-sectional area increased from 5.20 m^2 to 5.54 m^2, approximately 6.6%. Over the entire monitoring period, the cross-sectional area increased by only 4.8%. The cross-section can be considered stable.

While location of the monitoring cross-section was stable, the surrounding reach exhibited frequent undercutting of banks and slumping of material. The erosion pin data indicated that pins were frequently lost during the monitoring period. When erosion pins cannot be located it is assumed that they have been eroded out of the banks. It also occurs when sufficient undercutting has occurred for the bank to collapse on top of the erosion pin, burying it. This is likely what has occurred in GCC-6. Erosion pin 3 was located in an outside bank downstream of a slumped bank area. It could not be located in 2006, 2009, or 2016. The only year it was located, 2012, the exposure increased by 48 cm, indicating an erosion rate of 16 cm/year. Erosion pin 1 was located every monitoring year and exhibited dramatic increases in exposure ranging from 26 to 87 cm. Three of the five erosion pins had an average erosion rate of 16 cm/year. Therefore while the cross-section itself was stable, the surrounding reach is active.

The substrate at GCC-6 is primarily composed of medium gravels. The grain size was consistent with minimal variability during the 13-year monitoring period. This is expected because the cross-section graph indicated that the bed of the channel was largely unchanged.

6.4 GCC-4

The GCC-4 monitoring station is located south of a railway crossing in a forested valley. Channel sinuosity is reduced through the reach by the confining effects of the surrounding valley. Surrounding land use is residential development which is located on either side of the valley. The residential development on the east side began around 2005 and was completed around 2014. On the west side, development began around 2012 and was completed around 2015. The forested valley consists of a variety of both coniferous and deciduous species. Leaning and fallen trees were common, particularly along the right bank which coincided with the valley wall.

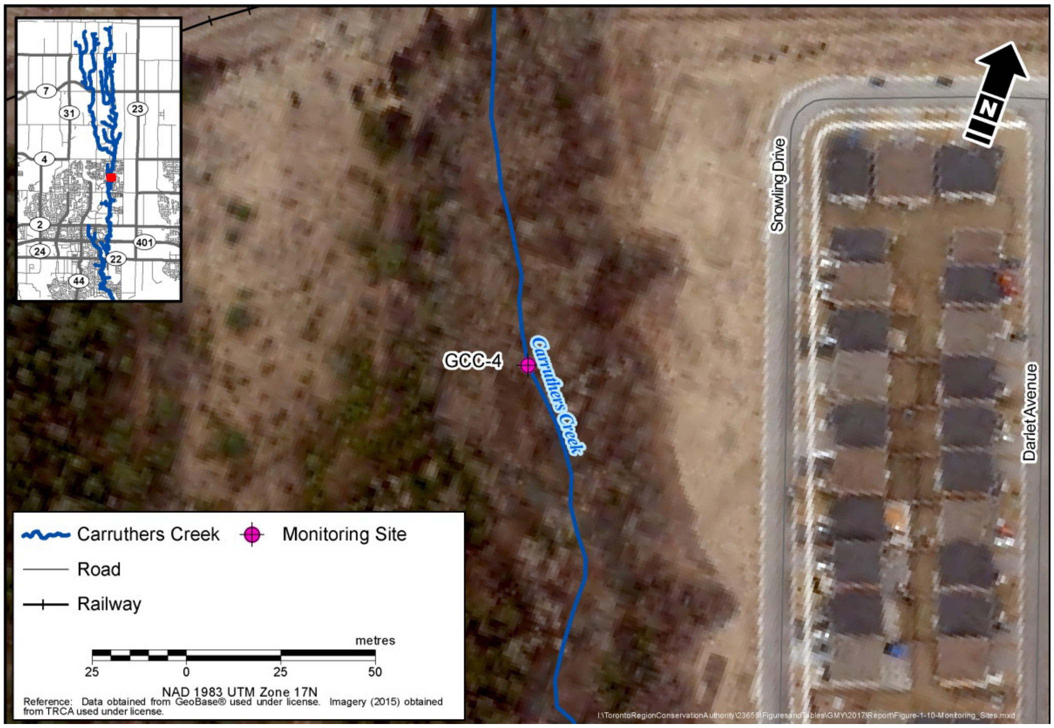

FIGURE 15 Location of GCC-4 Monitoring Station

The monitoring cross-section is located in a straight section which flows along the western toe of the valley. The cross-section is wide compared with other monitoring stations located in grass-lined areas. Toe erosion was noted along both banks. The cross-sectional area in 2003 was 7.81 m^2 with a maximum depth of 1.38 m. Over the monitoring period, the cross-sectional area steadily reduced to 6.41 m^2 in 2016 and a maximum depth of 1.13 m. The cross-section overlay indicates that the reduction was primarily through accumulation of bed material. There was erosion of the right bank which is expected because the channel abuts the valley wall along this side. The reduction in cross-sectional area was approximately 18%. Generally, a reduction in cross-sectional area is related to accumulation of fine material as a result of reduced velocity. Reviewing the monitoring photographs suggests that the reduction is a result of accumulation of coarse material across the riffle. This material appears to be a result of natural geomorphic processes where coarse materials settle out in the riffles and fine materials are flushed out, ultimately further armouring the riffle.

There are two erosion pins located at the cross-section, EP3 in the right bank and EP4 in the left bank. The data at EP3 indicated that the most substantial increase in exposure was between 2003 and 2006, 45 cm. Increases in exposure for the subsequent years were much less substantial. The left bank erosion pin, EP4 exhibited small increases in exposure ranging from 4.5 to 16 cm. This was relatively consistent with the other erosion pins. Generally, the erosion pins exhibited increases in exposure which were variable but provided similar erosion rates over the 13-year period. Three of the five pins provided average erosion rates of approximately 5 cm/year.

The substrate at GCC-4 was coarse and consisted primarily of coarse gravel and cobbles. The monitoring data indicated a general coarsening trend. The median grain size increased from medium and coarse gravel to very coarse gravel and small cobbles. This indicates that the accumulation of material is primarily through coarser material being deposited through natural processes at the riffle, while finer material is flushed out. This creates a feedback loop, which ultimately results in further armouring of the riffle.

6.5 GCC-2

The GCC-2 monitoring station is located immediately south of Kingston Road and it is the furthest downstream station. The channel flows through a meadow dominated area with some small deciduous woodlots. To the west is a residential development, a stormwater management pond, and a paved trail. The development was built over the course of the monitoring period, completed between 2009 and 2012. To the east is an agricultural field. The channel is quite sinuous through this reach. The reach was characterized by tall, steep, undercutting banks. Bank height was frequently 1 m with material scoured out from beneath the upper vegetative root layer. Deep scour pools and accumulation of fine material was also noted. The reach can be considered fairly active based on these indicators.

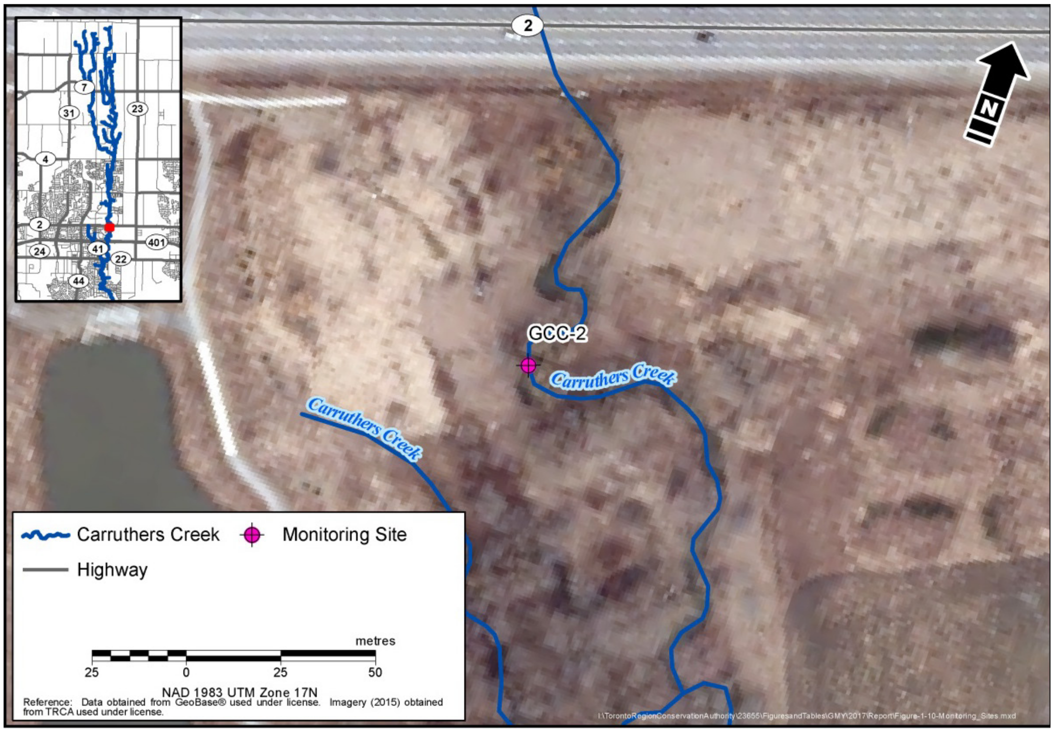

FIGURE 16 Location of GCC-2 Monitoring Station

The monitoring cross-section is located in a short, straight section of channel between two bends. The cross-section was highly active during the monitoring period, both increasing and decreasing cross-sectional area. The cross-section shape has shifted and changed but when cross-sectional areas from 2003 and 2016 are compared, there is negligable difference. The 2003 cross-sectional area was

3.27 m^2 while the 2016 area was 3.33 m^2. Between 2003 and 2006, the cross-sectional area reduced through bed accumulation reducing maximum depth from 1.05 to 0.83 m. Between 2006 and 2009, the cross-sectional area increased primarily through erosion of a high point along the right bank and erosion of both bank toes. There was some bed erosion during this time period as well, increasing the maximum depth by 0.04 m; however, lateral erosion was the dominant process. The 2006 to 2009 period exhibited the most significant change during the monitoring period; cross-sectional area by increased 0.54 m^2 or 19%. The cross-section continued to increase through 2012 to 3.62 m^2, with a maximum depth of 0.95 m. This increase was a result of retreat of the right bank, erosion along the left bank toe, and deepening of the bed. Near the left bank toe, there was a narrow notched area where the channel has cut down. This is likely where the thalweg and the strongest forces from the flow are focused. In 2016, the cross-sectional area was reduced by 7% to 3.33 m^2. This was primarily due to the accumulation of sediment above bankfull along the right bank and along the right bank toe. It is also worth noting that during the 2016 assessment, the right bank pin was buried under approximately 16 cm of fine material. This could suggest that the higher flows are regularly depositing fine material from bank erosion above bankfull. The bed of the 2016 cross-section exhibits a wider thalweg area than was document in 2012. The area is not as deep (0.92 m) but it is wider and more defined. This could suggest that the channel is slowly and systematically eroding downward.

Based on the variable changes in the cross-section, it can not be definitively said whether it is increasing or decreasing in size. It is clear that the channel is highly active, mobilizing sediment from both the bed and banks in this reach. The sediment then periodically accumulates within the channel or overbank areas due to the excess amount.

No erosion pins were located at the monitoring cross-section for GCC-2. Erosion pins 4 and 5 were located approximately 40 m upstream of the cross-section. Erosion pin 4 was located at the downstream end of an overwidened eroding bend with a large scour pool. Erosion pin 5 was also located at the downstream end of an area of severe erosion and undercutting. Both EP4 and EP5 exhibited large increases in exposure and were lost at once. Based on the data at these two pins, the average erosion rate was 10 cm/year and 12 cm/year, respectively. The other three erosion pins were in areas of less active erosion, EP2 exhibited small amount of accumulation during most monitoring periods.

The substrate at GCC-2 was predominantly fine material including silt, sand, and pebbles. and is likely a reflection of the ongoing bank erosion in which fine sediment gets transported into the channel. The median grain size typically consistents of pebbles.

6.6 Summary

Overall, three valley segments in the Main Branch are *In Regime*, and two are *Transitional*. All segments contain moderate stream health and have become more stable in comparison to the stability rankings from 2004. The cross-sectional area of surveyed cross-sections has decreased for the two lowermost monitoring stations (GCC-2 and GCC-4) of the main branch due to the accumulation of bed material. These two stations are within the southern developed portion of the watershed and are more susceptible to anthropogenic factors from land use development. The channel substrate at GCC-4 was coarse and consisted of gravel and cobbles, while the substrate at the lowermost station, GCC-2, contained substantial fine material (i.e. silt, fine sand). The high abundance of fine sediment indicates that there has been abundant deposition and is attributed to substantial bank erosion. Based on erosion pin measurements from these stations, the average erosion rate is 5.5 cm/year.

The cross-sectional area has increased at the three uppermost stations (GCC-6, GCC-7, and GCC-12) which is likely a result of cross-section deepening. There is active bank erosion along the right bank at these stations, and as a result, numerous erosion pin have been eroded out and relocated. The average erosion rate for these stations is approximately 6 cm/year. Bank slumping is commonly observed as well, and cross-sections mainly consist of medium to coarse gravel and small cobbles. The substrate generally remains the same over the entire monitoring period.

7 DISCUSSION AND RECOMMENDATIONS

7.1 Monitoring

The results from the 13-year monitoring period provide insight on channel processes at a variety of scales. Most reliably, the data describes the processes occurring at various discrete sites throughout the watershed. Each station is a reflection of the specific governing factors at that location which include surrounding vegetation, land use, geology, and flow regime. Reviewing the stations together based on their general location within the watershed may reveal broader characteristics of the watercourse. The results of the monitoring program also provide insight into the effectiveness of a long-term program as very few fluvial geomorphic programs are maintained for such an extensive period. This warrants additional discussion beyond results specific to the Carruthers Creek watershed.

Both of the stations on Tributary A have relatively small cross-sectional areas which have enlarged over the 13-year monitoring period (48% and 35%). Due to the small size of the cross-sections, small changes in area result in a large percentage change. The evolution of the two cross-sections is markedly different. While GTCC-11 exhibited a gradual consistent transition from a “V” to a “U” shaped cross-section, GTCC-9 appears to have experienced a more complex and abrupt transition. The GTCC-9 cross-section exhibited a large change in cross-sectional area between 2003 and 2006, shifting to a cross-sectional shape that differs from all other years. After 2006, the cross-section re-established itself as a distinctly different shape, which consistently migrated toward the right bank and deepened for the remainder of the monitoring period. These results suggest that the 2006 monitoring captured the cross-section after a specific event, a brief instance which is not necessarily representative of the ongoing long-term process. The difference in adjustment between the two sites highlights the importance of local site-specific characteristics. While both cross-sections are enlarging, potentially in response to the same governing factor, they do so differently. The consistent adjustment at GTCC-11 is reflective of equal resistance of vegetation and bank materials. At GTCC-9 the difference in bank vegetation, dense woody dogwood versus dense herbaceous grasses, has biased the cross-sectional adjustment to the right half of the cross-section where less force is required to erode the material.

Tributary B is the larger of the two tributaries and has three monitoring stations. For Tributary B, interpreting the cross-section adjustment with respect to potential systemic adjustment was complicated by additional factors for two of the three stations, GTCC-6 and GTCC-5. The GTCC-5 cross-section enlarged dramatically (98%), doubling in size through incision as a result of a debris jam failure. This adjustment in the response to the local event masks potential channel adjustment which could be attributed to broader systemic change. At GTCC-6, the data was incomplete due to issues with maintaining the cross-section as a result of severe erosion of the right bank. Only the last three monitoring years (2009, 2012, and 2016) were comparable. During this period, the cross-sectional area increased by 26% through retreat of the right bank and incision. The results definitively indicate that from 2009-2016 the cross-section is continually enlarging. Based on the issues with the right bank pin in 2003 and 2006, it can be inferred that these cross-sections would have exhibited the same trend if the bank pin had been maintained. The third station, GTCC-4 did not appear to be impacted by any identifiable site-specific issues. Therefore, it is more plausible that adjustment at GTCC-4 is reflective of potential broader scale influences. At GTCC-4, the cross-section adjusted primarily through lateral erosion as vertical adjustment was limited by coarse bed material. The cross-sectional area increased by 25% between 2003 and 2016, transitioning to a distinctly different shape with increased bed width. The enlargement of GTCC-6 and GTCC-4 may be indicative of a broader scale response of Tributary B. The GTCC-5 cross-section may also support this, but it is unclear due to the prominent influence of a local event.

There are five monitoring stations located on the Main Branch of Carruthers Creek. Similar to Tributary B, two of the stations had challenges with maintenance and produced incomplete data which was not definitive. At GCC-12, the overall trend of cross-sectional adjustment could not be determined. The two monitoring periods for which cross-sectional area could be compared produced conflicting results; cross-sectional area reduced from 2003 to 2006 and increased from 2009 to 2012. It is not completely apparent why this trend may have occurred, as a review of aerial imagery through this period indicates that land use generally remained unchanged (i.e., farmland). However, changes in farming practices which impact the geomorphology of downstream watercourses, such as the use and disuse of tile drains may be attributable to the conflicting changes in cross-sectional area. At GCC-7, cross-section graphs after 2006 could not be used due to movement or loss of the right bank pin. With only one monitoring period of data (2003-2006) in which cross-sectional area was reduced, no definitive trends could be identified. Both GCC-7 and GCC-12 exhibited ongoing erosion of one of their banks; this could not be attributed to a particular channel process. The remainder of the stations, GCC-6, GCC-4, and GCC-2 were all located in the lower half of the watershed where ongoing development has occurred during the monitoring period. There does not appear to be an observable trend in the results from the three stations. The GCC-6 cross-section was the least active out of all the monitoring stations. Cross-sectional area increased by 4.8% during the monitoring period, but the cross-sectional shape remained static. The increase in area was the result of erosion of the vertical left bank. However, beyond the cross-section the overall GCC-6 reach was active with ongoing erosion, slumping, and frequent loss of erosion pins. The GCC-4 cross-section was the only monitoring cross-section that exhibited well-documented aggradation, reducing cross-sectional area by 18%. This is the result of an accumulation of coarse material, which was indicated by a coarsening trend in the grain size distribution. Erosion pin data for the site was relatively consistent with most pins exhibiting average migration of 5 cm/year. The GCC-2 cross-section was highly active during the monitoring period, increasing and decreasing cross-sectional area between monitoring years. However, when comparing the 2003 and 2016 cross-sections, there was negligible change in cross-sectional area. Throughout the site vertical banks, severe undercutting, and bank collapses were common. It is assumed that the changes in the cross-section are a manifestation of the frequent input of fine bank material which temporarily deposits on the bed and then is periodically flushed downstream. This process is supported by the grain size distribution data which was notably fine for the size of the channel. The results of the three downstream main branch stations did not display a common response which could be attributed to broad scale influences such as the surrounding ongoing development.

The results of the Carruthers Creek monitoring program indicate that the watercourse is an active channel whether the cross-section is enlarging, aggrading, or continually adjusting while maintaining a similar size. The sites on both Tributary A and Tributary B suggest that channel dimensions are increasing. The magnitude of increase was larger for the Tributary A sites, presumably because it is the smaller of the two tributaries and is therefore more sensitive to surrounding change. Comparatively, while the Main Branch sites exhibited active channel processes, overall change was relatively minimal. There was no indication of a common adjustment response amongst the Main Branch sites. Similar to the tributaries, this is indicative of the larger channel's resilience to accommodate changes to the surrounding area. It should also be considered that the Main Branch stations are the only stations located in the developing area of the watershed, while most of the tributary sites are located in the upper agricultural and rural area of the watershed. The expectation would be that the ongoing development would alter the hydrologic regime of the downstream stations and this would manifest as changes in morphology. However, this is not supported by the results. Channel morphology and flow regime are intrinsically linked, which allows for inferences to be made about both characteristics when there is sufficient knowledge of one. Based on this, it can be inferred that the tributary stations are enlarging as a response to changes in the flow regime, which cannot be definitively determined without a complementary flow monitoring program. Flow monitoring stations from which hydrographs could be derived would facilitate a better understanding of the changes in channel morphology. A review of yearly hydrographs during the monitoring period would suggest if there is trend of increasing flows due to changes in hydrologic regime upstream, or if there was a particularly wet year in which a number of high flow events occurred.

Carruthers Creek flow gauge and watershed precipitation data were provided by TRCA for comparison with monitoring results. The flow gauges are: HY013, HY090, and HY089, which correspond to locations on reaches GCC-2, GCC-6, and GCC-7, respectively. In the case of HY013, the available date range for the streamflow data is 2008-2017, while for HY090 and HY089, data from 2015 to 2017 were provided. The monthly averaged data for the three locations are presented in Figure 17 for comparison, while Figure 18 shows the full range of flows available for HY013.

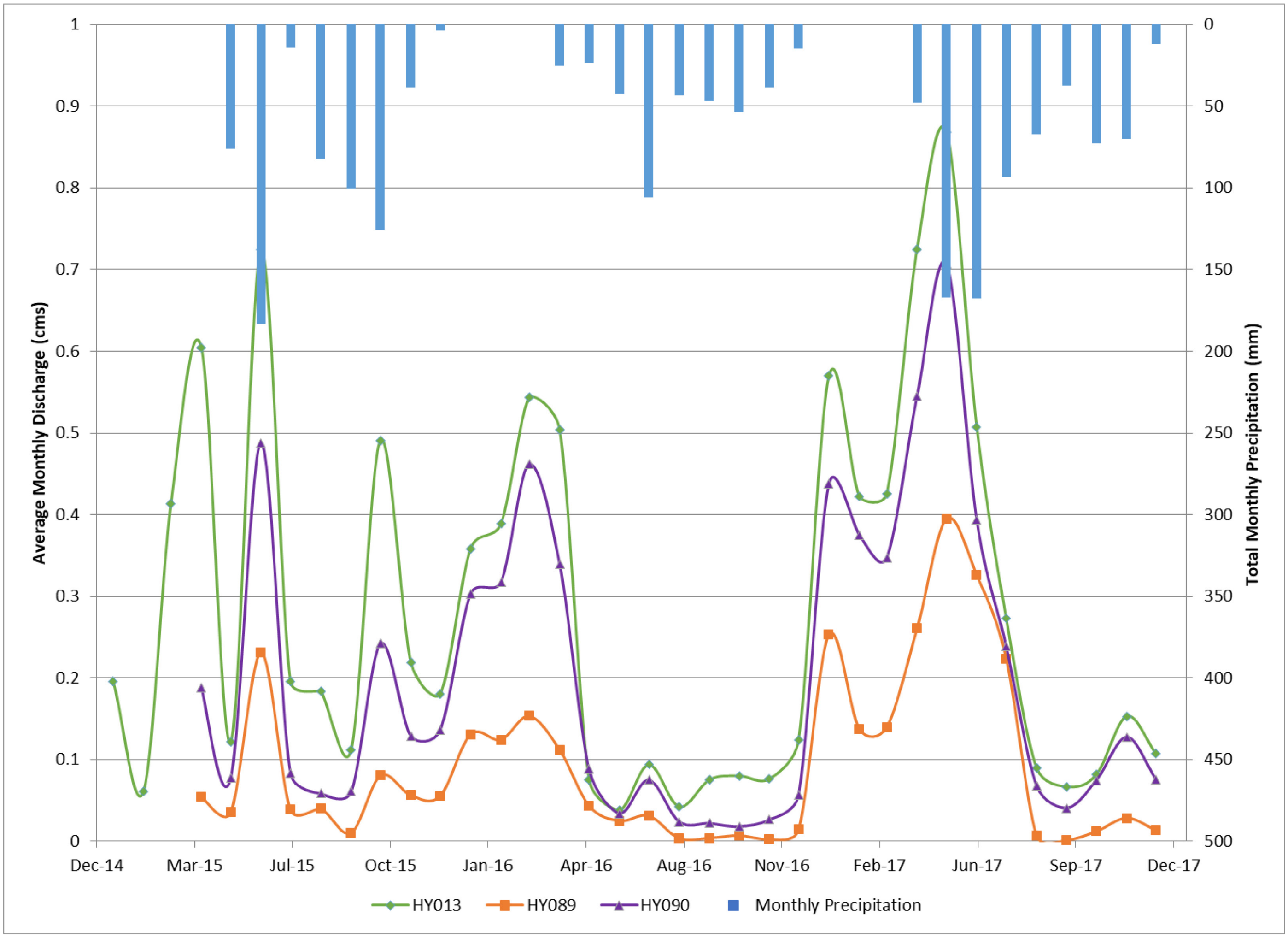

FIGURE 17 **Monthly Flow Gauge and Precipitation Data for Carruthers Creek Stations HY013, HY089, and HY090**

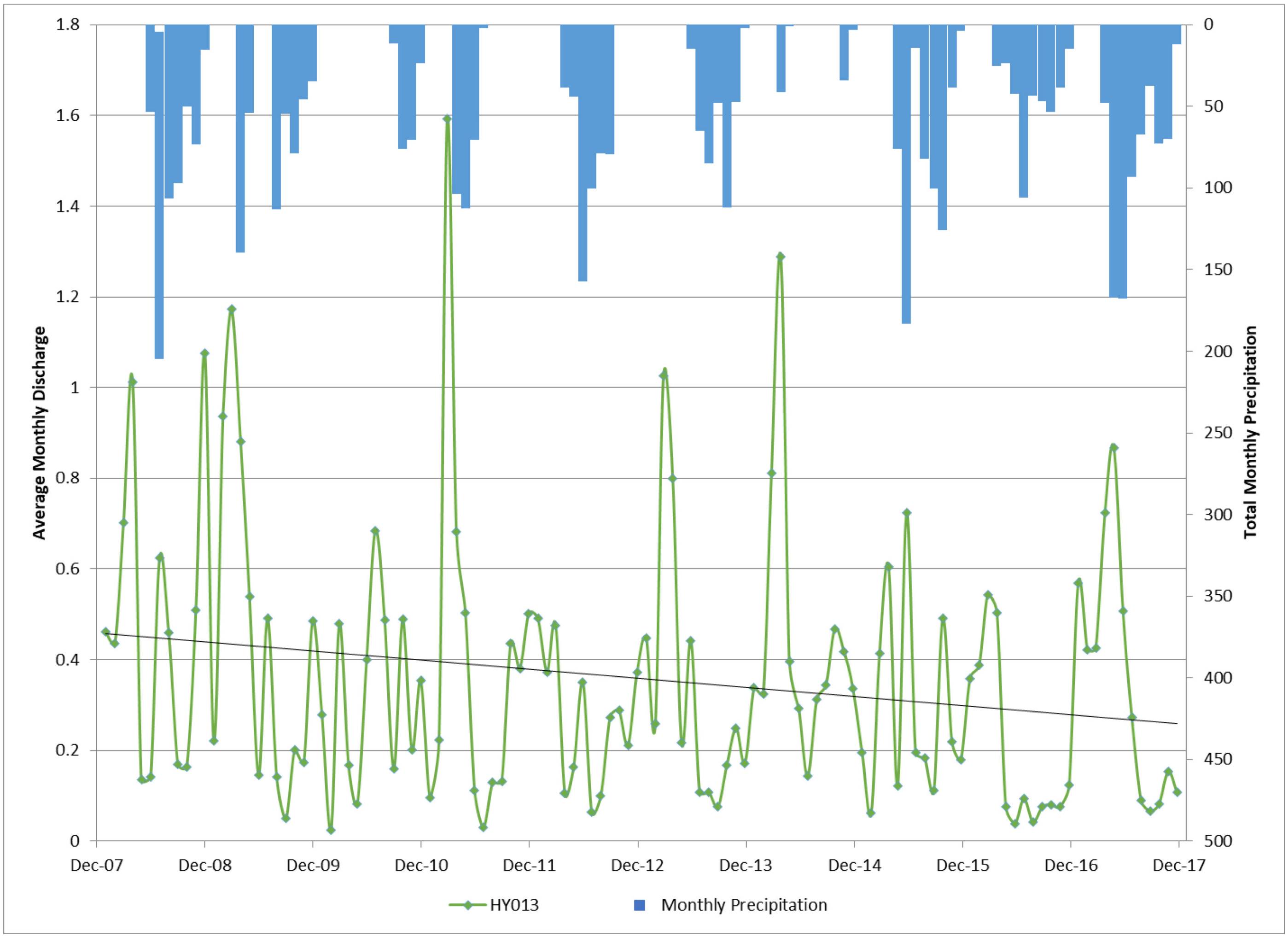

FIGURE 18 Monthly Flow Gauge and Precipitation Data for Station HY013

Ultimately, the data presented in Figure 17 is insufficient to infer a general trend in the overall flow regime of the Carruthers Creek watershed. This is due to a relatively short period of observations, especially in comparison with the erosion monitoring program. The time period observed also poses challenges in inferring trends as the amount of precipitation varied widely over the three years of available data. The year 2016 was notably dry and as such, responses to rain events within the channel were minimal as infiltration following precipitation added to a lowered water table rather than feeding watercourses. A drought year would generally result in increased deposition and aggradation and a decrease in erosion, and incision. This may correlate to the observed re-establishment of cross-sectional areas between years 2003 and 2016 discussed above. This comparison reiterates that annual changes have a significant impact on the watershed, especially on smaller tributaries that are most sensitive to change.

In the case of HY013, while data over the entire 13-year monitoring period is not available, data is available to at least 2008. Comparisons of the flow and precipitation data with the change in cross-sectional area for GCC-2 cannot be made for the monitoring period between 2003 and 2006. Figure 18 shows a wetter trend from 2007 into 2009, which could explain the significant increase in cross-sectional area noted between 2006 and 2009 at GCC-2. The remainder of the record shows an overall decline in average monthly discharge, but with seasonal variability in precipitation and flow, with peaks in discharge generally observed in the spring. A significantly higher peak in March 2011 may account for the continual increase in cross-sectional area through 2012. The overall reduction in flow as well as smaller peaks noted following 2014, may account for the gradual decrease in cross-sectional area noted through 2016.

Overall the 13-year monitoring period provided a unique opportunity to document changes in channel morphology for the purposes of understanding channel processes. Fluvial geomorphology monitoring programs are generally undertaken for 3 to 5 years following the completion of a natural channel design, shorter 1 to 3 year programs are completed for characterization studies. After reviewing the results of the Carruthers Creek monitoring, it is clear that a 3 to 5 year monitoring program would not have adequately captured the ongoing trends. The results also revealed the challenges with maintaining a long-term program, such as selecting an appropriate location and establishing a sufficiently wide cross-section. Updating the monitoring every three years was ideal for the cross-sections because it appears to remove the noise within the data. For the erosion pins and substrate, more frequent updates than the current once per year may be more suitable (i.e. at least twice a year). It may be most appropriate to develop an integrated approach with different timing for the various monitoring elements to most accurately document channel changes with optimized cost and effort. Fluvial geomorphology monitoring programs should be developed concurrently with hydrology monitoring programs to produce a thorough understanding of channel form and function. Longer term flow data can also provide clearer trends in overall hydrology and may be used to discern further development impacts on channel adjustment. Additionally, it is preferable to continue the monitoring beyond the current 13-year period, and through any planned development activities. This is helpful to determine the impacts of future development activities, and to implement watercourse management strategies. Following development, the monitoring should be continued for a similar time frame. This would ensure that long-term trends and adjustments to developmental activities are captured within the post-development monitoring, as shorter-term monitoring would not capture any ongoing or modified trends.

7.2 Impacts of Future Development

Increased development density can have significant impacts to a watershed and its receiving channels. The primary impact to watercourses from urbanization is a result due to changes to the hydrologic regime, as a result of impervious cover. A rise in surface runoff is a common result of development which can lead to increased channel adjustment (e.g. erosion and widening) as a result of higher flow velocity and discharge. Additionally, a reduction in infiltration and groundwater/aquifer recharge is also expected due to an increase in impervious surfaces. Observations of aggradation (bars and unconsolidated bottom) are also common, as sources of fine sediment (road sands, construction activities, etc.) become more frequent. Therefore, the potential impacts to the Carruthers Creek watershed were considered, based on potential future land use scenarios. This would ensure the natural channel morphology are protected and restored, as needed.

TRCA provided five future development scenarios for the Carruthers Creek watershed on December 19, 2018, which are as follows. The first is a “Historical” land use scenario, where land use changes within the watershed between 1999 and 2015 will be examined. This allows for an understanding of the shifts in land use conditions and implications on the CCWP objectives. The second scenario is the “Current” land use scenario, which assumes existing land use conditions and associated land cover characteristics (i.e. areas of imperviousness, vegetation, etc.) are maintained. Existing land uses and Natural Heritage Systems (NHS) were delineated based on aerial photograph interpretation, land use data, NHS data from municipalities, and Ecological Land Classification data (TRCA 2015). Agricultural lands were updated using maps that were ground verified. This scenario provides a benchmark for describing current watershed conditions, identifies elements to be protected, and describes existing problems to be addressed. The third scenario is the “Offical Plan” scenario, which uses information from current local and Regional Official Plans (OPs) to provide insight into how the watershed conditions will likely change as approved OPs are implemented, and whether key priorities for CCWP objectives may emerge for management consideration. The fourth scenario is the “Enhanced Natural Heritage System” scenario and is based on the “Official Plan” scenario supplemented with updated information from natural heritage planning science and practice locally and globally. This scenario provides insights into how the watershed conditions may change as OPs are implemented with explicit consideration for additional protection and management for goals and objectives associated with natural heritage features and system. This identifies additional potential key priorities and opportunities for proactive management to move toward a sustainable and resilient future. The fifth scenario is the “Potential Urbanization” scenario which assumes an urban boundary expansion within the “whitebelt” area in northern parts of the watershed. The potential urbanization area was added to S4, which included the existing land use and OP and the enhanced NHS. This illustrates prospective development in the headwaters area outside of the enhanced NHS should such land area be intensified from a land needs perspective. These areas are assumed to be built with similar implications on watershed processes and thus any analysis using this scenario interprets the entire potential urbanization area as having a uniform value. There is no change expected in the existing urban area south of the Greenbelt. Evaluation of this scenario in relation to watershed objectives provides insight into how the watershed conditions will likely change if urbanization is planned in this portion of the watershed and whether there are key priorities that emerge for management consideration. Additional details on how these scenarios were developed in included in the Carruthers Creek Watershed Plan (TRCA, 2003).

Increased surface runoff peak flows can be largely mitigated within the Carruthers Creek subwatershed through integrated stormwater management. However, it is difficult to fully mitigate the fundamental changes to the landscape, and therefore various targets are employed to ensure key elements of the fluvial system are maintained and protected to help absorb any potential impacts that may arise. The targets acknowledge the risks associated with land use change and provide direction for best management practices. As mentioned above, it is useful to continue the monitoring process beyond the current period, including during and after land development projects have been completed. Ideally, monitoring twice a year (e.g. once in the spring and fall) is preferable to capture inter-seasonality and understand changes in channel substrate and processes governing erosion/deposition. Generally, for all development scenarios, delineated meander belt widths and associated erosion hazard allowances should be maintained. Site-specific development considerations can lead to a refinement of previously delineated reach-based meander belt widths, but must be based on geotechnical and fluvial geomorphic considerations. Where changes in intensity and/or frequency of flow rates are expected, erosion threshold assessments are required. Erosion thresholds are used in combination with flow modelling to ensure sediment entrainment is maintained between pre- and post-development conditions and are used to inform stormwater management design to minimize potential post-development degradation. The goal of the erosion threshold analysis is to determine the hydraulic conditions, such as the discharge, channel depth, and average channel velocity, for a watercourse when boundary materials begin to entrain. Erosion and deposition are natural processes that are necessary for the maintenance of channel form and function. Existing flows will naturally exceed the threshold discharge and aid in erosion/transport and sediment/deposition of material throughout the channel. As such, the key to maintaining natural channel function of the system is not to prevent exceedance of the threshold, but to ensure that the frequency and duration of the exceedance does not substantially increase under the post-development condition. The erosion threshold should be completed downstream of any proposed stormwater management facilities, on the receiving watercourse that is deemed to be most sensitive to the impacts of the change in hydraulic regime. This could be a reach that is already adjusting to changes, as identified through an up-to-date rapid assessment score, or a stream that is currently stable but may be significantly impacted by the development activity. Additionally, consideration should be given to distance downstream, as the impacts of storm flows may be intensified immediately downstream of the stormwater management facility, but may be lessened with increasing distance, due to natural attenuation of flows. An exceedance duration analysis is further recommended following TRCA (2012) SWM guidelines, which compares the critical discharge with outflow hydrographs for the receiving watercourse, under existing and post-development conditions. This will ensure that the natural rates of erosion and depositional processes are maintained, and not exacerbated by increased storm flows or reduced through over-control of stormwater within the system. The exceedance duration analysis should follow the recommendations outlined by the TRCA in their Stormwater Management Criteria (TRCA, 2012).

Changes to flow regime may result in considerations for channel enhancement or channel hardening to prevent excessive erosion. Channel disturbances generally result from the implementation of channel alterations, such as construction of road crossings or other infrastructure within the vicinity of watercourses and can result in loss of fish habitat. As such, channel alterations should be avoided where possible. Meander belt widths and erosion threshold must be considered in development for all watercourses. More specifically, erosion thresholds should be conducted in the most sensitive reaches, which in this case, are the reaches downstream of proposed stormwater ponds and other areas where a change in land use will affect the flow regime of the watercourse. Valley segments that are considered *In Regime* or where the channel is relatively stable (e.g., as identified within Figures 2 and 4) are also at risk from land use development activities. Increases in flow to these segments can be detrimental if the channel is not currently exhibiting active signs of erosion.

7.3 Channel Restoration Opportunities

Occasionally, development activities provide an opportunity to restore or enhance aquatic habitat, to accommodate the proposed development, or to restore the degraded channel, which may have been impacted by past activities. Modifications of watercourses may be large-scale realignments or small-scale removals of a bend or reduction in sinuosity. Small-scale modifications are more common in areas which are partially- or fully-developed, and land use changes are less significant. These modifications should ensure that the stream's natural fluvial processes are maintained, primarily its ability to convey water and sediment. Generally, large-scale realignments of watercourses, particularly larger streams, are not advisable.

It is acknowledged that the TRCA has been involved in the restoration of two main branches of Carruthers Creek within the Deer Creek Golf and Country Club. The watercourse within the study area had become degraded and was experiencing channel adjustments, including channel bank erosion, channel widening, bed scour, and vegetation encroachment into the channel. The overall goal was to improve the overall ecological function of the site, including water quantity improvements, fish habitat enhancements, erosion mitigation, sediment reduction, bank stability improvements, and aquatic and riparian habitat enhancements. More specifically, by reducing bank erosion, the amount of sediment entering the watercourse is being reduced and ultimately improving the overall water quality and ecological function. Restoration options were developed, which included 'soft' treatments, such as natural woody vegetation and bioengineering techniques, as well as some 'harder' treatments involving stone armouring. It is recommended that such restoration activities should follow natural channel design principles where possible, as these are intended to improve aquatic habitat, by maintaining or enhancing natural fluvial processes. Key areas where restoration projects might be required include areas that are most impacted by active erosion and/or degradation. One area of concern is GTCC- 6, which is a highly active area, where ongoing erosion of the right bank is occurring. Based on the monitoring results, the cross-section has widened by 2.3 m between 2003 and 2006. Furthermore, cross-section have deepened and migrated into the right bank. Another area of concern is GTCC-5, where 0.62 m of channel incision has occurred between 2003 and 2016. This is a result of fallen trees and woody debris forming debris jams. Channel incision is causing fine sediment to be removed and channel substrate has coarsened over the monitoring period. Lastly, GCC-2 is located in the southern developed portion of the watershed. Deep scour pools have formed and there has been a substantial increase in fine sediment throughout the monitoring period. This is likely attributed to the west of the site where there is a stormwater management pond. Bank and toe erosion are also observed here. For reference, the reader is directed to Figure 6, for an overview map of these locations.

8 CONCLUSIONS

In total, ten valley segments within the Carruthers Creek watershed have been monitored across a 13-year time period. Based on the monitoring results, the watercourse is active, and it is recommended that changes to channel morphology through erosion and deposition continue to be monitored beyond the current monitoring period. It is preferable that the monitoring process be implemented twice a year; once in the spring and fall. Increasing monitoring to twice a year will allow better insight into how channel morphology is changing over time and will capture inter-seasonality. Streams are particularly vulnerable in the spring, where vegetation is much less dense and there is an increased water supply from spring snow melt. In the fall, it is important to monitor the watercourse after heavy precipitation events have occurred.

Where there is land development within the watershed, monitoring should be implemented in areas during and post-development, to ensure the watercourse remains in its ‘natural’ state. In addition to monitoring, meander belt widths and associated erosion hazard corridors should be maintained in the absence of further geotechnical and fluvial considerations. Erosion threshold assessments are necessary where changes in intensity and/or frequency of flow rates are anticipated and are used in conjunction with flow modelling. Changes to the flow regime that result in excessive erosion will require erosion threshold analyses and in the future may require channel enhancement or hardening as preventative measures. Where land development is anticipated in the watershed, meander belt widths will be completed and erosion thresholds should be conducted on the most sensitive reaches, which are generally the reaches downstream of stormwater ponds and/or outfalls.

Channel restoration opportunities within the Carruthers Creek watershed exist within key areas most impacted by active erosion and/or degradation. Based on field assessments, valley segments GTCC-6, GTCC-5, and GCC-2 are experiencing ongoing erosion. GTCC-6 is a highly active area where ongoing erosion has caused substantial channel widening. Channel incision within GTCC-5 has caused significant channel deepening, resulting in the removal of fine sediment. Finally in GCC-2, large, deep scour pools have formed and are likely attributed to a stormwater management pond to the west. Overall, these three areas are observed to have the highest degrees of erosion, warranting the opportunity for channel restoration works. It is recommended that geomorphic monitoring be continued to examine what is governing the active erosion and evaluate preventative measures in the future.

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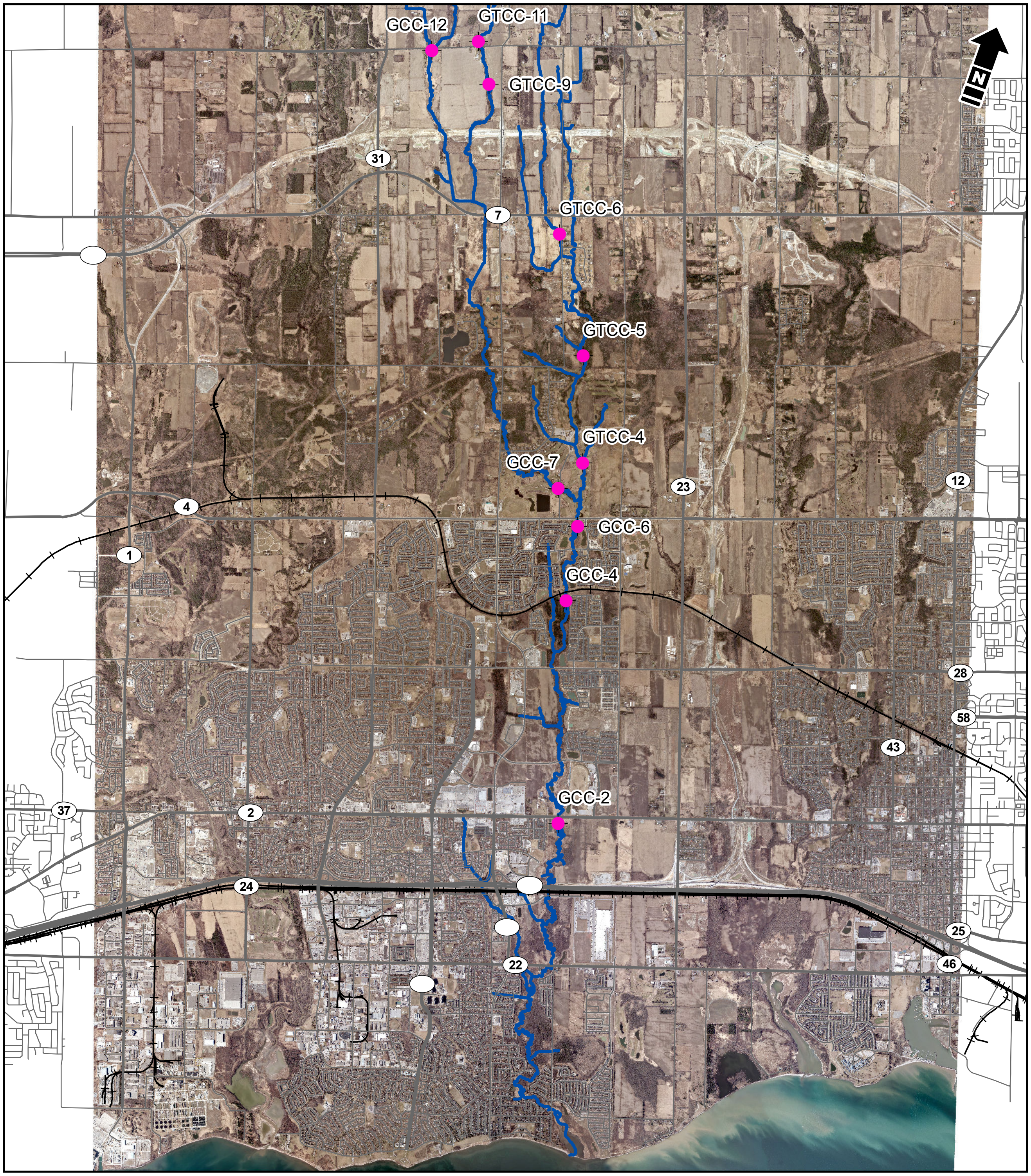
APPENDIX A

Carruthers Creek Regional Watershed Monitoring Program Site Map



- 〰 Carruthers Creek
- ▬ Highway
- — Road
- ┼ Railway
- ● Monitoring Site

1:80,000 m
800 0 800 1,600
NAD 1983 UTM Zone 17N

Reference: Data obtained from GeoBase® used under license. Carruthers Creek watercourse (2016) obtained from TRCA unsed under license. Imagery (2015) obtained from TRCA used under license.

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

Toronto Region Conservation Authority
Carruthers Creek Monitoring Report

Carruthers Subwatershed Monitoring Sites

Date:	Project:	Technical:	Reviewer:	Drawn:
27 Jan 2017	23655	T. Hrytsak	J. Parish	C. Curry

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Figure
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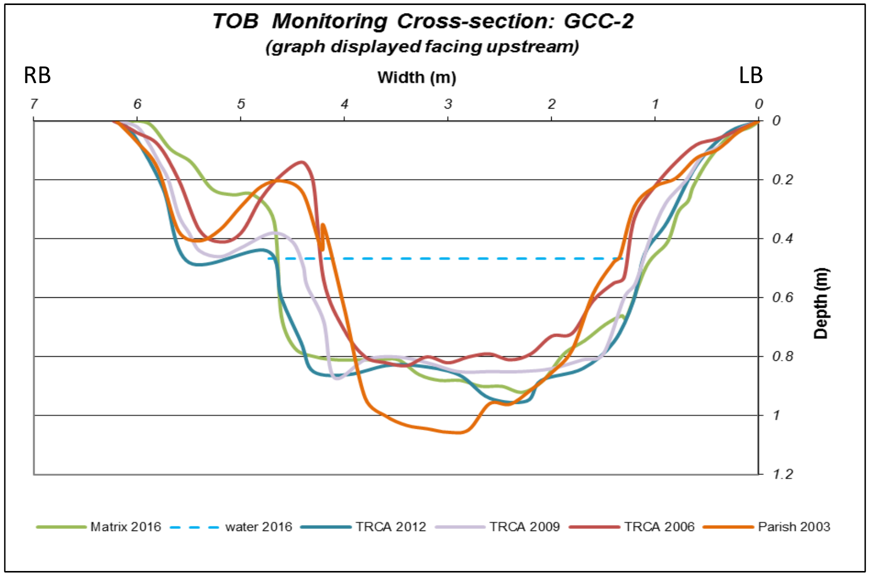
APPENDIX B

Individual Site Summary Sheets


TOB Monitoring Cross-section: GCC-2
(graph displayed facing upstream)
RB
Width (m)
LB
7
6
5
4
3
2
1
0
0
0.2
0.4
0.6
0.8
1
1.2
Depth (m)
Matrix 2016
water 2016
TRCA 2012
TRCA 2009
TRCA 2006
Parish 2003


2012


2016


2009


2006


2003

Notes:

Cross-section

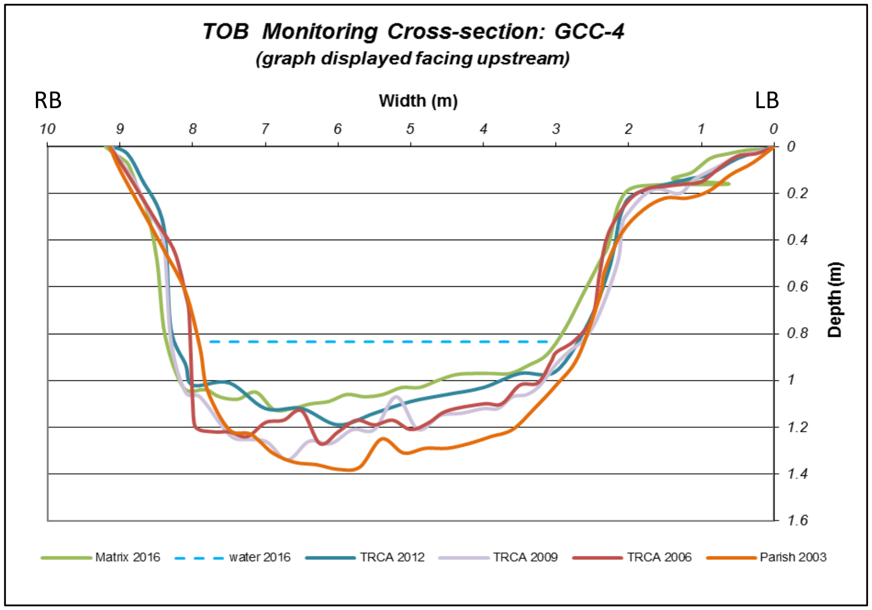
1. The cross-section experienced different changes over the monitoring period. The cross-sectional area both increased and decreased to result in an overall minimal change in area (-1.8% over the 13 years). The cross-section shape has shifted and changed.
2. Between 2003 and 2006, the area decreased through accumulation of bed material reducing the overall depth.
3. Between 2006 and 2009 the area increased due to the erosion of a high point above bankfull along the right bank and erosion of the left bank.
4. Between 2009 and 2012, the cross-sectional area increased to the largest size during the monitoring period. This was due to erosion of the right bank and erosion of the bed along the left bank toe.
5. Between 2009 and 2016, the cross-sectional area decreased due to an accumulation of sediment above bankfull on the right bank. It is worth nothing that the right bank pin was buried under approximately 16cm of material in 2016.
6. After 2009, it appears that most of the cross-sectional changes occurred at and above bankfull. This could suggest that the bankfull flows are becoming more frequent or larger.
7. This site also seems to be actively producing and flushing extra fine material from bank erosion which periodically accumulates in the channel.

Erosion Pins

1. No erosion pins were located at the cross-section.
2. EP4 and EP5 which were located upstream of the cross-section exhibited large increases in exposure between monitoring periods and were lost as well. They were both located downstream of severe erosion and undercutting. The average migration rate calculated was 10cm/year and 12cm/year, respectively.

3. EP2 had minimal changes in exposure and most were small decreases.
4. The reach had several areas of active undercutting, erosion, and bank failure.

Substrates
1. During the monitoring period, the grain size distribution remained consistent overall.
2. The distribution is consists primarily of fine material. The distribution is particularly small given the size of the channel.
3. This is reflective of the active bank erosion.
4. The D_{50} typically consisted of pebbles, the coarsest material was coarse gravel.


TOB Monitoring Cross-section: GCC-4

(graph displayed facing upstream)


2012


2016


2009

Notes:

Cross-section

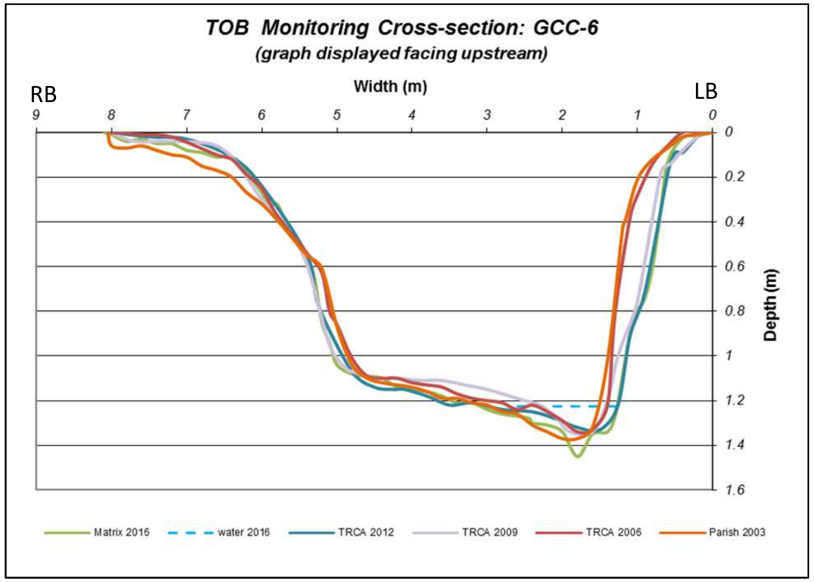
1. During the 13-year monitoring period the cross-sectional area reduced by approximately 17%. The overlay graph illustrates the accumulation of material on the bed. Max depth between 2003 and 2016 decreased by 0.25m.
2. Erosion of the right bank occurred which is expected because it is a valley wall contact.
3. A review of the photos suggests that the reduction of cross-sectional area is a result of accumulation of material on the riffle that the cross-section is located at.

Erosion Pins

1. Two erosion pins were located at the cross-section, EP3 (RB) and EP4 (LB).
2. EP3 had a large increase in exposure between 2003 and 2006 (45cm). The other documented changes were less substantial ranging from 2-13.5cm.
3. Migration rates based on erosion pin data were relatively similar, the average migration rate was 5.8cm/year.

Substrates

1. The substrate data shows a general coarsening trend.
2. The D_{50} has increased from coarse gravel to small cobbles.
3. The cross-section is located at a riffle which has accumulated increased coarse material.


TOB Monitoring Cross-section: GCC-6
(graph displayed facing upstream)
RB
LB
Width (m)
9
8
7
6
5
4
3
2
1
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
Depth (m)
Matrix 2016
water 2016
TRCA 2012
TRCA 2009
TRCA 2006
Parish 2003


2012


2016


2009

Notes:

Cross-section

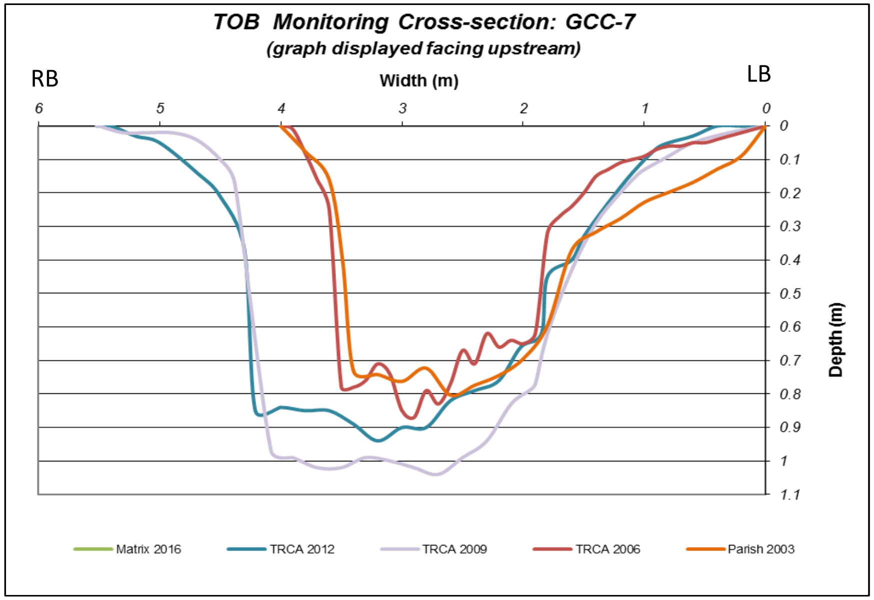
1. The cross-section has experienced minimal change over the 13-year monitoring period.
2. The vertical left bank has slowly eroded, with the largest change between 2006 and 2009 (appoximately 0.30m).
3. There has been some of erosion at the toe of the left bank where the thalweg has deepened, but it is minimal considering the 13-year monitoring period.

Erosion Pins

1. There is one erosion pin located at the monitoring cross-section, EP2 (LB).
2. EP2 exhibited the largest increase in exposure between 2006 and 2009 (increase of 15.5cm)
3. There was frequent loss of erosion pins at GCC-6 due to erosion and frequent slumping. EP3 was lost in 2006, 2009 and 2016. The only year it was found (2012) a large change in exposure was recorded (48cm).
4. EP1 had the most substantial documented changes in exposure ranging from 26cm (2012-2016) to 87cm (2003-2006).
5. Three of the five erosion pins had an average migration rate of 16cm/year.

Substrate

1. The grain size distributions have been generally similar over the length of the monitoring period.
2. The D50 has not varied substantially and was the same in 2006 and 2012. Generally the D50 was between pebbles and medium gravel.
3. More variability was seen in the D16 and D84 which is typical because the ends of the distribution are more sensitive to sampling bias. It is not necessarily indicative of changes in the overall distribution.



2016

**Cross-section bank pins could not be located;
cross-section was not reinstalled**

Notes:

Cross-section

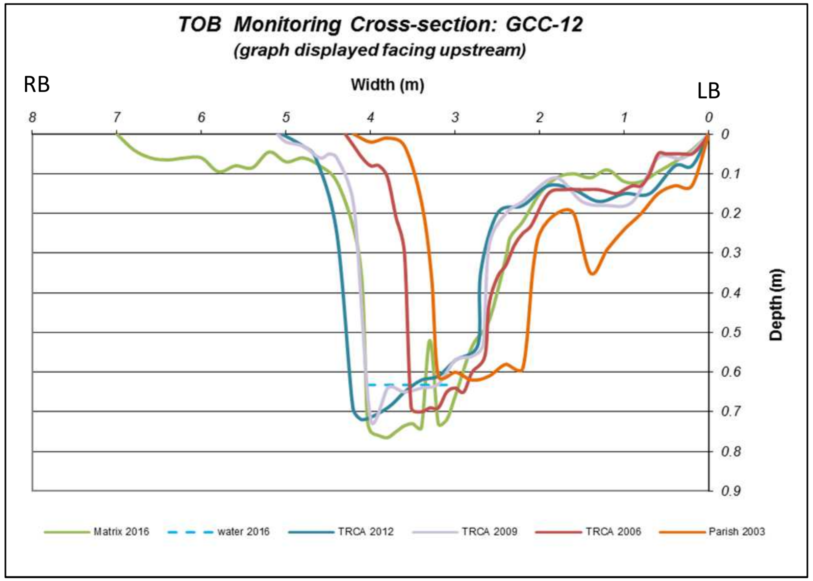
1. There have been challenges maintaining the cross-section at GCC-7, which complicates potential comparisons between monitoring years.
2. Between 2003 and 2006 the cross-section showed evidence of erosion along the right bank face and bed erosion on the right side of the cross-section. This was paired with build-up of material on the left side of the cross-section. Cross-sectional area was reduced between the two years, suggesting the change in cross-sectional shape is a result of channel migration.
3. In 2009, the RBP was moved approximately 1.50m back from the top of bank due to erosion to prevent loss of the pin. Comparing the 2009 and 2006 cross-section, it is clear that there is some sort of error as a result of moving the pin in 2009. The 2009 cross-section appears artificially enlarged which can happen if a pin is moved back and results in an unlevel cross-section. Unless properly documented this issue can not be fixed.
4. In 2012, the RBP had been removed by maintenance staff and had to be reinstalled. While this cross-section appears more accurate than the 2009 cross-section, it is likely to have similar issues and is therefore not useful for comparison.
5. In 2016 neither of the bank pins could be located, the cross-section was not reinstalled.

Erosion Pins

1. Erosion pins provide additional insight into cross-section changes particularly due to the challenges maintaining the monitoring cross-section.
2. Two erosion pins were located at the cross-section, EP3 (RB) and EP4 (LB).

3. Data from both pins support the cross-section changes that were seen between 2003 and 2006; that the channel is migrating towards the right bank and as a result material is accumulating along the left bank.
4. EP3 (RB) was lost twice (2009 and 2016), likely as a result of erosion. For two of the monitoring periods, the exposure increased 30cm resulting in an average migration rate 10cm per year for the right bank.
5. EP4 (LB) exhibited decreased exposure for each monitoring year between 2006 and 2016 ranging from -3.5cm to -11.5cm indicating ongoing sediment accumulation or bank slumping. During the 2016 visit it appeared that the decreased exposure was the result of bank slumping.
6. EP2 was located in an eroding bend, changes in exposure were variable and indicative of erosion followed by bank slumping (large increases in exposure followed by a large decrease in exposure).

Substrates
1. Grain size distributions were consistent through the various monitoring periods with minimal variation
2. The majority of the material at the cross-section consists of medium gravel to coarse gravel.
3. The largest material is classified as small cobbles.
4. The coarse nature of the material is expected due to the location within the golf course and high potential for modification and erosion protection


TOB Monitoring Cross-section: GCC-12
(graph displayed facing upstream)
RB
Width (m)
LB
8
7
6
5
4
3
2
1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Depth (m)
Matrix 2016
water 2016
TRCA 2012
TRCA 2009
TRCA 2006
Parish 2003


2012


2016


2009

2006

Photo Missing for GCC-12


2003

Notes:

Cross-section

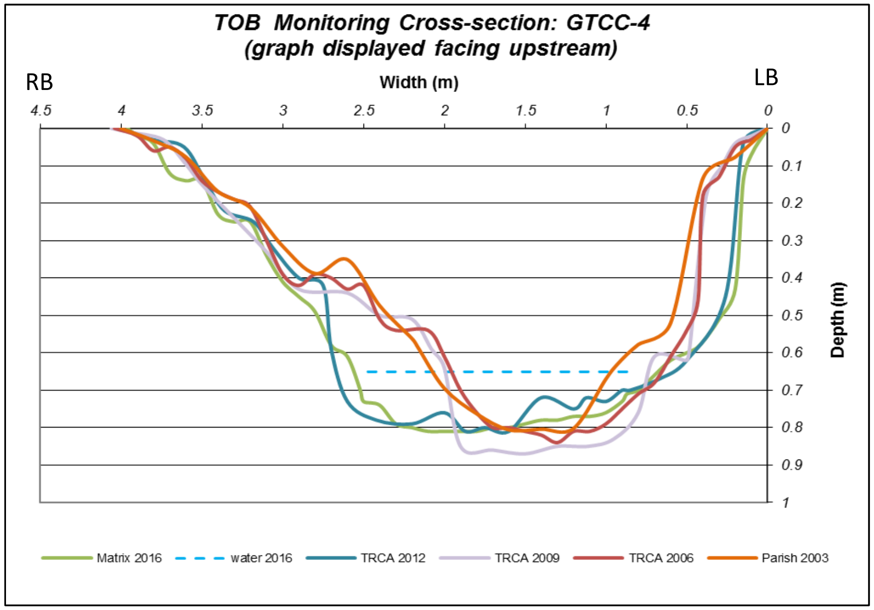
1. In 2009, the right bank pin was moved back to widen the cross-section presumably due to erosion and potential to lose the pin.
2. In 2016, neither of the bank pins could be located. The cross-section location was approximated based on an erosion pin that corresponded to the cross-section location. The cross-section was reinstalled in the same general location with the bank pins set further back from the top of bank.
3. Generally, the cross-section is migrating towards the right bank and steadily eroding it. The cross-section has also deepened as evidenced by the overlay graph and the photo documentation.

Erosion Pins

1. Two erosion pins were located at the monitoring cross-section: EP3 (LB) and EP4 (RB).
2. EP4 (RB) was eroded out/lost twice during the monitoring period in 2006 and in 2016. In 2016, partially buried on the bed by slumped material indicating failure of the right bank.
3. EP3 (LB) was eroded out/lost twice during the monitoring period, in 2012 and 2016. In 2006, 34.5cm of the pin was covered by material. This corresponds with the change in the left bank profile between 2003 and 2006. In 2016, EP3 could not be located, attempts to locate it using a pin finder suggest it was buried by material on the bed.
4. EP2 and EP1, located downstream of the cross-section in a bend, exhibited large increases in exposure between 2003 and 2006. The bend is actively eroding.
5. Based on the change in exposure of EP4 between 2006 and 2012 the migration rate is approximately 8.33cm/yr.

Substrates

1. Grain size distributions are generally at the site are primarily composed of medium to coarse gravels.
2. There appears to be a coarsening of the distribution in 2012 and 2016. The D_{16} value for both years is similar to the D_{50} values from previous monitoring years. The D50 and D84 from 2012 and 2016 also suggest a shift to coarser material.
3. The coarsening of the distribution could be attributed to the deepening of the cross-section. As the channel continually erodes the bed over time, fines are removed and coarser material that the channel can not transport is left behind.


TOB Monitoring Cross-section: GTCC-4
(graph displayed facing upstream)


2012


2016


2009

Notes:

Cross-section

1. From 2003-2009 the cross-sectional area steadily increased, primarily through erosion of the left bank.
2. In 2009, the cross-section incised , the bottom width of the cross-section also widened.

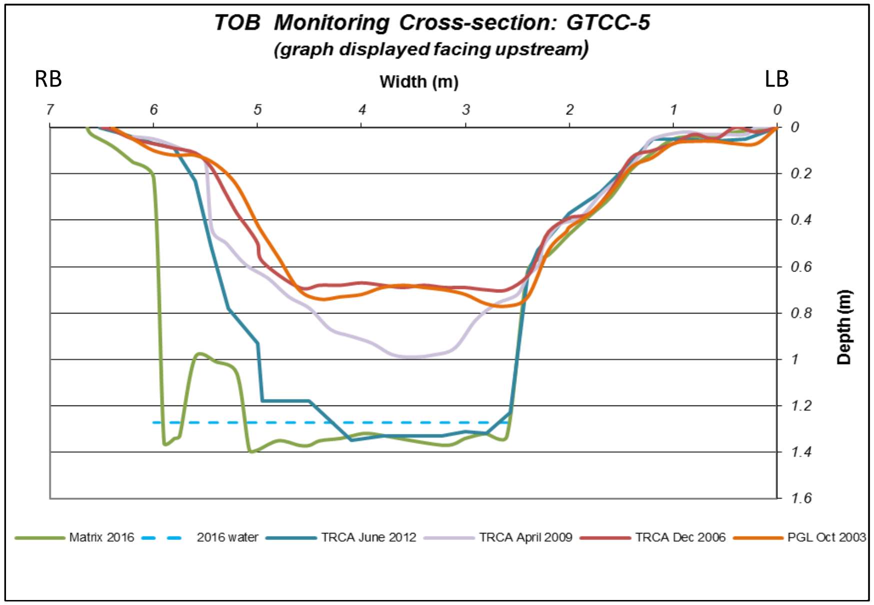
3. The 2012 and 2016 cross-section shapes are markedly different than the shape of the previous three cross-sections. The cross-section is much more 'U' shaped with a wider bottom width, whereas the 2003-2009 cross-sections have a more defined low-flow area.
4. Another difference with the 2012/2016 cross-sections is the retreat of the lower portion of the right bank. Whereas the previous cross-sections show very little change in the right bank, in the 2012 cross-section it appears to have eroded approximately 0.70m and established a vertical bank profile. It's unclear from the photos what could have caused this change.
5. The 2012/2016 cross-sections are relatively similar in shape. Comparing the six cross-sections, the 2009 cross-section appears to be a transition between the earlier and latter years. This suggests some sort of change occurred during this time to impact the cross-section. Overall the percent change from 2003-2016 is approximately 25.4%.

Erosion Pins

1. One erosion pin was located at the cross-section, EP2 (LB).
2. EP2 exhibited increased exposure ranging from 6-15.5cm and was lost in 2009.
3. The other erosion pins exhibited large changes in exposure during the various monitoring years. Overall the average migration rate based on the erosion pin data is 5.03cm/year.

Substrate

1. The grain size distributions were consistent throughout the monitoring period with minimal change.
2. The D_{50} varied between 1.0-2.5cm which corresponds to medium and coarse gravel.
3. The D_{90} was indicative of coarse to very coarse gravels (3.0-4.8cm)
4. The material is relatively coarse for the size of the channel and could be why most of the cross-sectional change was lateral (bank erosion).


TOB Monitoring Cross-section: GTCC-5
(graph displayed facing upstream)
RB
LB
Width (m)
7
6
5
4
3
2
1
0
Depth (m)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
Matrix 2016
2016 water
TRCA June 2012
TRCA April 2009
TRCA Dec 2006
PGL Oct 2003


2012


2016


2009

2006

2003

Notes:

Cross-section

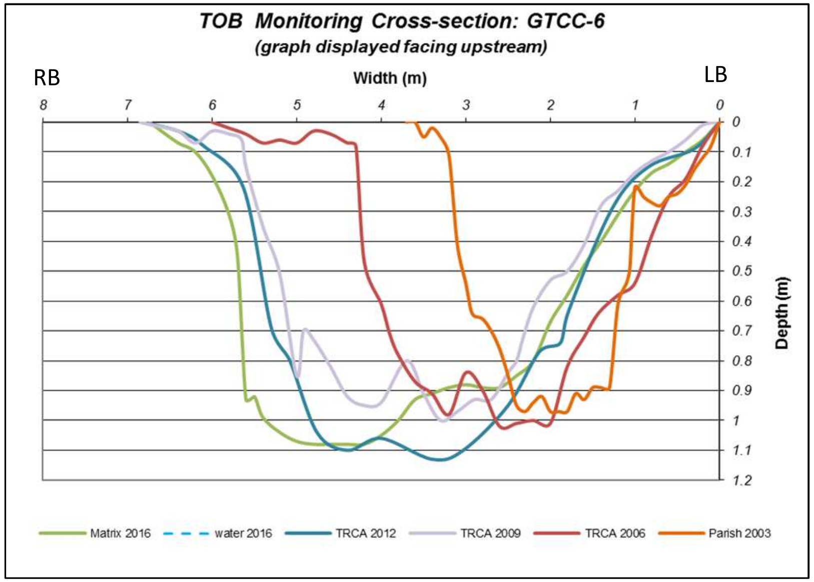
1. During the 13-year monitoring period the cross-section has enlarged significantly (98% increase in area).
2. Cross-section was stable between 2003 and 2006 with some accumulation of material resulting in a small reduction in area. Photos indicate a small debris jam immediately downstream of the cross-section creating a backwater and encouraging deposition at the cross-section.
3. A review of the 2003 long profile indicates that there was a 0.53m drop in elevation associated with the debris jam.
4. Between 2006 and 2009 the debris jam appears to have destabilized based on the 2009 cross-section photo. As a result, the 2009 cross-section is deeper and widening with erosion noted along the right bank. The max depth increased from 0.7m (2006) to 0.99m (2009).
5. Between 2009 and 2012 the cross-section increased dramatically (42%), based on the 2012 photo it is assumed this is a result of the large tree that fell into the channel. The tree can also be seen on the left bank in the 2009 photo.
6. Erosion is focused on the right bank and right half of the cross-section.
7. Between 2012 and 2016 the cross-section continued to enlarge with severe undercutting of the right bank and subsequent retreat. It is worth noting that the bed may have stabilized as the is minimal change in bed elevation. Additionally, a mid-channel bar has formed at the cross-section also suggesting that the cross-section may have begun to vertically stabilize.
8. In total the cross-section incised approximately 0.62m based on the difference in maximum depth between the 2003 and 2016 cross-sections.
9. During the monitoring period the profile of the left bank exhibited minimal change even after substantial channel incision.

Erosion Pins

1. In general, there is a lack of erosion pin data from GTCC-5 due to frequent loss of pins.
2. It can be assumed that the pins were lost due to ongoing erosion which was noted not just at the monitoring cross-section but throughout the reach.
3. EP2 (LB) and EP3(RB) were located at the monitoring cross-section.
4. Similar to the cross-section, EP2 exhibited minimal change in exposure over the monitoring period.
5. Based on the data collected for EP3 the average migration rate for the right bank is 5cm/year. The pin was found eroded out and lying on the bed in 2016.

Substrates

1. Grain size distributions are similar between 2003/2006/2009. Fine material (coarse sand, pebbles, silt) is a large part of the distribution. Medium and coarse gravels represented the coarse fraction.
2. The distribution coarsened in 2012 and 2016. When the debris jam no longer created a backwater, fine sediment was more efficiently transported downstream, leaving coarser material behind. As the channel incised more, more fine material was removed.
3. Coarsening of the bed is an indication that incision is slowing as the accumulation of coarse material acts to reduce bed erosion.


TOB Monitoring Cross-section: GTCC-6

(graph displayed facing upstream)


2012


2016


2009

2006

Photo Missing for GTCC-6

Notes:

Cross-section

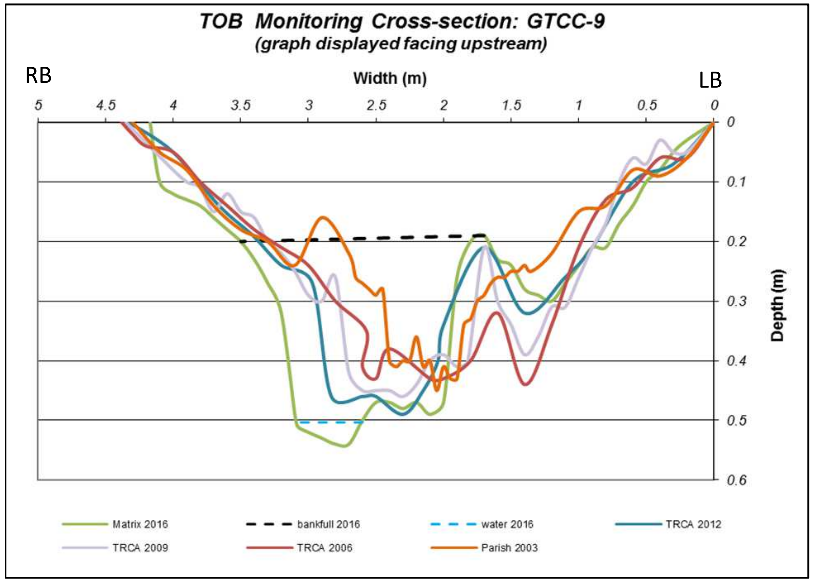
1. The original 2003 cross-section is not useful for comparison because a new right bank pin was installed in 2006 when the original pin could not be located. A larger cross-section was installed (6m as opposed to original 3.8m).
2. In 2009, the cross-section was widened from 6m to 6.8m, there are no notes regarding the change. It is assumed it was to protect the pin from erosion.
3. There also appears to be an issue with the 2009 cross-section related to the relocation of the RBP. The top of bank points for the two cross-sections is approximately 1.3m apart. It is not likely that erosion this significant occurred over the 3-year period. It could be that relocating the pin made the cross-section un-level and impacted the cross-section graph.
4. The best comparisons can be made between the 2009, 2012, and 2016 cross-sections when there was no movement of the bank pins.
5. Between 2009 and 2016 the right bank has retreated. The cross-section has also deepened and become more biased towards the right bank, particularly in the 2016 cross-section.
6. During the 2009-2016 period the cross-sectional area increased approximately 26% from $3.35m^2$ in 2009 to $4.23m^2$ in 2016.

Erosion Pins

1. Two erosion pins were located at the monitoring cross-section EP4 (RB) and EP5 (LB).
2. EP4 indicated that the right bank is retreating relatively quickly, as is seen in the cross-section and field photos. The average migration rate based on the exposure data is approximately 13.3cm/year
3. Data for EP5 is variable suggesting periodic erosion followed by slumping of the material.

4. EP2 and EP3 are both located in an actively eroding bend and exhibit evidence of this. EP3 was documented as eroded out and lying on the channel bed during at least two monitoring visits. EP2 was also documented as eroded out and found on the bed during two of the monitoring visits.

Substrates
1. Bed material is primarily composed of fine material (silt/sand/pebbles) and therefore minimal variation is noted between years.
2. The coarsest material consists of medium and coarse gravel (1-3cm).


TOB Monitoring Cross-section: GTCC-9

(graph displayed facing upstream)


2012


2016


2009

Notes:

Cross-section

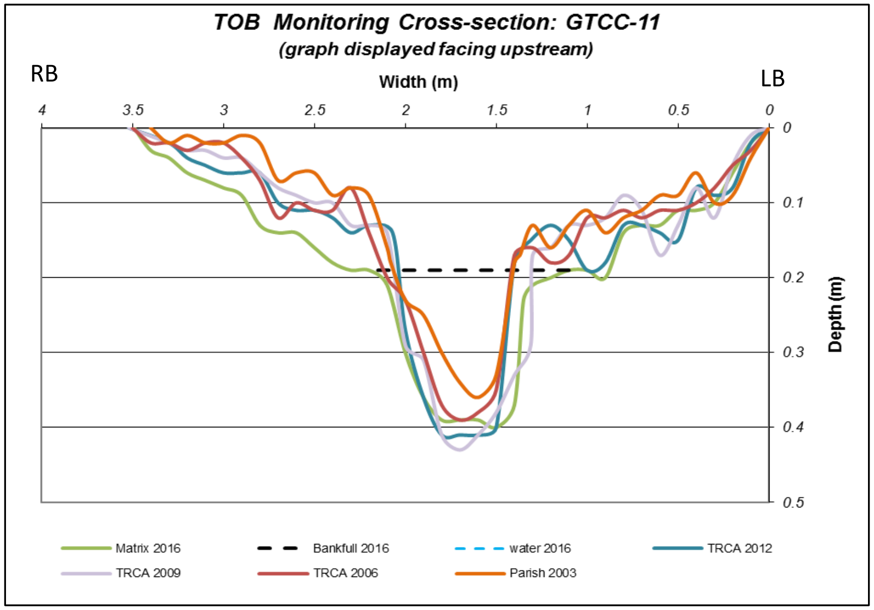
1. Overall, cross-section area has increased during the monitoring period by approximately 35%.
2. The cross-section area was largely unchanged from 2006-2012
3. Between 2003 and 2006 the bottom width of the cross-section increased from 0.50m to 1.20m, resulting in increased cross-section area. In 2016, the bottom width of the cross-section was
4. The 2006 cross-section appears to have documented the channel in transition. The bankfull cross-section is wider than any other year. In 2009, the bankfull cross-section narrows and the shape is better defined. The shape of the bankfull cross-
5. Between 2012 and 2016 the cross-section area increased primarily through erosion along the right bank. Which has widened the low flow area and deepend the cross-section
6. Overall, the bankfull cross-section within the monitoring cross-section has become larger through deepening and widening. The cross-section has also shifted further towards the right bank and filled in along the left bank. This shift could be related to the onging growth of the red-osier dogwood stabilizing the left bank.

Erosion Pins

1. Erosion pins located at monitoring cross-section, EP3 (LB) and EP4 (RB), show changes in exposure that are in agreement with cross-section changes.
2. EP3 exhibited a small increase in exposure between 2003 and 2006 when the overall bankfull cross-section widened. Pin exposure was then reduced for both the 2006-2009 period and the 2009-2012 period as the cross-section shifted towards the right bank and infilled along the left bank where EP3 is located.
3. EP4 exhibited large increases in exposure during the 2003-2006 period and then 2006-2009 period, 16cm and 16.5cm respectively. This corresponds with the shift towards the right
4. No erosion pins were located during the 2016 monitoring visit.
5. EP1 and EP5 also exhibited large increases in exposure throughout the monitoring period.

Substrate

1. Substrate is primarily fine grained material with gravels.
2. Grain size distribution relatively consistent between monitoring periods.
3. Finer fraction consists of silt and sands while coarsest material is typically medium to coarse gravel.

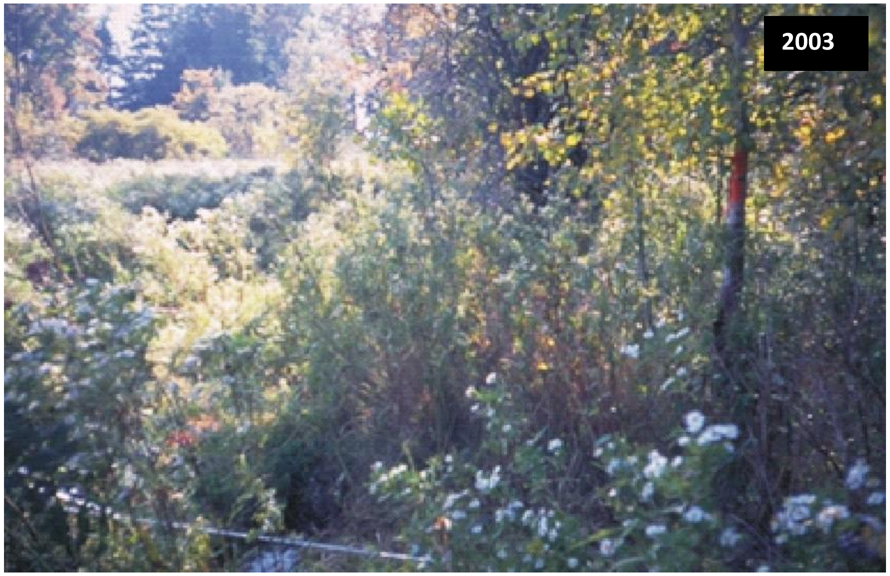

TOB Monitoring Cross-section: GTCC-11
(graph displayed facing upstream)
RB
LB
Width (m)
4
3.5
3
2.5
2
1.5
1
0.5
0
0.1
0.2
0.3
0.4
0.5
Depth (m)
Matrix 2016
Bankfull 2016
water 2016
TRCA 2012
TRCA 2009
TRCA 2006
Parish 2003


2012


2016


2009


2006


2003

Notes:

Cross-section

1. Cross-section area increased consistently between monitoring periods for a total increase of 48% over 13 years
2. The cross-section shape is transitioning from a 'V' shape to a 'U' shape
3. Change in shape is evident when looking at the bankfull area within the overall monitoring cross-section
4. Comparing the bankfull width of the cross-section year to year supports this. Bankfull width in 2003 was approximately 0.71m and had increased to approximately 1.1m by 2016.
5. The floodplain area beyond bankfull appears to have deepened which could indicate that above bankfull flows are more frequent. However, this is difficult to determine as the floodplain topography for a small channel is closely tied to the growth and die-off of vegetation.

Erosion Pins

1. Generally, pin exposure increased between monitoring periods
2. The average migration rate based on the erosion pin data is 1.63cm/yr
3. In 2016, exposure decreased for 3 of the pins as a result of slumped banks

Substrates

1. Bed material is composed of fine grained material, silt, sand and small pebbles. It is difficult to determine any variation over time when the dominant material is fine grained.

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