Brampton Transit

BUS MAINTENANCE & STORAGE FACILITY

Appendix H

Fluvial Geomorphology

March 18, 2021

Prepared for

BRAMPTON Flower City
brampton.ca

Prepared by

IBI GROUP

Environmental Assessment Study
City of Brampton Transit Facility

Fluvial Geomorphological Assessment
Rainbow Creek

Brampton, Ontario

Prepared for:
IBI Group
100 – 175 Galaxy Blvd
Toronto, ON M9W 0C9

January 16, 2020
PN19086

GEO MORPHIX
Geomorphology
Earth Science
Observations

Report Prepared by:	GEO Morphix Ltd. 36 Main Street North PO Box 205 Campbellville, ON L0P 1B0
Report Title:	Environmental Assessment Study City of Brampton Transit Facility Fluvial Geomorphological Assessment, Rainbow Creek
Project Number:	PN19086
Status:	Draft
Version:	1.0
Submission Date:	January 16, 2020
Prepared by:	Cara Hutton, M.Sc., Suzanne St. Onge, M.Sc.
Approved by:	Paul Villard, Ph.D., P.Geo., CAN-CISEC, EP, CERP

Table of Contents

List of Tables

Appendices

1 Introduction and Background

GEO Morphix Ltd. was retained as part of a multi-disciplinary team to complete a fluvial geomorphological assessment of Rainbow Creek as part of the Environmental Assessment Study to construct a new transit maintenance facility in the City of Brampton. The facility is to be located at 10192 Highway 50, southwest of the intersection of Cadetta Drive and Highway 50. It is understood that the original intent was to use the site as a Works Yard/Operations Facility as documented in the Schedule C Municipal Class Environmental Assessment completed by AECOM in 2012. Since that time, the City has identified this location for the construction of a transit maintenance facility to allow for the expansion of transit storage and maintenance facility capacity.

Rainbow Creek generally flows from north to south near the western limit of property owned by the City of Brampton. A fluvial geomorphological assessment is therefore required to delineate, in part, development constraints and identify appropriate mitigation measures.

The following activities were completed as part of the assessment:

- Complete a review of available background reports and data (i.e., previous studies and geologic and topographic mapping)
- Delineate watercourse reaches in vicinity of the subject lands
- Review site history and changes/impacts to Rainbow Creek using historical aerial photographs
- Conduct a field investigation to confirm watercourse reach breaks and characterize existing conditions, where possible
- Determine meander belt widths and the extent of erosion hazards
- Confirmation of an appropriate erosion mitigation strategy in support of the stormwater management (SWM) plan

2 Background Review

Several studies have been completed along Rainbow Creek in vicinity of the subject lands, and relevant findings pertaining to fluvial geomorphology are summarized below. The following documents were reviewed as part of our assessment:

- Works and Transportation Satellite Yards Municipal Class Environmental Assessment Environmental Study Report (AECOM, 2012)
- Master Environmental Servicing Plan: Highway 427 Industrial Secondary Plan Area (Area 47) (Aquafor Beech Limited, 2016)
- Rainbow Creek MESP Addendum (Savanta et al., May 2019)

The Environmental Study Report (ESR; AECOM, 2012) largely considered existing conditions, opportunities and constraints related to terrestrial and aquatic resources, as well as species at risk. There was limited information related to the watercourse from a geomorphological perspective and as such, this study is not discussed in further detail herein.

2.1 Master Environmental Servicing Plan

The Master Environmental Servicing Plan (MESP; Aquafor Beech Limited, 2016) was completed to support the secondary planning process for Area 47 by documenting natural resources that would potentially be impacted by future development and identifying opportunities and constraints to development. Area 47 is bounded by Mayfield Road to the north, Old Castlemore Road to the south, The Gore Road to the west, and Regional Road 50 the east. The fluvial geomorphological component of the study included an assessment of historical and existing conditions, delineation of meander belt widths on a reach basis, development of a stormwater management strategy, and preliminary design for the realignment of Rainbow Creek.

Six reaches were delineated along Rainbow Creek within Area 47, as well as several headwater drainage features (HDFs). Observations collected during field reconnaissance showed that Rainbow Creek contained a historically altered channel with predominantly fine-grained substrates. Poor channel definition and organic substrates were associated with extensive vegetation encroachment (i.e. meadow grasses or marsh vegetation) and all reaches generally showed evidence of aggradation and no bank erosion. Rapid assessment results showed that the reaches within Area 47 were stable. Aggradation processes were attributed to sediment inputs from adjacent agricultural fields. Channel processes were limited due to vegetation-dominated conditions and the broad floodplain. All HDFs identified along Rainbow Creek within Area 47 were located upstream of the subject lands.

The MESP identified preliminary meander belt widths for Rainbow Creek; however, it was noted that meander belts do not typically apply to swale features that are vegetation-dominated. The MESP also noted that the meander belt width was not expected to be the governing constraint due to flooding hazards associated with the wide, shallow floodplain. Preliminary belt widths were determined using the TRCA empirical method, which considers drainage area and stream power. Due to historic channel modifications, an adjacent tributary to the west with similar drainage characteristics was used as a surrogate for Rainbow Creek. A meander belt width of 58 m was delineated for the entirety of Rainbow Creek within Area 47. This meander belt width is further refined in **Section 5** of this report for reaches within the subject lands.

The MESP proposed a stormwater management strategy using a treatment train approach consistent with best management practices and relevant guidelines. Relevant stormwater management recommendations from a geomorphic perspective are explored further in **Section 6** of this report.

To achieve land use efficiencies, improve stormwater drainage, and enhance the natural heritage system, the MESP considered the realignment of Rainbow Creek. Through consultation with TRCA and the City of Brampton, the MESP proposed to create a well-defined corridor that would result in significant improvements to terrestrial and aquatic habitat while also offering various benefits from an engineering perspective. A 100 m wide corridor (including 10 m buffer on either side) was identified to minimize the loss of land area from the existing NHS while also conveying the Regional storm. Preliminary design recommendations were outlined in the MESP and refined as part of the MESP Addendum, summarized in **Section 2.2**, below

2.2 Master Environmental Servicing Plan Addendum

The MESP Addendum (Savanta Inc., 2019) presented an alternative natural corridor design to that proposed in the MESP (Aquafor Beech Limited, 2016) in accordance with the Terms of Reference approved by the City of Brampton. The revised corridor was approximately 49.1 ha in area, representing a slight increase in area from that proposed in the MESP. The conceptual design offered a significant improvement to channel form and function when compared to existing conditions, and the corridor was designed to convey the Regional storm and eliminate the flooding hazard within the existing Cadetta Road industrial area, immediately north of the subject lands.

In the context of the current study, the proposed corridor alignment would result in a shift of the channel to the west upstream of the subject lands, adjacent to Cadetta Road. Within/immediately adjacent to the subject lands, the corridor would result in an overall shift to the east. Notably, the proposed corridor would result in a significant reduction in the floodplain , as it is designed to safely convey the Regional storm event. This would therefore result in a reduced hazard to the future transit facility. The details of the proposed design are thoroughly documented in the MESP Addendum and therefore are not repeated herein. As the timing of implementation of the naturalized corridor is currently uncertain, **Section 5** of this report documents meander belt widths for the existing channel and potential constraints associated with the proposed realigned corridor.

3 Desktop Assessment

3.1 Site History

A series of historical aerial photographs were reviewed to determine changes to the channel and surrounding land use/cover. This information, in part, provides an understanding of the historical factors that have contributed to current channel morphodynamics. Aerial photographs from 1946 (scale 1:20,000), 1960 (scale 1:30,000), 1978 (Scale 1:10,000) and 1982 (scale 1:30,000) from various sources and recent satellite imagery from Google Earth Pro (2005 and 2016) were reviewed to complete the historical assessment. Refer to **Appendix A** for copies of the imagery.

In 1946, agricultural and rural land uses were predominant. The majority of natural vegetation had been cleared to facilitate farming, and Rainbow Creek had been extensively straightened and channelized to facilitate drainage and maximize arable land. This likely resulted in limited channel morphology, fine sediment inputs, and local increases in stream temperature.

There was limited change in channel planform or land use between 1946 and 1978. Industrial development in vicinity of what is now Cadetta Road appeared to have expanded and additional rural residences and commercial operations had established; however, the predominant land uses remained agricultural and rural residential. Cadetta Road and the crossing over Rainbow Creek upstream of the study area were constructed between 1978 and 1982. This allowed for the expansion of industrial operations on the west side of Rainbow Creek at Cadetta Road. It is likely that local channel realignment and potentially bank stabilization measures were installed at this time.

Although commercial/industrial development has expanded upstream of the study area north of Mayfield Road and east of Highway 50 since 1982, areas south of Mayfield and west of Highway 50 have remained under predominantly agricultural use. Between 1982 and the present, the eastern portion of the subject lands were converted from agricultural use to what appears to be a storage/works yard.

3.2 Surficial Geology and Physiography

Geology and physiography act as constraints to channel development and tendency. These factors determine the nature and quantity of the availability and type of sediment. Secondary variables that affect the channel include land use and riparian vegetation. These factors are explored as they not only offer insight into existing conditions, but also potential changes that could be expected in the future as they relate to a proposed activity.

The subject lands are located within the Peel Plain physiographic region and bevelled till plains physiographic landform (Chapman and Putnam, 1984; Chapman and Putnam, 2007). Based on published mapping, surficial geology within and upstream of the subject lands is predominately composed of fine textured glaciolacustrine deposits comprised of silt, clay, and minor sand and gravel (OGS, 2010). Fine textured glaciolacustrine deposits are not readily erodible material and therefore inhibit the watercourse's ability to meander.

3.3 Reach Delineation

Reaches are homogeneous segments of channel used in geomorphological investigations. They are studied semi-independently as each is expected to function in a manner that is at least slightly different from adjoining reaches. This allows for the meaningful characterization of a watercourse as the aggregate of reaches, or an understanding of a particular reach, for example, as it relates to a proposed activity. Reaches are typically delineated based on changes in the following:

- Channel planform
- Channel gradient
- Physiography
- Land cover (land use or vegetation)
- Flow, due to tributary inputs
- Soil type and surficial geology
- Certain types of anthropogenic channel modifications

This follows scientifically defensible methodology proposed by Montgomery and Buffington (1997), Richards et al. (1997), Brierley and Fryirs (2005), and the Toronto and Region Conservation Authority (2004). Reaches were previously delineated along Rainbow Creek between Mayfield Road and Castlemore Road as part of the Master Environmental Servicing Plan (MESP) for Area 47 (Aquafor Beech Limited, 2012). These reaches were further refined as part of the MESP Addendum and have been carried forward to the current study. The downstream extent of **RCT-4** and the upstream extent of **RCT-3** are located within the subject lands (**Appendix B**).

4 Field Assessment

Field reconnaissance along accessible portions of Rainbow Creek was completed on November 30, 2019 and included the following activities:

- Estimates of bankfull channel dimensions
- Observations of bed and bank material composition and structure
- Observations of riparian conditions and any locations of erosion and/or aggradation
- Collection of georeferenced photographs to document the location and timing of all observations

These observations and measurements are summarized below. The descriptions are supplemented and supported with representative photographs, which are included in **Appendix C**. Field sheets are provided in **Appendix D**. Due to access along the western portion of the study area, the field assessment was limited to the downstream section of Reach **RCT-4** and the upstream section of Reach **RCT-3**.

Channel instability is typically objectively quantified through the application of the MOE (2003) RGA. Using this tool, observations are quantified using an index that identifies channel sensitivity based on evidence of aggradation, degradation, channel widening, and planimetric adjustment. The index produces values that indicate whether a channel is stable/in regime (score <0.20), stressed/transitional (score 0.21-0.40), or adjusting (score >0.41).

The RSAT can also be employed to provide a broader view of the system as it considers the ecological function of the watercourse (Galli, 1996). Observations were made of channel stability, channel scouring or sediment deposition, instream and riparian habitats, and water quality. The RSAT score ranks the channel as maintaining a poor (<13), fair (13-24), good (25-34), or excellent (35-42) degree of stream health.

Due to limited channel definition and morphology, the RGA and RSAT were not applied to the portions of reaches **RCT-3** and **RCT-4** assessed in the field. This is consistent with the field assessment along reaches adjacent to the subject lands that was completed as part of the MESP Addendum (Savanta Inc., 2019).

4.1 General Reach Observations

Reach **RCT-3** conveys flows in a generally northeast to southwest orientation through agricultural fields, with a small section of the reach located within the western extent of the subject lands. Due to site access limitations, approximately 60 m of this reach was field confirmed in the upstream extent of the study area. The reach lacked a defined channel for most of the extent assessed, with the exception of the upstream area, where bankfull channel width and depth were approximately 1.5 m and 0.15 m, respectively. Riffles and pools were absent and channel bed and bank materials were comprised of clay and silt. Riparian vegetation was continuous along the length assessed, consisted of grasses, and was approximately 4-10 channel widths across. There was also extensive vegetation encroachment in the feature. Bank angles ranged from 0° to 30° degrees, and there was no evidence of active erosion.

Reach **RCT-4** extended from the upstream limit of Reach **RCT-3**, through the industrial area associated with Cadetta Road north of the subject lands. Due to site access limitations, only the downstream section, approximately 110 m in length, was assessed in the field. This reach consisted of a single, low gradient perennial channel with a bankfull width and depth of approximately 3.5 m and 0.45 m, respectively. Similar to Reach **RCT-3**, the channel did not have riffles or pools, and channel substrate was composed of clay and silt. Riparian vegetation consisted of grasses, was continuous, and extended approximately 4-10 channel widths. The riparian buffer is likely narrower within the industrial area upstream based on Google Earth Pro imagery. Bank angles ranged from 0° to 30°, and there was erosion in less than 5% of the reach. General reach characteristics are provided below in **Table 1**.

Table 1: General channel characteristics

Reach	Average Bankfull Width (m)	Average Bankfull Depth (m)	Substrate		Riparian Vegetation	Notes
			Riffle	Pool		
RCT-3*	1.5	0.15	No riffles and pools, clay/silt		Grasses	Unconfined, perennial flow, majority of reach lacked defined banks, largely a wetland feature within agricultural fields
RCT-4	3.5	0.45	No riffles and pools, clay/silt		Grasses	Unconfined, perennial flow, appeared entrenched upstream where it flowed through industrial area

*Channel measurements collected where channel was defined near the upstream extent of the reach. The majority of reach assessed contained a wetland/swale feature and lacked a defined channel.

5 Meander Belt Width Assessment

Most watercourses in southern Ontario have a natural tendency to develop and maintain a meandering planform, provided there are no spatial constraints. A meander belt width, or erosion hazard assessment, estimates the lateral extent that a meandering channel has historically occupied and will likely occupy in the future. This assessment is therefore useful for determining the potential limit of development adjacent to a watercourse.

When defining the erosion hazard for a watercourse, Ministry of Natural Resources (MNR; 2002) guidelines treat unconfined and confined systems differently. Unconfined systems are those with poorly defined valleys or slopes well outside where the channel could realistically migrate. Confined systems are those where the watercourse is contained within a defined valley, where valley wall contact is possible. Based on field reconnaissance, the portion of Rainbow Creek within and adjacent to the subject lands is an unconfined system.

In unconfined systems, the meander belt boundaries centre along the general valley orientation and are defined as parallel lines drawn tangentially to the outside bends of the most laterally extreme meanders within the reach (TRCA, 2004). Georeferenced historic aerial imagery can be used to examine past positions and configurations of the channel planform and to delineate the channel centreline, and its central tendency (i.e., meander belt axis). A modelling approach can be used where the channel has been previously modified, or its position cannot be determined in the imagery due to tree cover or poor photograph resolution. These models are scientifically-defensible and have been verified in past projects as suitable for use in southern Ontario.

5.1 Existing Channel

Due to extensive historical channel modifications to sections of Rainbow Creek within and adjacent to the subject lands, a modelling approach was used. Empirical relations from Williams (1986) were applied using average bankfull channel dimensions measured in the field by GEO Morphix Ltd. to estimate the meander belt width (m), B_w:

$$B_w = 18A^{0.65} + W_b \quad \text{[Eq. 1]}$$

$$B_w = 4.3{W_b}^{1.12} + W_b \quad \text{[Eq. 2]}$$

where A is bankfull cross-sectional area (m^2) and W_b is average bankfull channel width (m). An additional 20% buffer, or factor of safety, was applied to the computed results to address issues of under prediction.

The Ward et al. (2002) model was also used to determine meander belt widths (ft), B_w:

$$B_w = 6{W_b}^{1.12} \quad \text{[Eq. 3]}$$

Again, an additional 20% factor of safety was applied to the results.

Results of the meander belt width analysis are provided in **Table 2**. **Appendix E** illustrates the recommended meander belt widths for reaches **RCT-3** and **RCT-4**. As a conservative approach, a meander belt width of 25 m was assigned to both reaches. **Section 2.1** of this report noted that Aquafor Beech Limited (2016) calculated a meander belt width of 58 m for all reaches of Rainbow Creek within the study area. The MESP also acknowledged that meander belt widths/erosion hazards typically do not apply to swale features as they are stable and erosion potential is limited (Aquafor Beech Limited, 2016). As the existing drainage features are unlikely to migrate or adjust their planform due to limited energy and vegetation control, it is our opinion that a meander belt width of 25 m more than adequately addresses any potential erosion hazard.

In addition, the existing floodplain delineated in the MESP was much larger than the theoretical meander belt width for Rainbow Creek under existing conditions.

Table 2: Meander belt widths for Rainbow Creek under existing conditions

Reach	Meander Belt Width (m)			Recommended Meander Belt Width (m)
	Williams - Area (1986)	Williams - Width (1986)	Ward (2002)	
RCT-3	10	10	13	25
RCT-4	33	**25**	34	25

5.2 Proposed Naturalized Corridor

A meander belt width was delineated as part of the MESP Addendum for the proposed realigned channel to define, in part, corridor requirements within the Area 47 development. Due to the scale of the watercourse and limited meander potential, it was noted that the delineated floodplain would be substantially larger than the theoretical meander belt width. The MESP Addendum also confirmed that there was little to no erosion hazard anticipated in association with the proposed channel design (Savanta Inc., 2019). As such, the hazard limits calculated were considered to be conservative.

The bankfull dimensions of the proposed channel between Old Castlemore Road and the Trans Canada Pipeline (immediately north of Cadetta Road industrial area) had an average width and depth of 3.60 m and 0.38 m, respectively. The predicted meander belt width of the designed channel was determined by applying the modified Williams (1986) model (refer to Eq. 2 above) that included the width of the channel and a factor of safety. This resulted in a meander belt width of 26 m. The bottom width of the proposed corridor documented in the MESP Addendum varied from 26 m to 70 m. It was anticipated that proposed channel would be stable given the low gradient, vegetation control and intermittent flow conditions. The predicted meander belt width for the designed channel could therefore be accommodated within the proposed corridor (Savanta Inc., 2019). The alignment and extent of the proposed corridor, including required buffers, is shown in **Appendix E**. The MESP Addendum noted that a 10 m vegetated buffer from the top of slope of the realigned corridor would be required where trails are absent. Where trails are proposed, a 15 m vegetated buffer would be provided in accordance with the MESP Addendum (Savanta Inc. 2019). A future recreational trail is to be located on the west side of the realigned corridor opposite the subject lands.

6 Erosion Mitigation Assessment

Erosion control requirements for Area 47 were outlined in the MESP through consultation with the TRCA. As per the MESP and TRCA (2012) guidelines, a minimum stormwater retention of 5 mm is required to minimize downstream erosion potential. This was to be achieved through onsite controls or conveyance LID techniques (e.g., bioswales). Extended detention storage is also required to capture and release runoff from a 25 mm storm event over 48 hours. From a geomorphological perspective, the capture and gradual release of all storm events up to the 25 mm event was anticipated to provide control for over 90% of all storm events in a typical year (Aquafor Beech Limited, 2016).

Conceptual extended detention targets and release rates for erosion control were identified based on runoff coefficients for future residential (0.6) and industrial land uses (0.9). TRCA defined pre-development release rates for the 2-yr to 100-yr storm events through unit flow relationships established in the 1997 Humber River Watershed Hydrology/Hydraulics and Stormwater Management Study. Hydrological analyses were completed using SWMHYMO to estimate active storage requirements to meet established erosion and flood control targets for each stormwater management pond (SWMP) in Area 47. The drainage area for SWMP R2 included consideration of the subject lands, and was proposed to outlet to Rainbow Creek upstream of Old Castlemore Road. As such, targets established as part of the MESP have been carried forward to the current study and can be refined during future project stages, as appropriate. **Table 3** includes a summary of relevant information related to erosion mitigation from the MESP for SWMP R2.

Table 3: Conceptual SWMP R2 characteristics and extended detention release rates for flood control (Aquafor Beech Limited, 2016).

Estimated Drainage Area (ha)	Imperviousness (%)	Extended Detention for Erosion Control		
		Erosion Control Release Rates	2-Yr Control Release Rates	100-Yr Control Release Rates
42.8	95%	0.056 m^3/s 1.3 L/s/ha	0.291 m^3/s 6.8 L/s/ha	0.907 m^3/s 21.2 L/s/ha

7 Summary

A fluvial geomorphological assessment along a portion of Rainbow Creek was completed in support of the Environmental Assessment for the City of Brampton Transit facility. The assessment included a review of previously completed studies, topographic and geologic mapping, as well as confirmatory field reconnaissance to provide an update to existing conditions documented in the MESP (Aquafor Beech Limited, 2016) and MESP Addendum (Savanta Inc., 2019). Meander belt widths previously delineated in the MESP (Aquafor Beech Limited, 2016) were also revisited and refined to reflect local conditions and the potential future alignment of Rainbow Creek adjacent to the subject lands.

A tributary of Rainbow Creek flows in the western portion of and immediately adjacent to the subject lands. The desktop assessment revealed that reaches proximal to the subject lands had been significantly impacted by agricultural land use practices including the removal of natural riparian vegetation and channelization/straightening. As part of the current study, the upstream portion of **Reach RCT-3** and the downstream portion of **Reach RCT-4** were assessed in the field. Although standard rapid assessment techniques (i.e., RGA and RSAT) could not be applied due to poor channel definition, general reach conditions along portions assessed were documented. The upstream portion of **Reach RCT-3** consisted of a poorly defined, stable swale feature with extensive vegetation encroachment. Channel substrate and bank materials consisted of silt and clay. The channel was only defined near the upstream extent of the reach, where channel width and depth were measured to be 1.5 m and 0.15 m, respectively. The downstream portion of **Reach RCT-4** consisted of a stable, low gradient perennial channel with a bankfull width and depth of approximately 3.5 m and 0.45 m, respectively. Riffles and pools were absent, and channel substrate and bank materials consisted of clay and silt.

Meander belt widths delineated as part of the MESP were refined for Reaches **RCT-3** and **RCT-4** as part of the current study. Due to historical channel modifications and poor channel definition, meander belt widths were determined using empirical modelling. The recommended meander belt width for Reach **RCT-4** is 25 m using a modified Williams (1985) method and the bankfull channel width. Although the modelled belt width for Reach **RCT-3** was 10 m, as a conservative approach a meander belt width of 25 m was applied. These value includes a 20% factor of safety and is considered a theoretical belt width given the exiting channel is poorly defined, vegetation controlled, and has limited erosion/migration potential. To ensure that future conditions following build-out of Area 47 were considered, the Rainbow Creek channel realignment outlined in the MESP Addendum was also reviewed. **Appendix E** illustrates the meander belt widths under existing conditions and the location of the proposed realigned corridor.

Erosion control requirements for Area 47 were outlined in the MESP following TRCA (2012) guidelines and using a treatment train approach. Conceptual extended detention targets and release rates for erosion control were identified based on runoff coefficients for future residential (0.6) and industrial land uses (0.9). Pre-development release rates for the 2-yr to 100-yr storm events through unit flow relationships established by the TRCA, along with hydrological modelling using SWMHYMO, were used to complete the quantity control analysis for each SWMP in Area 47. The drainage area for SWMP R2 included consideration of the subject lands, and was proposed to outlet to Rainbow Creek upstream of Old Castlemore Road. As such, targets established as part of the MESP have been carried forward to the current study and can be refined during future project stages, as appropriate.

We trust this report meets your requirements. Should you have any questions please contact the undersigned.

Respectfully submitted,

Paul Villard, Ph.D., P.Geo., CAN-CISEC, EP, CERP
Director, Principal Geomorphologist

Suzanne St. Onge, M.Sc.
Senior Environmental Scientist

8 References

AECOM. 2012. Works & Transportation Satellite Yards Municipal Class Environmental Assessment Environmental Study Report. Prepared for the City of Brampton.

Aquafor Beech Limited. 2016. Master Environmental Servicing Plan: Highway 427 Industrial Secondary Plan Area (Area 47).

Brierley, G. J. and Fryirs, K. A. 2005. Geomorphology and River Management: Applications of the River Styles Framework. Blackwell Publishing, Oxford, UK, 398pp. ISBN 1-4051-1516-5.

Chapman, L.J. and Putnam, D.F. 1984. The Physiography of Southern Ontario. Ontario Geological Survey, Special Volume 2, Map 226.

Chapman, L.J. and Putnam, D.F. 2007. Physiography of southern Ontario. Ontario Geological Survey, Miscellaneous Release – Data 228.

Galli, J. 1996. Rapid Stream Assessment Technique, Field Methods. Metropolitan Washington Council of Governments.

Ministry of the Environment (MOE). 2003. Ontario Ministry of the Environment. Stormwater Management Guidelines.

Montgomery, D.R. and J.M. Buffington. 1997. Channel-reach morphology in mountain drainage basins. Geological Society of America Bulletin, 109 (5): 596-611.

Ontario Geological Survey (OGS). 2010. Surficial geology of Southern Ontario. Ontario Geological Survey. Miscellaneous Release – Data 128-REV.

Richards, C., Haro, R.J., Johnson, L.B. and Host, G.E. 1997. Catchment and reach-scale properties as indicators of macroinvertebrate species traits. Freshwater Biology, 37: 219-230.

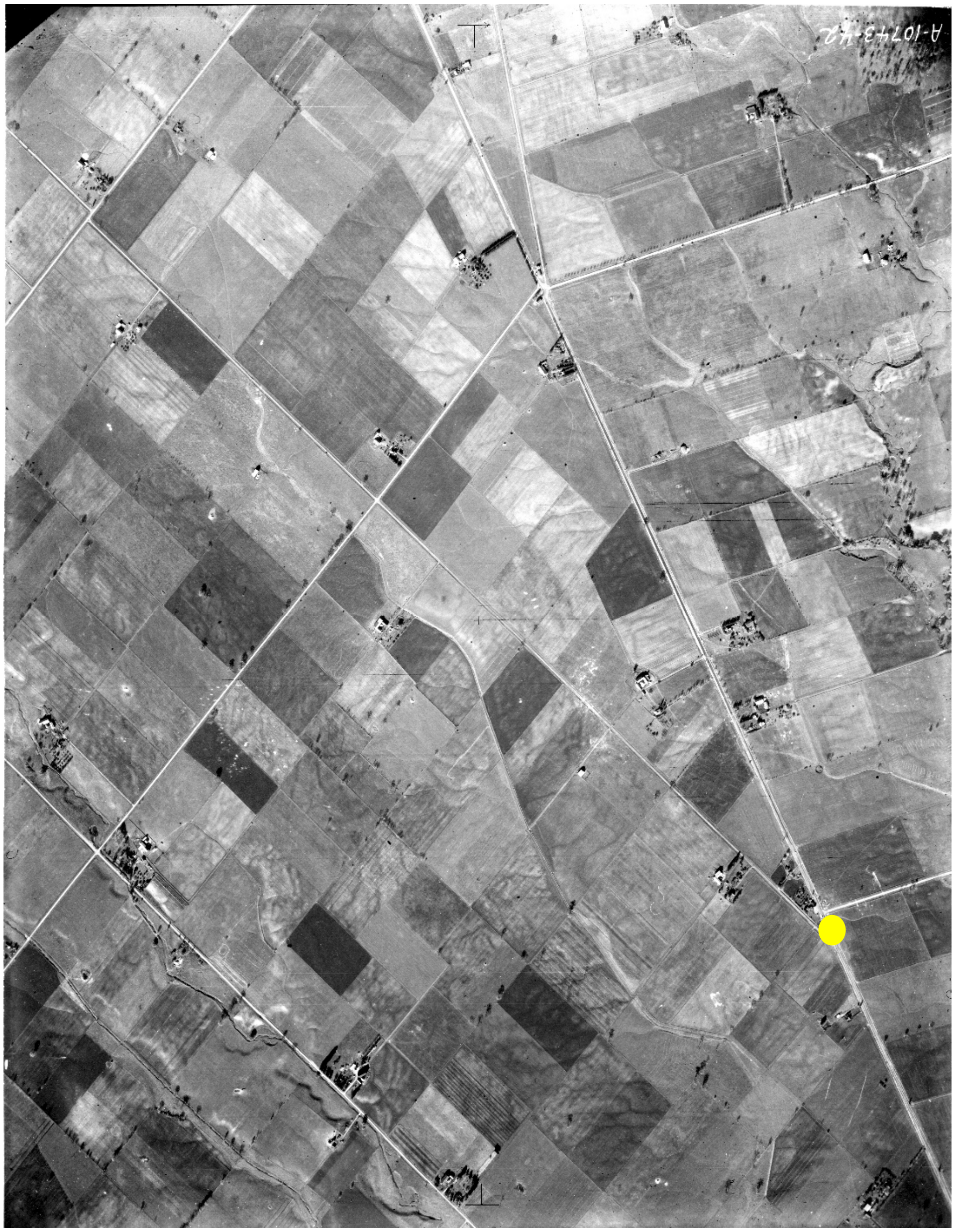
Savanta Inc. 2019. Rainbow Creek MESP Addendum. Prepared for the Rainbow Creek Corridor Landowners Group Inc.

Toronto and Region Conservation Authority. 2004. Belt Width Delineation Procedures.

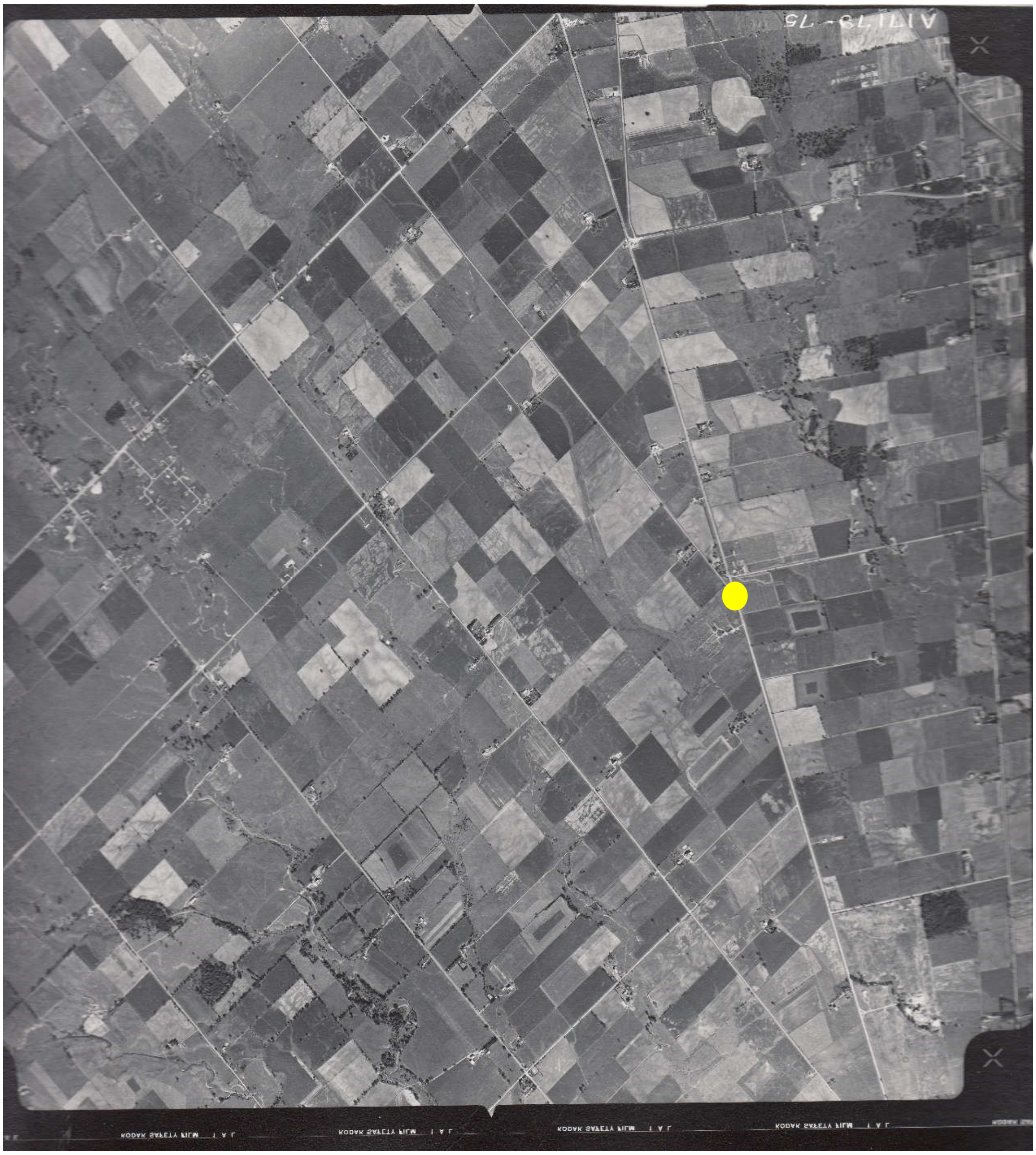
Ward, A. D. Mecklenberg, J. Mathews, and D. Farver. 2002. Sizing Stream Setbacks to Help Maintain Stream Stability. Paper Number: 022239. 2002 ASAE Annual International Meeting. Chicago, IL, USA. July 28-July 31, 2002.

Williams, G.P. 1986. River meanders and channel size. Journal of Hydrology, 88 (1-2): 147-164.

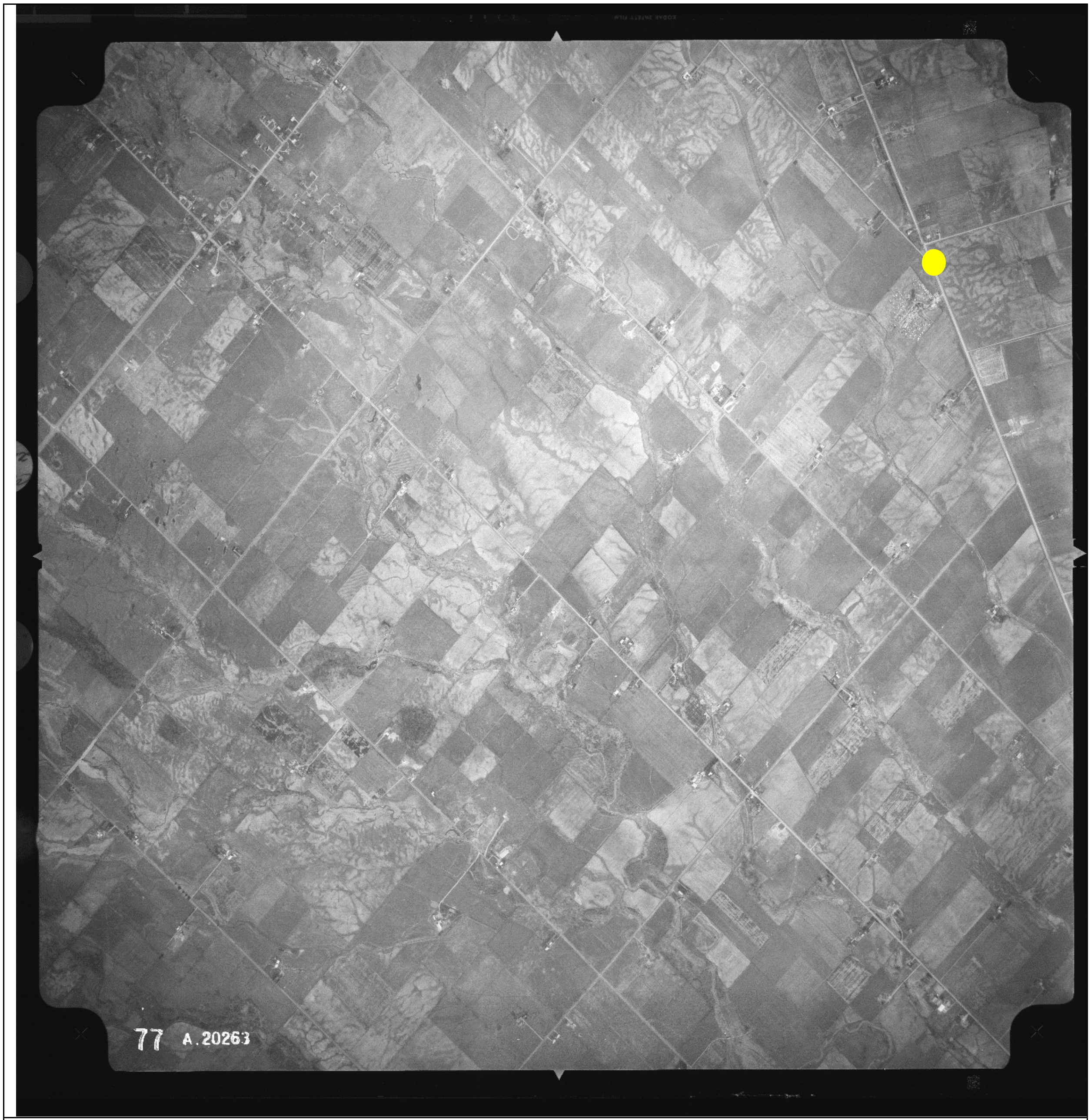
Appendix A
Historical Aerial Photographs



Location: Highway 50 and Coleraine Drive, Brampton (yellow dot)
Year: 1946
Scale: 1:20,000
Source: National Air Photo Library

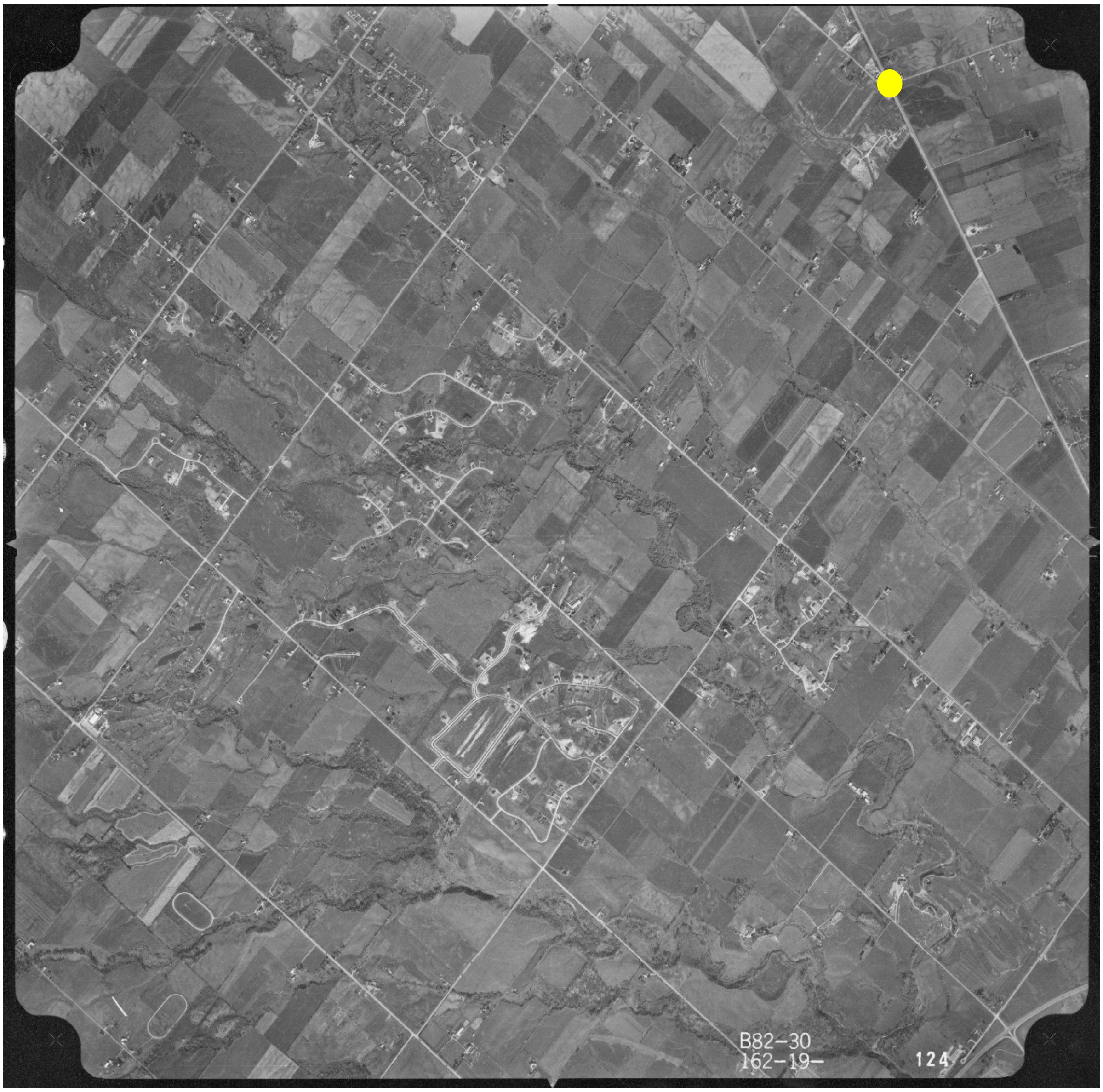


Location: Highway 50 and Coleraine Drive, Brampton (yellow dot)
Year: 1960
Scale: 1:30,000
Source: National Air Photo Library



Location: Highway 50 and Coleraine Drive, Brampton (yellow dot)
Year: 1969
Scale: 1:25,000
Source: National Air Photo Library

Location: Highway 50 and Coleraine Drive, Brampton (yellow dot)
Year: 1978
Scale: 1:10,000
Source: Ministry of Natural Resources



Location: Highway 50 and Coleraine Drive, Brampton (yellow dot)
Year: 1982
Scale: 1: 30,000
Source: Kenting Earth Sciences Limited

Appendix B
Reach Delineation

Legend

Reach Break and ID

Watercourse

Study Area

Environmental Assessment Study

City of Brampton Transit Facility

Rainbow Creek Reach Delineation

GEO MORPHIX

N

0 125 250 500

Metres

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Imagery: December, 2019.
Reach Break and ID: GEO Morphix Ltd., 2017. Watercourse: MNRF and GEO Morphix Ltd., 2019. Study Area: IBI, 2020.
Print Date: January 2020. PN19086. Drawn By: W.B., S.S.

Appendix C
Photographic Record

Photo 1 **Rainbow Creek Reach RCT-3**	
	Photograph taken facing upstream. The majority of the reach consisted of a wetland/swale feature.
Photo 2 **Rainbow Creek Reach RCT-3**	
	Photograph facing downstream at the upstream extent. A defined channel was observed at the upstream extent.

Photo 3
Rainbow Creek Reach RCT-4

Photograph taken facing downstream at the downstream extent.
The reach consisted of a plain bed, with no riffle-pool development

Photo 4
Rainbow Creek Reach RCT-4

Photograph taken facing downstream at the upstream extent.
The banks had low angles with little to no erosion.

Appendix D
Field Observations

GEO | MORPHIX
Geomorphology Earth Science Observations

Reach Characteristics

Project Code: PN19086

Date:	Nov 30, 2019	**Stream/Reach:**	RCT-3
Weather:	cloudy + -2°C	**Location:**	Hwy 50, Brampton.
Field Staff:	CH	**Watershed/Subwatershed:**	Rainbow Crk
UTM (Upstream)		**UTM (Downstream)**	

Land Use (Table 1): 3 | **Valley Type** (Table 2): 1 | **Channel Type** (Table 3): 11 | **Channel Zone** (Table 4): 2 | **Flow Type** (Table 5): 1 | ☐ Groundwater | Evidence: None

Riparian Vegetation

Dominant Type: (Table 6) 3

Species: ____

Coverage: ☐ None ☐ Fragmented ☑ Continuous

Channel widths: ☐ 1-4 ☑ 4-10 ☐ > 10

Age Class (yrs): ☑ Immature (<5) ☐ Established (5-30) ☐ Mature (>30)

Encroachment: (Table 7) 5

Aquatic/Instream Vegetation

Type (Table8) 1 Coverage of Reach (%) 30

Woody Debris: ☐ Present in Cutbank ☐ Present in Channel ☑ Not Present

Density of WD: ~~☐ Low ☐ Moderate ☐ High~~ WDJ/50m: NA

Water Quality

Odour (Table 16) 1

Turbidity (Table 17) 1

Channel Characteristics

Sinuosity (Type) (Table 9) 1 | **Sinuosity (Degree)** (Table 10) 2 | **Gradient** (Table 11) 1 | **Number of Channels** (Table 12) 1

Entrenchment (Table 13) 1 | **Type of Bank Failure** (Table 14) None | **Downs's Classification** (Table 15) S

	Clay/Silt	Sand	Gravel	Cobble	Boulder	Parent	Rootlets
~~Riffle Substrate~~	~~☐~~	~~☐~~	~~☐~~	~~☐~~	~~☐~~	~~☐~~	~~☐~~
Bed ~~Pool~~ Substrate	☑	☐	☐	☐	☐	☐	☐
Bank Material	☑	☐	☐	☐	☐	☐	☐

Bankfull Width (m)	1.5 *	/	/	**Wetted Width (m)**	1.25	/	/ *
Bankfull Depth (m)	0.15	/	/	**Wetted Depth (m)**	0.2	/	/

Riffle/Pool Spacing (m) NA | **% Riffles:** NA | **% Pools:** NA | **Meander Amplitude:** NA

Pool Depth (m) NA | **Riffle Length (m)** NA | **Undercuts (m)** NA

Velocity (m/s) NA | / | / | **Wiffle ball / ADV / Estimated**

Bank Angle: ☑ 0 – 30 * ☐ 30 – 60 ☐ 60 – 90 ☐ Undercut

Bank Erosion: ☑ < 5% ☐ 5 – 30% ☐ 30 – 60% ☐ 60 – 100%

Comments: ▷ Wetland feature
* Bank definition briefly @ U/S extent. No banks D/S.

Notes:

▷ U/S extent of reach assessed

Completed by: CH Checked by: ____

GEO | MORPHIX
Geomorphology Earth Science Observations

Reach Characteristics

Project Code: PN19086

Date:	Nov 30, 2019	**Stream/Reach:**	RCT-4
Weather:	cloudy + -2°C	**Location:**	Hwy 50, Brampton
Field Staff:	CH	**Watershed/Subwatershed:**	Rainbow Crk.
UTM (Upstream)		**UTM (Downstream)**	

Land Use (Table 1): 3/4 | **Valley Type** (Table 2): 1 | **Channel Type** (Table 3): 11 | **Channel Zone** (Table 4): 2 | **Flow Type** (Table 5): 1 | ☐ Groundwater | Evidence: None

Riparian Vegetation

Dominant Type: (Table 6) 3
Species: ______

Coverage:
- ☐ None
- ☐ Fragmented
- ☑ Continuous

Channel widths
- ☐ 1-4
- ☑ 4-10
- ☐ > 10

Age Class (yrs):
- ☑ Immature (<5)
- ☐ Established (5-30)
- ☐ Mature (>30)

Encroachment: (Table 7) 4

Aquatic/Instream Vegetation

Type (Table8) 1 | Coverage of Reach (%) 70

Woody Debris
- ☐ Present in Cutbank
- ☐ Present in Channel
- ☑ Not Present

Density of WD:
- ☐ Low
- ☐ Moderate
- ☐ High

WDJ/50m: NA

Water Quality

Odour (Table 16) 1
Turbidity (Table 17) 1

Channel Characteristics

Sinuosity (Type) (Table 9) 1 | **Sinuosity (Degree)** (Table 10) 1 | **Gradient** (Table 11) 1 | **Number of Channels** (Table 12) 1

Entrenchment (Table 13) 1 | **Type of Bank Failure** (Table 14) None | **Downs's Classification** (Table 15) S

	Clay/Silt	Sand	Gravel	Cobble	Boulder	Parent	Rootlets
~~Riffle Substrate~~	☐	☐	☐	☐	☐	☐	☐
Bed ~~Pool~~ Substrate	☑	☐	☐	☐	☐	☐	☐
Bank Material	☑	☐	☐	☐	☐	☐	☐

Bankfull Width (m)	3.5	/	/	**Wetted Width (m)**	3.2	/	/
Bankfull Depth (m)	0.45	/	/	**Wetted Depth (m)**	0.39	/	/

Riffle/Pool Spacing (m) NA | **% Riffles:** NA | **% Pools:** NA | **Meander Amplitude:** NA

Pool Depth (m) NA | **Riffle Length (m)** NA | **Undercuts (m)** NA

Velocity (m/s) NA | NA | NA | **Wiffle ball / ADV / Estimated**

Bank Angle
- ☑ 0 – 30
- ☐ 30 – 60
- ☐ 60 – 90
- ☐ Undercut

Bank Erosion
- ☑ < 5%
- ☐ 5 – 30%
- ☐ 30 – 60%
- ☐ 60 – 100%

Comments: ▷ Appears entrenched U/S
▷ Partially frozen.

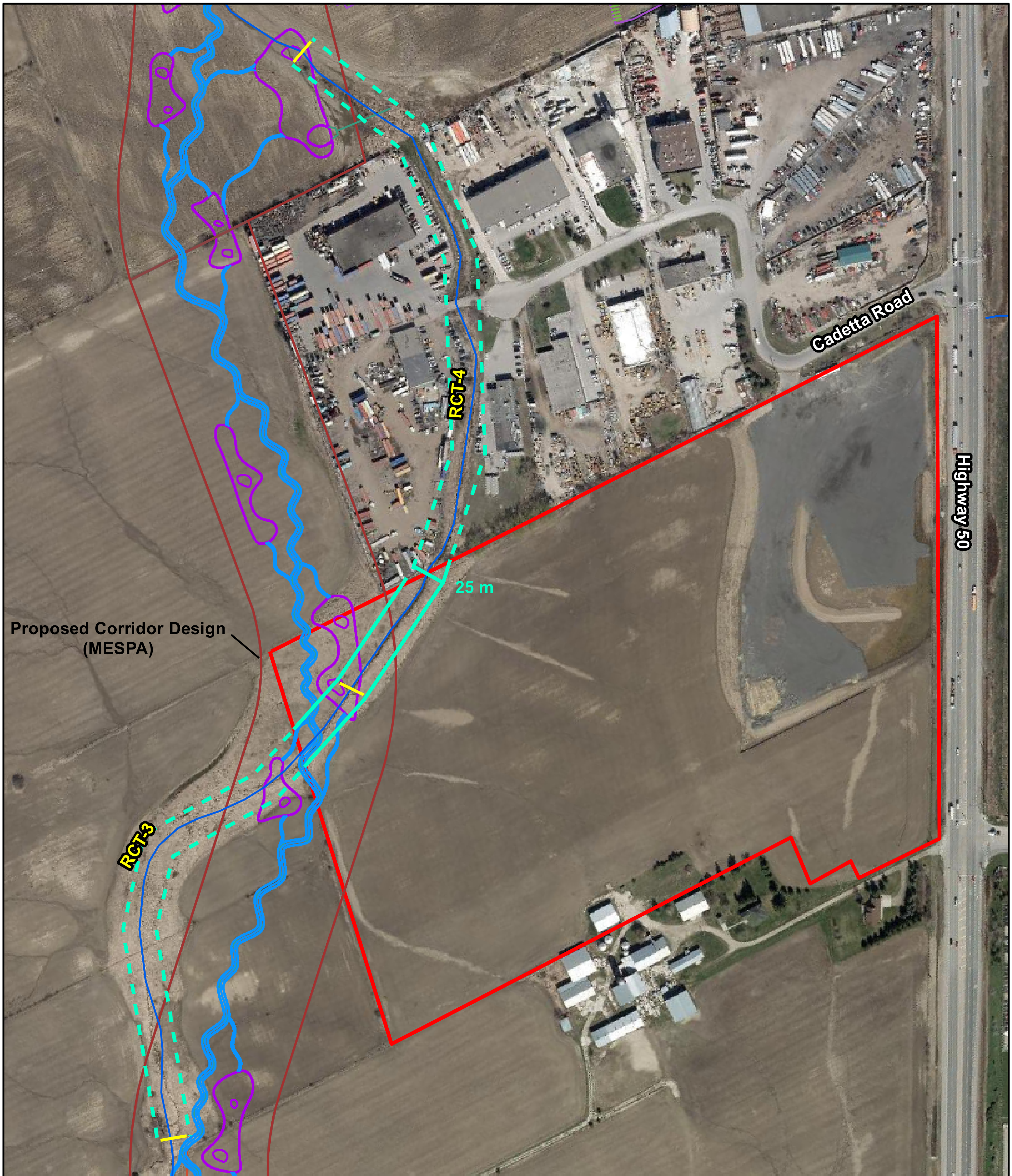
Notes:

▷ D/S extent of reach assessed

Completed by: CH

Checked by: ______

Appendix E
Meander Belt Width Delineation



Legend

- Reach Break and ID
- Meander Belt Width
- Watercourse
- Study Area
- Limit of Proposed Corridor
- Proposed Wetland
- Proposed Watercourse

Environmental Assessment Study

City of Brampton Transit Facility

Rainbow Creek
Meander Belt Width Delineation

GEO MORPHIX

1:3,750

N

0 25 50 100
Metres

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community Imagery: December, 2019. Reach Break and ID: GEO Morphix Ltd., 2017. Watercourse: MNRF and GEO Morphix Ltd., 2019. Meander Belt Width and Proposed Corridor Design: GEO Morphix Ltd., 2019. Study Area: IBI and GEO Morphix Ltd., 2020.
Print Date: January 2020. PN19086. Drawn By: W.B., S.S.