Erosion Hazard and Mitigation Assessment Sixteen Mile Creek Tributaries

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Oakville, Ontario

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GEO MORPHIX
Geomorphology
Earth Science
Observations

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1 Introduction

GEO Morphix Ltd. (GEO Morphix) was retained to complete an erosion hazard and mitigation assessment within the property located at 1280 Dundas Street West in Oakville in support of a zoning by-law amendment (ZBA) application. The property, hereafter referred to as the subject lands, is bounded by Dundas Street West and Fourth Line to the north, Fourth Line and the main branch of Sixteen Mile Creek to the east, an existing development to the west, and the St Volodymyr Ukrainian Cemetery to the south (**Appendix A**).

Glenayr Creek, a tributary to the main branch of Sixteen Mile Creek, flows along the southern limit of the subject lands. A relatively small unnamed tributary of Sixteen Mile Creek is centrally located in the subject lands, and discharges to Glenayr Creek downstream of Fourth Line. In addition, a remnant pond feature is located on the tablelands immediately south of Fourth Line. Drainage from this pond is connected to the central ravine via a 0.4 m diameter pipe. As noted in the Environmental Impact Study (EIS) prepared by SLR Consulting (2020), a CCTV investigation of the pipe revealed that it is blocked or has collapsed in more than one location. As such, the remnant pond currently does not contribute flows to the central ravine but may have historically.

The subject lands are approximately 4.6 ha in area, with the proposed development consisting of a seniors' living facility and associated amenities. The proposed stormwater management strategy includes an underground storage facility and a storm sewer outlet that will discharge to the central ravine. Conservation Halton provided comments on the first ZBA submission, noting concerns regarding potential increased erosion within the central ravine due to stormwater discharge. In addition, the determination of a toe erosion allowance was requested by Conservation Halton for the ravine system, which includes Glenayr Creek and the unnamed tributary.

The following activities were completed by GEO Morphix to address comments from Conservation Halton and the Town of Oakville regarding delineation of the erosion hazard and erosion mitigation for the proposed storm sewer outlet:

- Review topographic and geologic maps and previously completed reporting
- Complete a historical assessment using aerial photographs to identify changes to the tributaries due to land use and past channel modifications
- Delineate watercourse reaches through a desktop exercise
- Conduct rapid field reconnaissance to document reach-scale observations of channel substrate, flow behaviour, geomorphological units, and locations of any valley wall contacts and areas of active erosion
- Define the erosion hazard to establish, in part, development limits within the subject lands
- Complete a detailed geomorphological field assessment, the primary objective of which is to determine the critical flow or erosion threshold
- Determine an erosion threshold for use in the proposed stormwater management strategy using an in-house model that predicts the discharge at which the dominant channel material will become entrained
- Completed an erosion exceedance assessment using hydrological modelling provided by R.V. Andreson Associates Ltd to evaluate the potential impacts of the development on the receiving watercourse

2 Background Review

2.1 Site History

A series of historical aerial photographs were reviewed to determine changes to the channel and surrounding land use and land cover. This information, in part, provides an understanding of the historical factors that have contributed to current channel morphodynamics and potentially how past changes may affect channel planform in the future. Historical aerial photographs from 1934 (1:20,000), 1954 (1:15,840), 1965 (1:20,000), 1974 (1:25,000), 1978 (1:10,000), and 1985 (1:40,000) from the Ministry of Natural Resources and National Air Photo Library were reviewed to understand site history and inform the erosion hazard assessment. Recent satellite imagery from Google Earth Pro was also reviewed. Copies of this imagery are provided in **Appendix B** for reference.

In 1934, the subject lands and upstream drainage area were actively cultivated. Minor drainage features were visible on the landscape, draining in a northwest to southeast orientation across Dundas Street West, with an overland flow route to the central ravine apparent within the property. A rural residence and associated outbuildings were present on the site, and the Dundas Street bridge crossing Sixteen Mile Creek had been constructed. A narrow buffer of woody riparian vegetation was present along the central and southern ravines but appeared to have been selectively cleared to facilitate agriculture.

In 1954, land use surrounding the property remained predominantly agricultural. Woody vegetation establishment within the riparian zone of the central ravine channel and southern ravines was evident, and tree plantings were visible on the property. The existing pond at the northern extent of the property had been constructed by this time, as well as an additional driveway access from Dundas Street. Outflows from the pond travelled through a narrow forested buffer towards the central ravine channel, though it is not certain whether these flows traveled over land or through a culvert. However, the existing crossing immediately south of the pond is visible in the 1954 image. The inflow source for the constructed pond is not discernable from the available aerial photograph.

The Dundas Street Bridge over Sixteen Mile Creek had expanded from two lanes to four lanes between 1954 and 1965. The driveway access off of Dundas Street was also relocated further west, likely to accommodate the bridge widening. By 1974, a farm road crossing at the downstream extent of the central ravine was visible. This crossing may have been established as early as 1954 but was not explicitly visible in the aerial imagery until 1974. By 1978, construction was underway to widen Dundas Street West from two lanes to four lanes on either side of Sixteen Mile Creek.

Despite the expansion of linear infrastructure, overall land use changes within and around the property were relatively limited between 1954 and 1985. During this period, vegetation in the channel riparian zone continued to establish and was not significantly modified. Vegetation within and around the pond feature became increasingly established as well. Notably, the 1974 image suggests that the drainage feature in the field north of Dundas Street West that may have historically fed the central ravine was directed to a roadside ditch on the north side of Dundas Street West and drained east to Sixteen Mile Creek.

In 2004, one of the rural residential buildings within the subject lands was removed. The vegetation buffer spanning from the pond to the central ravine was reduced, which was presumably associated with the building removal process. It is clear during this time that the pond outflows were directed through an underground culvert to the central ravine channel. In 2016, the remaining rural residential building was removed while the vegetation communities remained relatively unchanged.

Overall, the subject lands have not experienced significant land use changes throughout the period of available record. Vegetation communities were established in the riparian zones of the central and southern ravines and would remain relatively unchanged to present day. The most significant changes were associated with Dundas Street West construction. The drainage features that may have fed the central ravine channel historically appear to have been cut off at Dundas Street West. Thus, it is evident that the drainage area of the central ravine channel has been reduced from its natural extent.

2.2 Surficial Geology

Channel morphodynamics are largely governed by the flow regime and the availability and type of sediments (i.e., surficial geology) within the stream corridor. 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. Understanding local surficial geology is important for delineating the erosion hazard and determining appropriate erosion thresholds, as the stability of the channel banks and bed is dependent on the composition of soils, sediment, and underlying parent materials (MNR, 2002).

The subject lands are located within the South Slope physiographic region. This region is situated on the southern slope of the Oak Ridges Moraine and is characterized by a subdued morainic topography overlying till plains with localized sand and gravel deposits. Drainage is typically controlled by and oriented in the direction of the predominant regional south-facing slope, with exposed red shales of the Queenston Formation being common on valley walls (Chapman and Putnam, 1984). The surficial geology of the subject lands is characterized by both clay to silt-textured till derived from glaciolacustrine deposits or shale (OGS, 2010).

3 Watercourse Characteristics

3.1 Reach Delineation

Reaches are homogeneous segments of channel used in geomorphological investigations. Reaches are divided as such because they are expected to have similar inputs and outputs in terms of sediments and discharge. They are also expected to react similarly throughout to flow events and other stressors. 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 a 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 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 channel modifications by humans

This follows scientifically defensible methodology proposed by Montgomery and Buffington (1997), Richards et al. (1997), and the Toronto and Region Conservation Authority (2004). Reaches are first delineated as a desktop exercise using available data and information such as aerial photography, topographic maps, geology information and physiography maps. The results are then verified in the field.

A single reach was delineated along the relatively small ravine that is central to the subject lands and is labelled as **GCT-1** in **Appendix A**. Reaches of Glenayr Creek adjacent to and upstream of the subject lands were previously delineated in support of a future development north of Dundas Street West. These reaches have been carried forward and included in this report for consistency. **Reach GC-3** extends approximately 280 m upstream from the confluence with **Reach GCT-1**.

3.2 General Reach Observations

Rapid and detailed field assessments were completed along **Reach GCT-1** on August 26, 2021. Observations along **Reach GC-3** were collected on November 2, 2020 and have also been included as conditions along this reach were used to inform toe erosion allowance recommendations. Photographs from the field assessments are provided in **Appendix C**, rapid field observations are provided in **Appendix D**, and the detailed assessment summary is provided in **Appendix E** for reference. A summary of the general observations characterizing the delineated reaches is presented in **Table 1**.

Table 1. Reach characteristics summary

Reach Name	Avg. Bankfull Width (m)	Avg. Bankfull Depth (m)	Riffle Substrate	Pool Substrate	Dominant Riparian Condition	Notes
GCT-1	3.08	0.24	Cobble, clay, and silt	Clay and silt	Mature trees, herbaceous species in understory	Confined system with valley wall contact, no bedrock exposed in reach, herbaceous vegetation present on channel bed
GC-3	5.29	0.45	Shale cobbles and gravel	Clay, soil, and shale cobbles	Mature trees	Confined system with moderate-high gradient, parent material exposed in banks

Reach GCT-1 is an ephemeral channel contained within the relatively small ravine central to the subject lands. Two small, corrugated pipes are present at the upstream extent of the reach that formerly drained the small pond at the north end of the subject lands. The reach was dry during the time of assessment and likely remains dry outside of major storm events. Mature trees characterize the riparian zone, which extends to the top of the valley walls. Herbaceous vegetation on the channel bed exists throughout approximately 30% of the reach. Bed substrate ranges from silt and clay to small cobbles, with higher proportions of finer sediment being found at the downstream extent of the reach, where backwatering-induced deposition is evident. Banks are comprised of a silty-clay loam with trace amounts of shale particles. Valley wall contact in the ravine was nearly constant, but evidence of ongoing bank erosion was not excessive, likely due to the ephemeral flow regime and blocked outlet from the upstream pond.

Reach GC-3 is a meandering mixed load channel conveying flows within a confined valley. The channel is entrenched, with poor access to its floodplain and a relatively high gradient. The channel's bed and banks are predominantly composed of shale parent material, with clay rich soils also present on the banks. The channel has an average bankfull width of 5.29 m, and an average bankfull depth of 0.45 m.

3.3 Rapid Assessments

Rapid assessments were completed to identify dominant geomorphic processes, document stream health, and to identify any areas of concern regarding erosion or instability. Channel instability was objectively quantified through the application of the Ontario Ministry of the Environment's (2003) Rapid Geomorphic Assessment (RGA). Observations were 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 Rapid Stream Assessment Technique (RSAT) was also 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.

Reaches were also classified according to a modified Downs (1995) Channel Evolution Model. The Downs Model describes successional stages of a channel because of a perturbation, namely hydromodification. Understanding the current stage of the system is beneficial as this allows one to predict how the channel will continue to evolve or respond to an alteration to the system. The results of these assessments are summarized below.

The River Styles Framework (Brierley and Fryirs, 2005) provides a geomorphic approach to examining river character, behaviour, condition and recovery potential through the identification of the Geomorphic Process Zone. Geomorphic attributes are assessed, larger scale interactions between zones are analyzed, and historical data are studies in order to understand the historical evolution and future trajectories of those reaches. This ultimately provides a physical template for river management. A modified classification approach was applied to the study reaches. A summary of the reach classifications and rapid assessment scores is provided in **Table 2**.

For **Reach GCT-1**, the RGA score was 0.28, indicating that the channel was in transition/stress. The dominant geomorphic process shaping the channel in this reach was determined to be widening, largely due to the erosion of the banks. Aggradation was also noted as dominant, but this process was largely confined to the lower-gradient portion of the reach at the downstream extent. The RSAT was not applicable to **Reach GCT-1**, as it was completely dry during the time of assessment. Under the Downs (1995) model, the dominant channel evolution mechanism was determined to be lateral migration. **GCT-1** was classified as a mixed-load dominated meandering channel under the River Styles Framework (Brierley and Fryirs, 2005).

Table 2: Summary of reach classification and rapid assessment results

Reach	RGA (MOE, 2003)			RSAT (Galli, 1996)			Downs Channel Evolution Model (1995)	River Styles Framework †
	Score	Condition	Dominant Systematic Adjustment	Score	Condition	Limiting Feature(s)		
GCT-1	0.28	In transition/ Stress	Aggradation, widening	N/A (Channel dry)			m - Lateral migration	Mixed-load meandering
GC-3	0.38	In transition/ Stress	Widening	23	Fair	Channel stability	U - Undercutting	Mixed load meandering

† Brierley and Fryirs, (2005)

3.4 Detailed Geomorphological Assessment

The detailed geomorphological assessment, used to inform the erosion threshold analysis, was completed on **Reach GCT-1** on August 26th, 2021. Activities completed for the detailed assessment included the following:

- Longitudinal survey of the channel centre line
- Eight detailed cross-section surveys of the watercourse
- Detailed instream measurements at each cross-section location including bankfull channel geometry, riparian conditions, bank material, bank height/angle, and bank root density
- Bed material sampling at each cross-section following a modified Wolman (1954) pebble count or substrate sample, as appropriate

The resulting measured channel parameters are outlined in **Table 3** in **Section 4.2**, and a summary of the detailed assessment results is provided in **Appendix E**.

4 Erosion Threshold Analysis

Erosion thresholds are used to determine the magnitude of flow required to potentially entrain and transport bed and/or bank material. As such, they are used to inform erosion mitigation strategies in channels influenced by conceptual flow and stormwater management plans.

Erosion thresholds were determined from detailed field observations of **Reach GCT-1**. The erosion threshold is the theoretical point, typically expressed as a critical discharge or shear stress, at which entrainment of sediment would occur based on bed and bank materials. Due to variability between bed and bank composition and structure, erosion thresholds are determined for both bed and bank materials. The lower of the bed and bank erosion thresholds is adopted, as it provides the more conservative and limiting estimate.

Threshold targets are determined using different methods that are dependent on channel and sediment characteristics. For example, thresholds for non-cohesive sediments are commonly estimated using a shear stress approach, similar to that of Miller et al. (1977), which is based on a modified Shield’s curve. A velocity approach could also be applied, such as that described by Komar (1987). For cohesive materials, empirically derived values such as those compiled by Fischenich (2001), Chow (1959) or Julien (1998), could be applied.

4.1 Methods

An erosion threshold is quantified based on the bed and bank materials and local channel geometry, in the form of a critical discharge. Theoretically, above this discharge, entrainment and transport of sediment can occur. To determine this discharge, the velocity, *U* is calculated at various depths for a representative cross section until the average velocity in the cross section slightly exceeds the critical velocity of the bed material. The velocity is determined using a Manning’s approach, where the Manning’s n value is visually estimated through a method described by Acrement and Schneider (1989) or calculated using Limerinos’ (1970) approach. The velocity is mathematically represented as:

$$U = \frac{1}{n} d^{2/3} S^{1/2} \qquad \text{[Eq. 1]}$$

where, *d* is depth of water, *S* is channel slope, and *n* is the Manning’s roughness coefficient. The Limerinos (1970) approach was adopted for determining the Manning’s roughness coefficient.

For the bank materials, following Chow (1959) in a simplified cross section, 75% of the bed shear stress acts on the channel banks. In a similar approach, the depth of flow is increased until the shear stress acting on the banks exceeds the resisting shear strength of the bank materials.

4.2 Results

For **Reach GCT-1,** the bed and bank materials were both characterized, and a corresponding permissible velocity for each was obtained from literature. From this, the critical discharge was computed within several representative cross-sections, where the minimum resulting value was selected as the erosion threshold.

The bed materials within **Reach GCT-1** range from silty-clay to cobbles, with a D_{50} below 2 mm. Consequently, limitations exist with the methodologies outlined by Miller et al. (1977) and Komar (1987) for the D_{50}, as the cohesive properties of this finer material are not properly accounted for. The D_{84} material provides a more accurate representation of the dominant, non-cohesive material within the channel and is more suitable for use with the aforementioned methodologies. Further, the composition of the bed material (silt to cobbles) may better suit the methodology outlined by Komar (1987), which accounts for the particle shielding effects that modify critical shear stress and velocity in poorly-sorted sediment environments.

Under Miller et al. (1977), the D_{84} results in a critical shear of 40.94 N/m. The critical shear stress approach to defining the bed material erosion threshold was considered but was ultimately rejected as an appropriate method due to high channel roughness and highly variable grain size.

Under Komar (1987), the D_{84} of 56 mm results in a critical velocity of 1.26 m/s. This was compared to other stated critical velocities within literature. Julien (1998), for non-colloidal graded loam to cobbles, states a critical velocity of 1.14 m/s. To remain conservative, the 1.14 m/s velocity was adopted. The critical velocity from Julien (1998) accounts for the full range of materials present within the bed of **GCT-1**.

The channel banks within **Reach GCT-1** are comprised of a fairly compact silty-clay loam. The material has cohesive properties and is somewhat stabilized by the large root systems present within the banks. For the bank material, a critical velocity of 0.61 m/s for silt loam (Julien, 1998) was adopted as the erosion threshold criteria. As the bank shear stresses are a function of the bed shear stresses, this approach was similarly rejected due to the aforementioned reasons.

Summarized results of the erosion threshold analysis are provided in **Table 3**. The resulting critical discharge required to entrain the bed materials was 0.402 m^3/s. The critical discharge required to entrain the bank materials was 0.117 m^3/s. Thus, the bank material was the limiting factor, and the erosion threshold was defined accordingly by the computed critical discharge of 0.117 m^3/s. The bank-limited erosion threshold is consistent with the findings of the RGA, which identified channel widening (erosion of the banks) as the dominant geomorphic process shaping the channel within **Reach GCT-1**.

The apparent shear stresses acting on bed appear large but are typically overstated in the modelling process. The effective (actual) shear stress applied to bed materials is dissipated by the high roughness from the coarse bed material itself, as well as the encroached vegetation, large woody debris, and meandering planform of the channel. The Miller et al. (1977) shear stress computations do not directly account for high roughness or high quantities of flow impeding structures. Since the velocity computation methods are a partial function of channel roughness, this approach was deemed more suitable and was adopted for the threshold computations.

Table 3: Bankfull conditions and erosion threshold calculation parameters for Reach GCT-1

Channel parameter	Reach GCT-1
Bankfull Conditions	
Average bankfull width (m)	3.08
Average bankfull depth (m)	0.36
Channel gradient (%)	5.94
D_{50} (mm)	<2
D_{84} (mm)	56
Manning’s n roughness coefficient	0.050
Bankfull discharge (m^3/s)	1.23
Bankfull velocity (m/s)	1.64
Channel Bed Erosion Threshold	
Bed Material	Silty-clay loam to cobbles, D_{84} = 56 mm
Apparent shear stress acting on bed (N/m^2)	52.45
Critical velocity at the bed (m/s) *	1.26
Critical discharge (m^3/s)	0.403
Channel Banks Erosion Threshold	
Bank Material	Non-colloidal silt loam
Apparent shear stress acting on banks (N/m^2)	28.12
Critical velocity at the banks (m/s)**	0.61

Channel parameter	Reach GCT-1
Critical discharge (m^3/s)	0.117
Limiting Critical discharge (m^3/s)	**0.117**

* Criteria of Julien (1998) for non-colloidal graded loam to cobbles
** Criteria of Julien (1998) for non-colloidal silt loam

Using a drainage area of 4.281 ha provided by R.V. Anderson Associates Ltd., a unitary threshold of 0.0274 $m^3/s/ha$ was computed. This value is significantly higher than other established erosion thresholds in the Town of Oakville and is likely a result of the small existing drainage area. As evidenced by the historical aerial photograph analysis, **Reach GCT-1** originally likely had a drainage area that extended into the agricultural fields north of Dundas Street. Connectivity to the northern extent of the drainage area past Dundas Street was removed, likely due to the road widening and pond construction activities adjacent to and within the site. It is therefore expected that the true drainage area for **Reach GCT-1**, which had historically formed and sized the channel, was significantly larger than the existing drainage area. Thus, the true unitary erosion threshold would be much lower than the stated value of 0.0274 $m^3/s/ha$.

For comparison, a critical discharge erosion threshold of 0.55 m^3/s was established by GEO Morphix (2020) for Glenayr Creek **Reach GC-3** in support of a separate development. The 120.2 ha drainage area for **Reach GC-3**, obtained from the Ontario Flow Assessment Tool (OFAT), extended beyond Dundas Street, resulting in a unitary erosion threshold of 0.0046 $m^3/s/ha$. Despite having comparably similar bankfull dimensions, the drainage area obtained for **GC-3** is orders of magnitude larger than that of **GCT-1**. This discrepancy provides further evidence that the existing drainage area for **GCT-1** is undersized relative to its bankfull dimensions, and that the true unitary erosion threshold is smaller than 0.0274 $m^3/s/ha$.

5 Post- to Pre-Development Erosion Exceedance Assessment

Using the results of the erosion threshold analysis and hydrological modelling, provided by R.V. Anderson Associates Limited (2021) for post- and pre-development conditions, additional analyses regarding the impacts of SWM controls on potential erosion within the receiving watercourse was completed with our own in-house model, based on four indices:

1) Cumulative time of exceedance
2) Number of exceedance events
3) Cumulative effective discharge
4) Cumulative effective work index (i.e. cumulative effective stream power)

These indices have been applied elsewhere in Conservation Halton's jurisdiction, as well as the jurisdictions of the Toronto and Region Conservation Authority and Credit Valley Conservation. They, as a product, provide an evaluation of the number of events, period of transport, and magnitude. We note that the most relevant indicator is the cumulative effective stream power.

Time of exceedance and number of exceedances can be simply calculated from the discharge record. For more relevant indicators, hydraulic information is required. Our model applies the discharge to a characteristic cross-section. Using a Manning's approach, the discharge at each time step in the continuous hydrological model is converted into a velocity, depth of flow, shear stress, and/or stream power. These parameters are calculated based on field measurements of slope, cross section and channel roughness. This provides analysis that is site appropriate and specific.

The post- and pre-development hydrological modelling reflects changes to the hydrological regime resulting from SWM measures being implemented within the catchment. Flow data was provided by R.V. Anderson Associates Limited (2021) in 10-minute increments for synthetic 25 mm, 2-year, 5-year, 10-year, 25-year, 50-year, and 100-year Chicago storm events. The hydrological modeling was analyzed to calculate the aforementioned erosion indices to identify changes in the erosive potential within **GCT-1** following development.

5.1 Methods

To calculate work terms, both velocity and shear stress were calculated at each time step. Through an iterative process, water depth and velocity were calculated for each discharge passing through a representative cross-section. The cross-section is divided into floodplain and bankfull sections. The cross-section is further broken into panels. Velocity, U, is calculated for each panel using the Manning's approach. This is a conservative approach as it allows dissipation of flood energy in the floodplain.

The total discharge, Q_T at each time step is based on the summation of the discharge of all panels, Q_i, such that:

$$Q_{T=}\sum Q_i \qquad \text{[Eq. 2]}$$

Q_i is discharge through a panel (which is set at 10 percent of the cross-section). Q_i is defined as:

$$Q_i = U_i w_i d_i \qquad \text{[Eq. 3]}$$

where, w_i and d_i are width and depth for each panel. The discharge for each panel was then summed to give a total discharge. This is more accurate than using average cross-sectional dimensions of a simple trapezoidal channel, as the bed is usually irregular, and a panel approach more accurately represents the true cross-sectional area.

For each event, the discharge is converted into a maximum depth and average velocity. The maximum depth is used to calculate a maximum bed shear stress, $\tau_{o_{\max}}$ based on:

$$\tau_{o_{\max}} = d_{\max}\rho g S_{\text{bed}} \qquad \text{[Eq. 4]}$$

where, d_{max} is the maximum water depth, ρ is water density, g is acceleration due to gravity, and S_{bed} is the channel bed slope.

Cumulative total work, ϖ_{tot} is defined as:

$$\omega_{\text{tot}} = \sum \tau_{0_{\max}} . U_{\text{avg}} . \Delta t \qquad \text{[Eq. 5]}$$

where, U_{avg} is average velocity (Q_{tot}/A_{tot}, where A_{tot} is wetted area), while cumulative effective work index (ϖ_{eff}) is defined by:

$$\omega_{\mathrm{eff}} = \sum \tau - \tau_{cr} . U . \Delta t, \omega < 0 = 0 \qquad \text{[Eq. 6]}$$

where, τ_{cr} is the critical shear stress.

Time of exceedance t_{ex} defined as:

$$t_{\mathrm{ex}} = \sum \Delta t \quad \text{for } (Q_T > Q_{\mathrm{threshold}}) \qquad \text{[Eq. 7]}$$

where, $Q_{\mathrm{threshold}}$ is the discharge at the erosion threshold.

5.2 Results

The full series of post- to pre-development hydrographs are included in **Appendix E**, and include the erosion threshold based on discharge, for reference. **Table 4** provides the results of the assessment based on the hydrographs provided by R.V. Anderson Associates Limited (2021).

Table 4: Post- to pre-development erosion exceedance analysis results for Reach GCT-1

Simulation		CED (m^3/s)	ω_{eff} (N/m^2)	t_{ex} (hrs)
25 mm	**(PRE)**	0.00	0.00	0.00
	(POST)	0.00	0.00	0.00
	Change (%)	**0%**	**0%**	**0%**
2-Year	**(PRE)**	0.00	0.00	0.00
	(POST)	0.00	0.00	0.00
	Change (%)	**0%**	**0%**	**0%**
5-Year	**(PRE)**	0.07	1.82	0.50
	(POST)	0.04	0.07	0.33
	Change (%)	**-44.13%**	**-96.09%**	**-33.33%**
10-Year	**(PRE)**	0.09	5.23	0.50
	(POST)	0.13	4.19	0.83
	Change (%)	**35.24%**	**-19.94%**	**66.67%**
25-Year	**(PRE)**	0.15	10.52	0.67
	(POST)	0.24	13.20	1.33
	Change (%)	**66.63%**	**25.50%**	**100.00%**
50-Year	**(PRE)**	0.17	14.63	0.67
	(POST)	0.30	19.21	1.50
	Change (%)	**76.14%**	**31.27%**	**125.00%**

Simulation		CED (m^3/s)	ϖ_{eff} (N/m^2)	t_{ex} (hrs)
100-Year	**(PRE)**	0.22	19.54	0.83
	(POST)	0.40	25.81	2.00
	Change (%)	**82.39%**	**32.11%**	**140.00%**

It is noted that the cumulative effective discharge (CED) and cumulative effective work index (ϖ_{eff}) are considered the most relevant erosion indices, as they reflect both the severity and duration of an exceedance event. Further, storms of moderate magnitudes and of relatively frequent recurrence typically exert the most influence on a given channel's geomorphic regime. Results from the 25 mm event and, to a lesser extent, the 2-year event are therefore the most relevant storm simulations in the context of evaluating erosion potential following hydrological regime changes.

For the 25 mm and 2-year storms, no exceedance events were predicted, as flows entering the reach did not exceed the threshold discharge under the post- and pre-development hydrological conditions. For the 5-year event, the CED is predicted to decrease by 44.13% in the post-development hydrological conditions relative to the existing conditions. The ϖ_{eff} is predicted to decrease by 96.09% and the cumulative exceedance duration (t_{ex}) by 33.33%. For the 10-year event, increases of 32.24% and 66.67% are predicted for the CED and t_{ex}, respectively, while the ϖ_{eff} is predicted to decrease 19.94%. For the larger, less-frequent storms, the CED is predicted to increase by 66.63-82.39%, he ϖ_{eff} is by 25.50-32.11%, and the t_{ex} by 100-140%.

The lack of exceedance events for the 25 mm and 2-year event is likely attributable to the historical reduction of the catchment area, leading to an oversized channel relative to the modelled flows. Since no exceedance events were predicted for either the post- or pre-development conditions, the channel is expected to retain its existing limited geomorphic function and dynamics during 25-mm and 2-year events. Further, the decrease in erosion potential predicted for the 5-year event is expected to offset the moderate increases predicted for the larger, less frequent storms. Thus, the modelling results indicate that exacerbated rates of erosion resulting from development will not occur within Reach **GCT-1**.

6 Erosion Hazard Assessment

The location and extent of erosion hazards associated with a given creek system are typically delineated in support of activities where infrastructure is proposed within or adjacent to a watercourse (e.g., new/replacement crossing structures and various types of land development). The extent of the hazard informs, in part, constraints to a proposed activity. When defining the erosion hazard for a creek system, TRCA (2004) and MNR (2002) protocols treat unconfined and confined systems differently. Confined systems are those where the watercourse is contained within a defined valley, where contact between the watercourse and a valley wall is possible. Partially confined systems are those where meander bends are adjacent to only one valley wall and the watercourse is therefore restricted in migration and floodplain occupation on one side of the valley system.

In contrast, unconfined systems are those with poorly defined valleys or slopes that are well-outside where the channel could realistically migrate. Unconfined systems are generally found within glaciated plains with flat or gently rolling topography. In this setting, a meander belt width assessment estimates the lateral extent that a meandering channel has historically occupied and will likely occupy in the future.

Reaches GCT-1 and **GC-3** are confined systems. In confined systems where the channel is less than 15 m from the toe of the valley slope, the erosion hazard can be delineated using a toe erosion allowance, stable slope allowance, and an erosion access allowance. Following MNR (2002) guidelines, the toe erosion allowance can be determined by 1) calculating the average annual recession rate based on a minimum of 25 years of record, 2) applying a 15 m toe erosion allowance measured inland horizontally and perpendicular to the toe of the watercourse slope, 3) identifying a toe erosion allowance based on soil types and hydraulic processes, or 4) use of a study that applies accepted geotechnical and engineering principles based on a minimum of 25 years of record.

In this case, channel migration rates could not be measured due to the presence of trees along the ravine corridors (i.e., planform not clearly visible). Table 3 in the MNR (2002) guidelines provides recommendations for an appropriate toe erosion allowance based on evidence of erosion, channel bank composition and bankfull channel width. With regard to **Reach GCT-1**, there was limited evidence of active erosion due to the blocked culvert between the remnant pond and the ravine. Should stormwater outlet to the central ravine is it anticipated that the channel will be activated on a regular basis. A toe erosion allowance of 5 m is recommended due to the presence of clay/silt in the channel banks. A toe erosion allowance of 2 m is recommended for **Reach GC-3.** This is due to the presence of shale bedrock in the channel banks, which will act to limit erosion at the channel toe. The recommended toe erosion allowances should be considered in conjunction with the geotechnical study prepared under separate cover by B.I.G. Consulting Inc.

7 Summary and Recommendations

GEO Morphix was retained to complete an erosion hazard and mitigation assessment for the proposed Delmanor West Oak development at 1280 Dundas St. West, Oakville, Ontario. Our assessment included a review of previously completed reports and secondary source information, an examination of site history, determination of the erosion threshold based on the detailed geomorphological assessment completed in August 2021 and toe erosion allowance recommendations in support of the erosion hazard assessment and slope stability assessment being undertaken by others.

The site history assessment was completed using a series of historical images ranging from 1934 to 2016. Land use change within and upstream of the subject lands has been relatively limited throughout the period of available record. No significant changes in channel planform were noted for **Reach GCT-1**, but a large reduction in its natural drainage area was evident. The drainage features which naturally fed **Reach GCT-1** were cut off at Dundas Street. In addition, it is understood that the pipe that formerly directed discharge from the remnant pond to the central ravine is currently blocked in multiple locations.

The purpose of the erosion threshold analysis was to provide an appropriate critical discharge (the theoretical discharge at which the bed or bank materials will become entrained) to support the sizing and release rate planning procedures associated with the proposed underground SWM storage facility. To complete this, rapid and detailed assessments were conducted within the receiving watercourse (**Reach GCT-1**). An erosion threshold was determined from the field assessment data and was expressed as a critical discharge of 0.117 m^3/s. Maintaining a post-development flow regime that exceeds this threshold discharge at similar frequencies and magnitudes to the existing conditions will help preserve the function and stability of the receiving watercourse. Due to the historical differences in drainage area, the unitary erosion threshold of 0.0274 $m^3/s/ha$ is considered large and should not be used for SWM planning purposes outside of the subject lands.

A post- to pre-development comparison of erosion indices was completed using the hydrological modelling provided by R.V. Anderson Associates Limited (2021) and the erosion threshold determined for **Reach GCT-1**. While the applicability of this approach was limited by the historical truncation of the drainage area, the results indicated that no exacerbated rates of erosion are expected within **Reach GCT-1** as a consequence of the development. The channel within **GCT-1** is expected to maintain its current geomorphological regime in the post-development condition. Thus, no additional modifications to the proposed SWM plan are recommended.

An erosion hazard assessment was completed for Reaches **GCT-1** and **GC-3**, adjacent to the proposed development. As these reaches are treed ravines that are confined, the erosion hazard can be delineated following MNR (2002) guidelines. A 5 m toe erosion allowance is recommended for **Reach GCT-1** as it has banks composed of clay/silt. A 2 m toe erosion allowance is recommended for **Reach GC-1** as exposed shale was observed in the channel banks, which will act to limit erosion at the bank toe. These recommendations should be considered in conjunction with the geotechnical study prepared under separate cover by B.I.G. Consulting Inc.

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
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Senior Environmental Scientist

John Tweedie, M.Sc.
Environmental Scientist

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Appendix A
Reach Delineation

Legend

GC-2 Reach Breaks and Label
Watercourse
Piped
Detailed Assessment Extent
Contour (0.25 m)
Pond
Study Area

Delmanor West Oak Inc.

Study Area and Reach Delineation

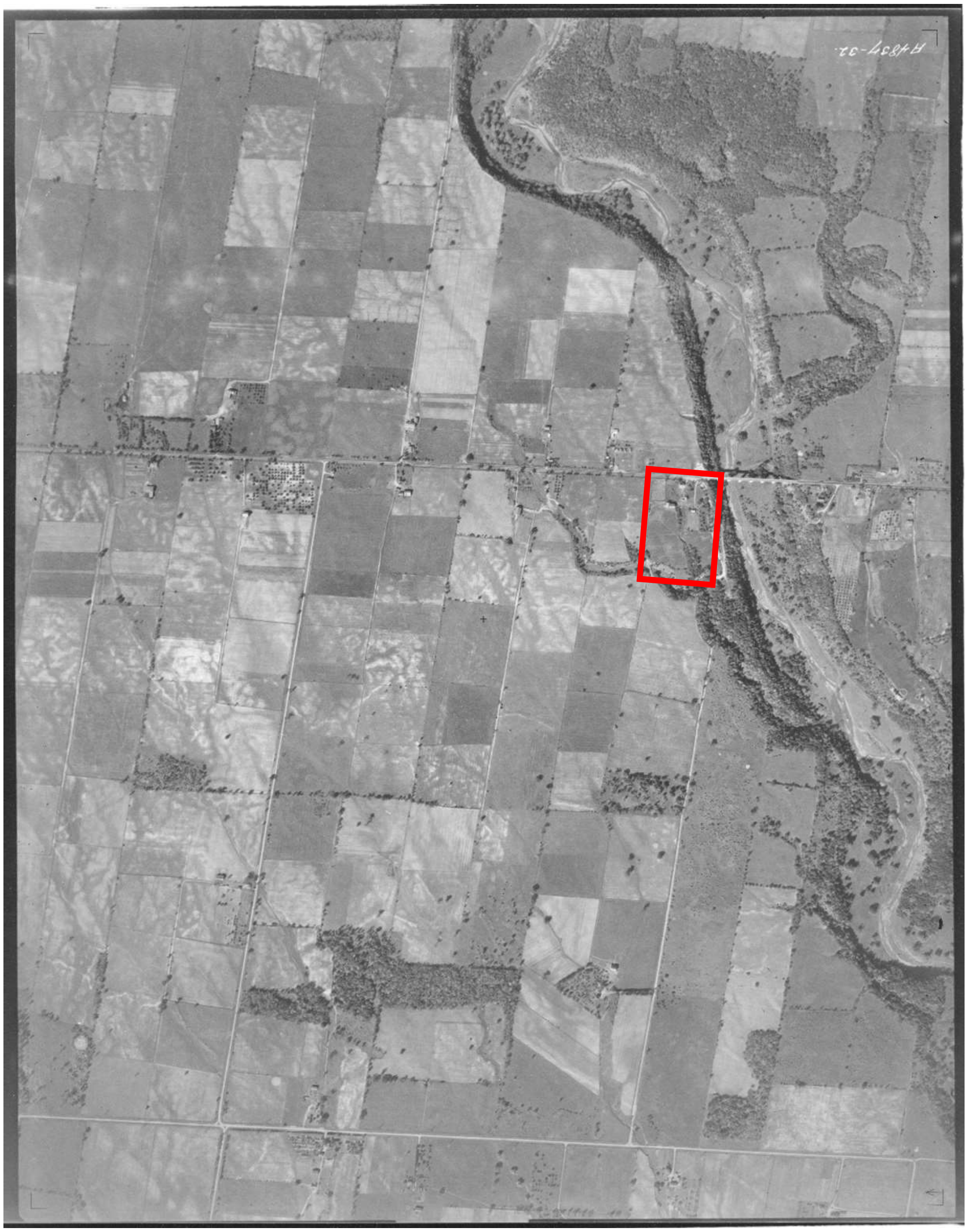
Oakville, Ontario

N
0 20 40
Metres

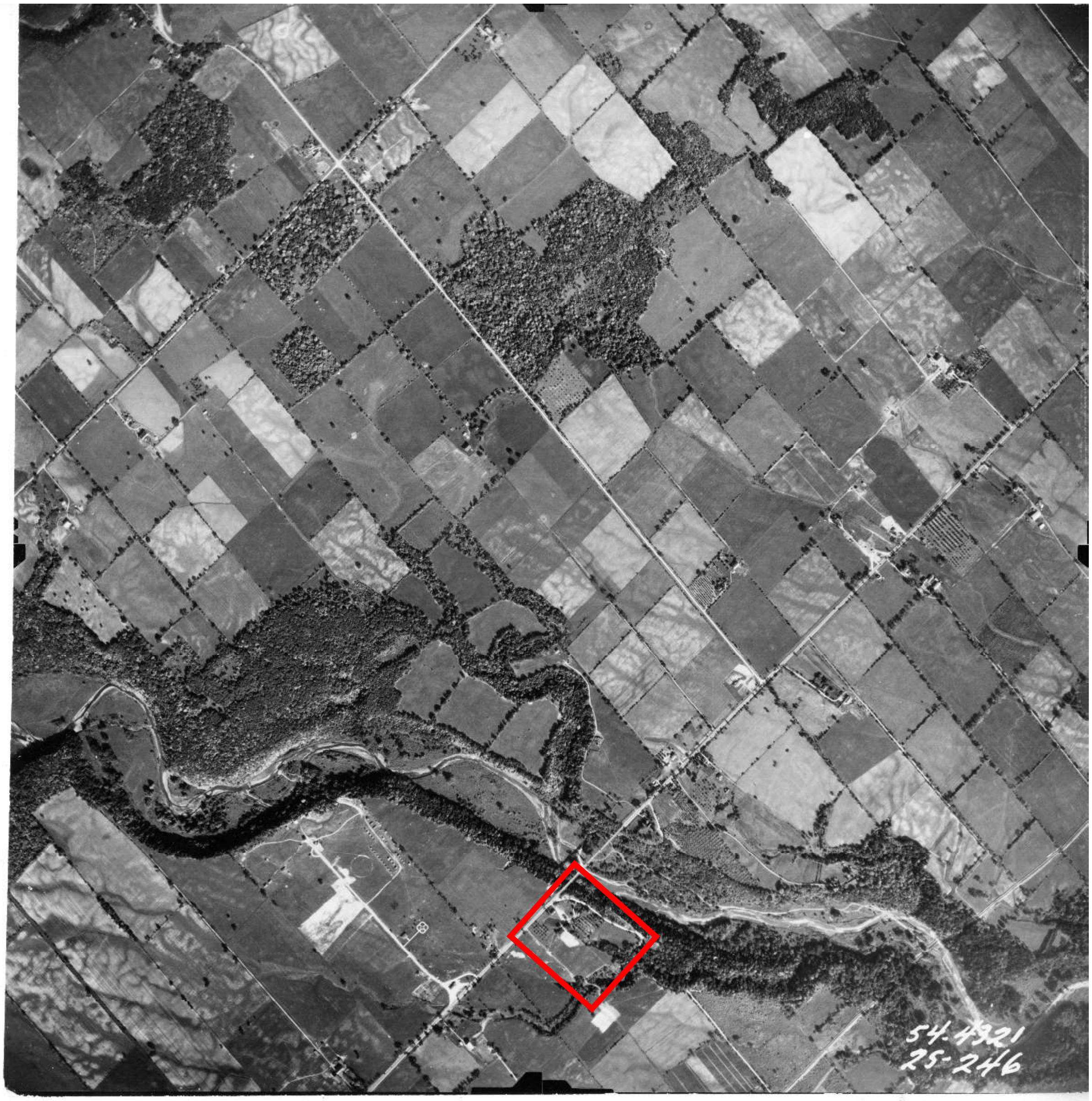
GEO MORPHIX™

Imagery: Town of Oakville, 2017.
Watercourse: Town of Oakville, 2020/GEO Morphix Ltd., 2021.
Culvert, Reach Break, Detailed Assessment, Pond: GEO Morphix Ltd., 2021.
Contour: JD Barnes, 2020.
Study Area: GEO Morphix Ltd., 2021.
Print Date: September 2021. PN21077. Drawn By: M.O., J.T., S.S.

Appendix B
Historical Aerial Imagery



Location: 1280 Dundas St W, Oakville, ON
Year: 1934
Scale: 1:20:000
Source: Ministry of Natural Resources



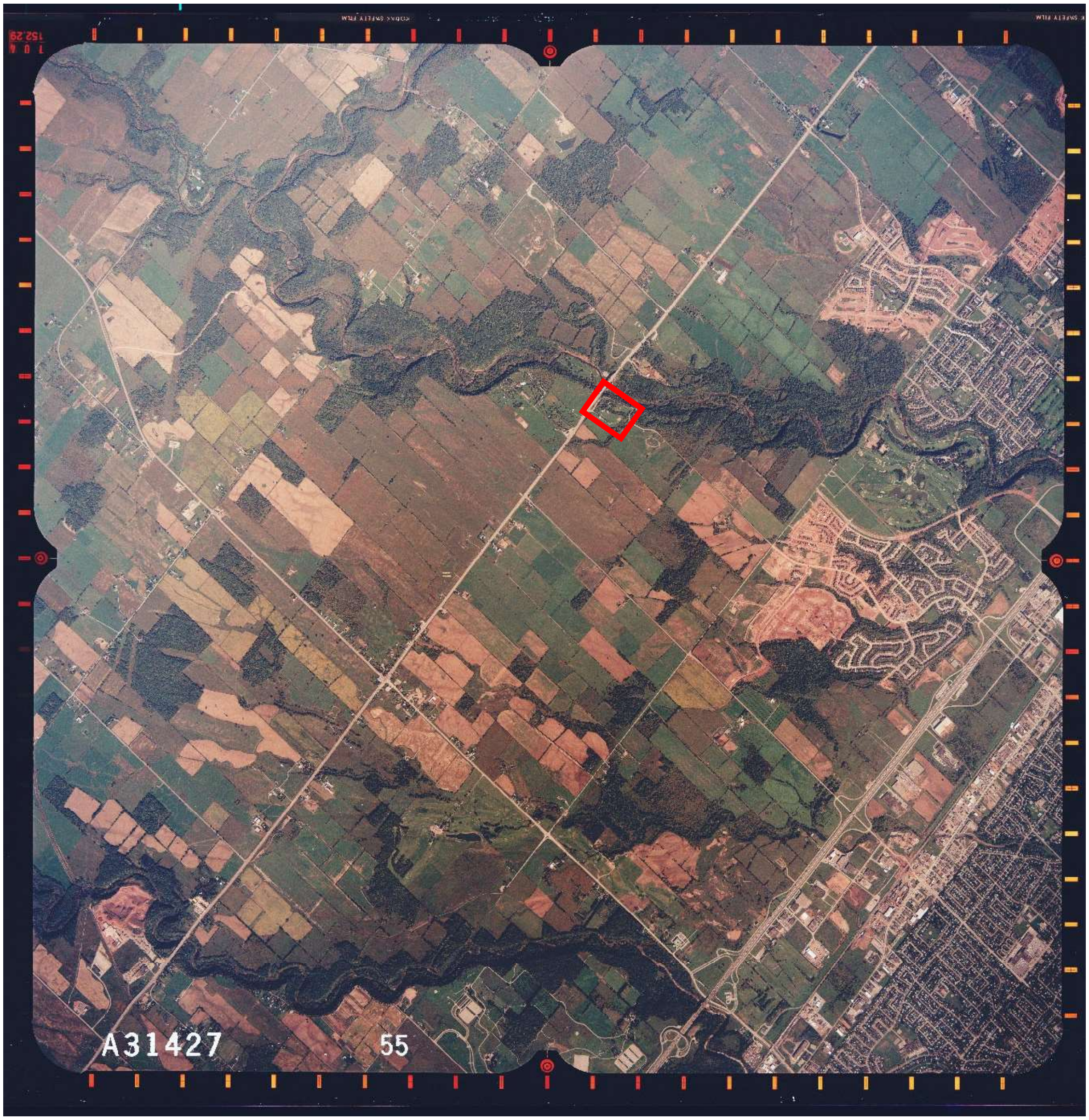
Location: 1280 Dundas St W, Oakville, ON
Year: 1954
Scale: 1:15,840
Source: Ministry of Natural Resources

Location: 1280 Dundas St W, Oakville, ON
Year: 1954
Scale: 1:15,840
Source: Ministry of Natural Resources

Location: 1280 Dundas St W, Oakville, ON
Year: 1965
Scale: 1:20,000
Source: National Air Photo Library

Location: 1280 Dundas St W, Oakville, ON
Year: 1974
Scale: 1:25,000
Source: National Air Photo Library

Location: 1280 Dundas St W, Oakville, ON
Year: 1978
Scale: 1:10,000
Source: Ministry of Natural Resources



Location: 1280 Dundas St W, Oakville, ON
Year: 1985
Scale: 1:40,000
Source: National Air Photo Library

Appendix C
Photo Record

Photo 1

Reach GCT-1 – Tributary of Sixteen Mile Creek


2021-08-26

Upstream view towards the upstream extent of the ravine feature. The two culverts, left to right, were approximately 0.40 m and 0.30 m in diameter.

Photo 2

Reach GCT-1 – Tributary of Sixteen Mile Creek


2021-08-26

Photograph taken in the upper section of the reach looking downstream where the channel gained definition.

Photo 3

Reach GCT-1 – Tributary of Sixteen Mile Creek

The riparian buffer zone was 4 to 10 channel widths. Riparian vegetation was comprised of a mix of mature tree species. Leaning/fallen trees, indicated by the red circle were observed approximately every 50 meters in the channel.

Photo 4

Reach GCT-1 – Tributary of Sixteen Mile Creek

Photograph taken looking downstream. The reach consisted of riffles and bed materials consisted primarily of cobble embedded by clay and silt. No shale bedrock was exposed in the channel bed or banks.

Photo 5

Reach GCT-1 – Tributary of Sixteen Mile Creek

2021-08-26

Downstream view of the watercourse. The reach was dry at the time of assessment. Average bankfull width and depth were 3.08 m and 0.24 m, respectively.

Photo 6

Reach GCT-1 – Tributary of Sixteen Mile Creek

2021-08-26

Photo taken at the downstream extent of reach, facing downstream. The culvert connected to Reach GC2 and was approximately 0.5 m in diameter.

Photo 7
Reach GC-3 – Tributary of Sixteen Mile Creek

Flows exited the culvert south of Glenayr Gate into a stone treatment. No scour was noted downstream of the outlet.

Photo 8
Reach GC-3 – Tributary of Sixteen Mile Creek

Reach **GC-3** was characterized as a narrow, confined, forested valley with a high gradient.

Photo 9
Reach GC-3 – Tributary of Sixteen Mile Creek


2020-11-02

Several instances of valley wall contact and erosion were noted in **Reach GC-3**.

Photo 10
Reach GC-3 – Tributary of Sixteen Mile Creek


2020-11-02

Exposed parent-material, Queenston shale, was frequently observed along the channel banks.

Photo 11

Reach GC-3 – Tributary of Sixteen Mile Creek


2020-11-02

Mature tree roots were commonly exposed on the banks. Substrate was coarse and consisted of platy pebbles and cobbles derived from the shale material.

Photo 12

Reach GC-3 – Tributary of Sixteen Mile Creek


2020-11-02

The meandering planform was constricted by the narrow valley corridor. Valley wall slopes were steep but well vegetated with mature trees. Grasses were largely absent.

Appendix D
Field Observations

Reach Characteristics Key

Table 1 Land Use

1. Forest
2. Pasture
3. Agricultural
4. Industrial
5. Park
6. Institutional
7. Residential
8. Golf Course
9. Commercial

Table 2 Valley Type

1. Unconfined
2. Confined
3. Partially Confined

Table 3 Channel Type

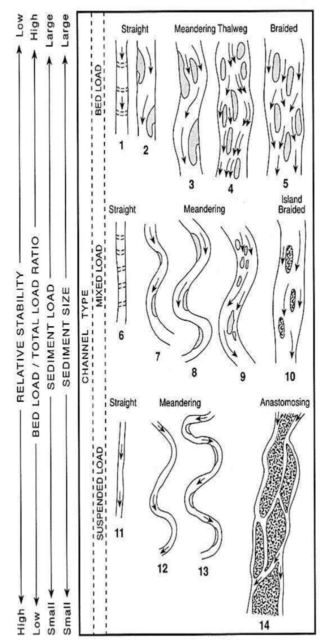


Table 4 Channel Zone

1. Headwater zone
2. Transfer zone
3. Deposition zone

Table 5 Flow Type

1. Perennial
2. Intermittent
3. Ephemeral

Table 6 Dominant Vegetation Type

1. Trees
2. Shrubs
3. Grasses
4. Herbaceous

Table 7 Extent of Encroachment into Channel

1. None
2. Minimal
3. Moderate
4. Heavy
5. Extreme

Table 8 Type of Aquatic Vegetation

1. Rooted Emergent
2. Rooted Submergent
3. Rooted Floating
4. Free Floating Roots
5. Floating Algae
6. Attached Algae

Table 9 Type of Sinuosity

1. Sinuous
2. Irregular Meanders
3. Regular Meanders
4. Tortuous Meanders
5. Confined pattern (within valley)

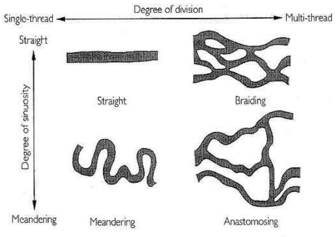


Table 10 Degree of Sinuosity

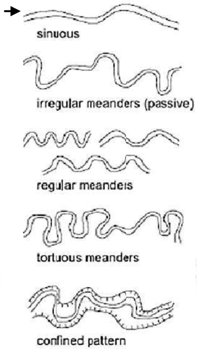
1. Straight (1 – 1.05)
2. Low sinuosity (1.06–1.30)
3. Meandering (1.31 - 3.0)

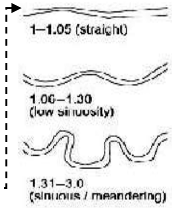
Table 11 Gradient

1. Low
2. Moderate
3. High

Table 12 Number of Channels

1. Single
2. Up to 3 (Wandering)
3. >3 (Braided)
4. >3 (Anastomosing or Anabranching)
5. Discontinuous or Absent





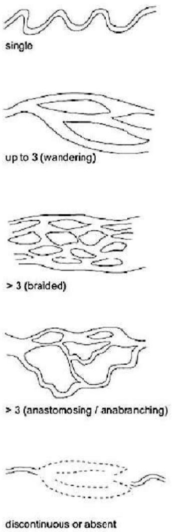


Table 13 Entrenchment

1. Low (>2.2)
2. Moderate (1.4 – 2.2)
3. High (<1.4)

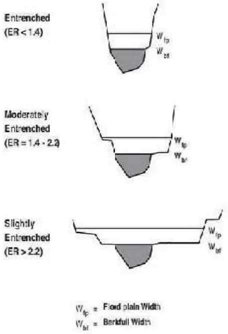
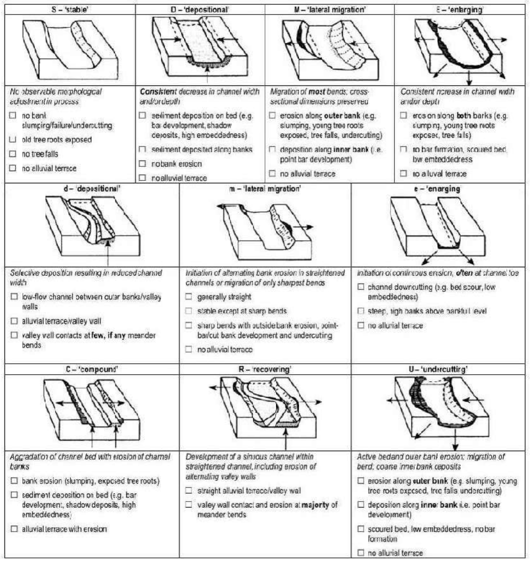


Table 14 Type of Bank Failure

1. Fluvial Entrainment (Hydraulic action)
2. Undercutting (Hydraulic action)
3. Slab Failure (Mass failure)
4. Parallel slide (Mass failure)
5. Fall/Sloughing (Mass failure)
6. Rotational slip and slump (Mass failure)

Table 15 Downs's Model of Channel Classification

S – Stable
D or d – Depositional
M or m – Lateral Migration
E or e – Enlarging
C – Compound
R – Recovering
U – Undercutting



S – 'stable'

No observable morphological adjustment in process

- ☐ no bank slumping/failure/undercutting
- ☐ old tree roots exposed
- ☐ no tree falls
- ☐ no alluvial terrace

D – 'depositional'

Consistent decrease in channel width and/or depth

- ☐ sediment deposition on bed (e.g. bar development, shadow deposits, high embeddedness)
- ☐ sediment deposited along banks
- ☐ no bank erosion
- ☐ no alluvial terrace

M – 'lateral migration'

*Migration of **most** bends; cross-sectional dimensions preserved*

- ☐ erosion along **outer bank** (e.g. slumping, young tree roots exposed, tree falls, undercutting)
- ☐ deposition along **inner bank** (i.e. point bar development)
- ☐ no alluvial terrace

E – 'enlarging'

Consistent increase in channel width and/or depth

- ☐ erosion along **both** banks (e.g. slumping, young tree roots exposed, tree falls)
- ☐ no bar formation, scoured bed, low embeddedness
- ☐ no alluvial terrace

d – 'depositional'

Selective deposition resulting in reduced channel width

- ☐ low-flow channel between outer banks/valley walls
- ☐ alluvial terrace/valley wall
- ☐ valley wall contacts at **few, if any** meander bends

m – 'lateral migration'

Initiation of alternating bank erosion in straightened channels or migration of only sharpest bends

- ☐ generally straight
- ☐ stable except at sharp bends
- ☐ sharp bends with outside bank erosion, point-bar/cut bank development and undercutting
- ☐ no alluvial terrace

e – 'enlarging'

*Initiation of continuous erosion, **often** at channel toe*

- ☐ channel downcutting (e.g. bed scour, low embeddedness)
- ☐ steep, high banks above bankfull level
- ☐ no alluvial terrace

C – 'compound'

Aggradation of channel bed with erosion of channel banks

- ☐ bank erosion (slumping, exposed tree roots)
- ☐ sediment deposition on bed (e.g. bar development, shadow deposits, high embeddedness)
- ☐ alluvial terrace with erosion

R – 'recovering'

Development of a sinuous channel within straightened channel, including erosion of alternating valley walls

- ☐ straight alluvial terrace/valley wall
- ☐ valley wall contact and erosion at **majority** of meander bends

U – 'undercutting'

Active bed and outer bank erosion; migration of bend; coarse inner bank deposits

- ☐ erosion along **outer bank** (e.g. slumping, young tree roots exposed, tree falls undercutting)
- ☐ deposition along **inner bank** i.e. point bar development)
- ☐ scoured bed, low embeddedness, no bar formation
- ☐ no alluvial terrace

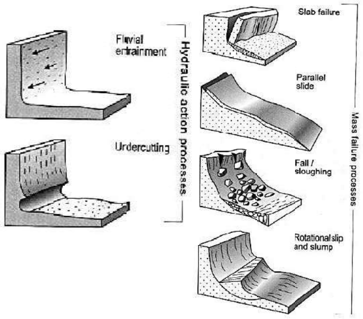


Table 16 Odours

1. None
2. Fishy
3. Petroleum
4. Sewage
5. Chemical
6. Other

Table 17 Turbidity

1. Clear
2. Slightly turbid
3. Turbid
4. Opaque
5. Stained
6. Other

GEO | MORPHIX
Geomorphology
Earth Science
Observations

Reach Characteristics

Project Code: PN21077

Date:	08-26-2021	**Stream/Reach:**	GCT1 (Ravine Feature)
Weather:	Sunny, 38°C	**Location:**	Oakville
Field Staff:	JT + DV	**Watershed/Subwatershed:**	16MC
UTM (Upstream)	4812314.48, 601045.40	**UTM (Downstream)**	4812277.31, 601181.74

Land Use (Table 1): 1
Valley Type (Table 2): 2
Channel Type (Table 3): 8
Channel Zone (Table 4): 2
Flow Type (Table 5): 2
☐ Groundwater
Evidence: N/A

Riparian Vegetation

Dominant Type: (Table 6): 1
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): 3

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: 4

Water Quality

Odour (Table 16): 1
Turbidity (Table 17): N/A

Channel Characteristics

Sinuosity (Type) (Table 9): 2
Sinuosity (Degree) (Table 10): 3
Gradient (Table 11): 2
Number of Channels (Table 12): 1
Entrenchment (Table 13): 3
Type of Bank Failure (Table 14): 1
Downs's Classification (Table 15): R

	Clay/Silt	Sand	Gravel	Cobble	Boulder	Parent	Rootlets
Riffle Substrate	☒	☐	☐	☒	☐	☐	☐
N/A **Pool Substrate**	☐	☐	☐	☐	☐	☐	☐
Bank Material	☒	☐	☐	☐	☐	☐	☐

Bankfull Width (m)	2.33	3.27	2.98	**Wetted Width (m)**	N/A	N/A	N/A
Bankfull Depth (m)	0.22	0.19	0.24	**Wetted Depth (m)**	N/A	N/A	N/A

Riffle/Pool Spacing (m) N/A **% Riffles:** 80 **% Pools:** N/A **Meander Amplitude:** N/A

Pool Depth (m) N/A **Riffle Length (m)** 15 **Undercuts (m)** N/A

Velocity (m/s) N/A N/A N/A **Wiffle ball / ADV / Estimated**

Comments: Channel predominantly made of riffles

Bank Angle
☐ 0 – 30
☒ 30 – 60
☒ 60 – 90
☐ Undercut

Bank Erosion
☐ < 5%
☒ 5 – 30%
☐ 30 – 60%
☐ 60 – 100%

Notes: Channel dry at time of assessment, confined valley, no shale exposed, vegetation present on bed of channel.

Completed by: DV
Checked by: ____

GEO | MORPHIX

Rapid Geomorphic Assessment **Project Code:** PN21077

Date:	2021-08-26	**Stream/Reach:**	Ravine Feature
Weather:	Sunny, 38°C	**Location:**	Oakville
Field Staff:	JT + DV	**Watershed/Subwatershed:**	16 MC

Process	Geomorphic Indicator		Present?		Factor Value
	No.	Description	Yes	No	
Evidence of Aggradation (AI)	1	Lobate bar		X	3/7
	2	Coarse materials in riffles embedded	X		
	3	Siltation in pools	X		
	4	Medial bars		X	
	5	Accretion on point bars		X	
	6	Poor longitudinal sorting of bed materials	X		
	7	Deposition in the overbank zone		X	
		Sum of indices =			0.43

Evidence of Degradation (DI)	1	Exposed bridge footing(s)	N/A		0/7
	2	Exposed sanitary / storm sewer / pipeline / etc.	N/A		
	3	Elevated storm sewer outfall(s)		X	
	4	Undermined gabion baskets / concrete aprons / etc.	N/A		
	5	Scour pools downstream of culverts / storm sewer outlets		X	
	6	Cut face on bar forms		X	
	7	Head cutting due to knick point migration		X	
	8	Terrace cut through older bar material		X	
	9	Suspended armour layer visible in bank		X	
	10	Channel worn into undisturbed overburden / bedrock		X	
		Sum of indices =			0

Evidence of Widening (WI)	1	Fallen / leaning trees / fence posts / etc.	X		3/7
	2	Occurrence of large organic debris	X		
	3	Exposed tree roots	X		
	4	Basal scour on inside meander bends		X	
	5	Basal scour on both sides of channel through riffle		X	
	6	Outflanked gabion baskets / concrete walls / etc.		X	
	7	Length of basal scour >50% through subject reach	N/A		
	8	Exposed length of previously buried pipe / cable / etc.	N/A		
	9	Fracture lines along top of bank		X	
	10	Exposed building foundation	N/A		
		Sum of indices =			0.43

Evidence of Planimetric Form Adjustment (PI)	1	Formation of chute(s)		X	2/7
	2	Single thread channel to multiple channel		X	
	3	Evolution of pool-riffle form to low bed relief form	X		
	4	Cut-off channel(s)		X	
	5	Formation of island(s)		X	
	6	Thalweg alignment out of phase with meander form		X	
	7	Bar forms poorly formed / reworked / removed	X		
		Sum of indices =			0.29

Additional notes:

Stability Index (SI) = (AI+DI+WI+PI)/4 =			0.28
Condition	**In Regime**	**In Transition/Stress**	**In Adjustment**
SI score =	☐ **0.00 - 0.20**	☑ **0.21 - 0.40**	☐ **0.41**

Completed by: DV Checked by: ________

GEO | M O R P H I X
Geomorphology
Earth Science
Observations

Reach Characteristics

Project Code/Phase: PN20048

Date:	2020-11-02	**Stream/Reach:**	GC-3
Weather:	SUNNY 4°C	**Location:**	OAKVILLE
Field staff:	BB JV	**Watershed/Subwatershed:**	16 MC
UTM (Upstream)		**UTM (Downstream)**	

CEMETERY
DS HALF

Land Use (Table 1): 7
Valley Type (Table 2): 2
Channel Type (Table 3): 9
Channel Zone (Table 4): 2
Flow Type (Table 5): 1
☐ Groundwater
Evidence: ____________

Riparian Vegetation

Dominant Type: (Table 6): 1
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): 3

Aquatic/Instream Vegetation

Type (Table8): 1
Coverage of Reach (%): <5

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

Density of WD:
☐ Low
☐ Moderate
☑ High

WDJ/50m: 5

Water Quality

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

Channel Characteristics

Sinuosity (Type) (Table 9): 2-3
Sinuosity (Degree) (Table 10): 5
Gradient (Table 11): 2
Number of Channels (Table 12): 1
Entrenchment (Table 13): 1
Type of Bank Failure (Table 14): 2
Downs's Classification (Table 15): U

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

	1	2	3		1	2	3
Bankfull Width (m)	3.60	0.69	4.30	**Wetted Width (m)**	1.88	0.60	0.64
Bankfull Depth (m)	0.50	0.25	0.40	**Wetted Depth (m)**	0.10	0.05	0.02

Riffle/Pool Spacing (m): \
% Riffles: 40
% Pools: 20
Meander Amplitude: \
Pool Depth (m) 0.26
Riffle Length (m) ~4.5
Undercuts (m) 0.45
Comments: ____________
Velocity (m/s) 0 | 0 | 0 Wiffle ball / ADV / [✓ Estimated]

STANDING WATER

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

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

Notes:

BF 4 MEASUREMENT
→ BF W = 4.68 m
D = 0.50 m
W W = 2.53 m
D = 0.03 m
V = 0 m/s

Completed by: BB
Checked by: ____________

GEO | MORPHIX

Rapid Geomorphic Assessment **Project Code:** PN20048

Date:	2020-11-02	**Stream/Reach:**	GC-3
Weather:	SUNNY 4°C	**Location:**	OAKVILLE
Field Staff:	BB JV	**Watershed/Subwatershed:**	16MC

Process	Geomorphic Indicator		Present?		Factor Value
	No.	Description	Yes	No	
Evidence of Aggradation (AI)	1	Lobate bar		✓	1/7
	2	Coarse materials in riffles embedded		✓	
	3	Siltation in pools	✓		
	4	Medial bars		✓	
	5	Accretion on point bars		✓	
	6	Poor longitudinal sorting of bed materials		✓	
	7	Deposition in the overbank zone		✓	
		Sum of indices =	1	6	0.14
Evidence of Degradation (DI)	1	Exposed bridge footing(s)	✓		2/8
	2	Exposed sanitary / storm sewer / pipeline / etc.	N/A		
	3	Elevated storm sewer outfall(s)		✓	
	4	Undermined gabion baskets / concrete aprons / etc.	N/A		
	5	Scour pools downstream of culverts / storm sewer outlets		✓	
	6	Cut face on bar forms		✓	
	7	Head cutting due to knick point migration		✓	
	8	Terrace cut through older bar material		✓	
	9	Suspended armour layer visible in bank		✓	
	10	Channel worn into undisturbed overburden / bedrock	✓		
		Sum of indices =	2	6	0.25
Evidence of Widening (WI)	1	Fallen / leaning trees / fence posts / etc.	✓		5/7
	2	Occurrence of large organic debris	✓		
	3	Exposed tree roots	✓		
	4	Basal scour on inside meander bends		✓	
	5	Basal scour on both sides of channel through riffle	✓		
	6	Outflanked gabion baskets / concrete walls / etc.	N/A		
	7	Length of basal scour >50% through subject reach	✓		
	8	Exposed length of previously buried pipe / cable / etc.	N/A		
	9	Fracture lines along top of bank		✓	
	10	Exposed building foundation	N/A		
		Sum of indices =	5	2	0.71
Evidence of Planimetric Form Adjustment (PI)	1	Formation of chute(s)	✓		3/7
	2	Single thread channel to multiple channel		✓	
	3	Evolution of pool-riffle form to low bed relief form		✓	
	4	Cut-off channel(s)		✓	
	5	Formation of island(s)		✓	
	6	Thalweg alignment out of phase with meander form	✓		
	7	Bar forms poorly formed / reworked / removed	✓		
		Sum of indices =	3	4	0.43

Additional notes:

Stability Index (SI) = (AI+DI+WI+PI)/4 =			0.38
Condition	**In Regime**	**In Transition/Stress**	**In Adjustment**
SI score =	☐ **0.00 - 0.20**	☑ **0.21 - 0.40**	☐ **0.41**

Completed by: BB Checked by: ________

Rapid Stream Assessment Technique

Project Code: PN20048

Date:	2020-11-02	**Stream/Reach:**	GC-3
Weather:	SUNNY 4°C	**Location:**	OAKVILLE
Field Staff:	BB JV	**Watershed/Subwatershed:**	16 MC

Evaluation Category	**Poor**	**Fair**	**Good**	**Excellent**
Channel Stability	[✓ • < 50% of bank network stable • Recent bank sloughing, slumping or failure frequently observed]	• 50-70% of bank network stable • Recent signs of bank sloughing, slumping or failure fairly common	• 71-80% of bank network stable • Infrequent signs of bank sloughing, slumping or failure	• > 80% of bank network stable • No evidence of bank sloughing, slumping or failure
	[✓ • Stream bend areas highly unstable • Outer bank height 1.2 m above stream bank (2.1 m above stream bank for large mainstem areas) • Bank overhang > 0.8-1.0 m]	• Stream bend areas unstable • Outer bank height 0.9-1.2 m above stream bank (1.5-2.1 m above stream bank for large mainstem areas) • Bank overhang 0.8-0.9m	• Stream bend areas stable • Outer bank height 0.6-0.9 m above stream bank (1.2-1.5 m above stream bank for large mainstem areas) • Bank overhang 0.6-0.8 m	• Stream bend areas very stable • Height < 0.6 m above stream (< 1.2 m above stream bank for large mainstem areas) • Bank overhang < 0.6 m
	• Young exposed tree roots abundant • > 6 recent large tree falls per stream mile	[✓ • Young exposed tree roots common • 4-5 recent large tree falls per stream mile]	• Exposed tree roots predominantly old and large, smaller young roots scarce • 2-3 recent large tree falls per stream mile	• Exposed tree roots old, large and woody • Generally 0-1 recent large tree falls per stream mile
	• Bottom 1/3 of bank is highly erodible material • Plant/soil matrix severely compromised	• Bottom 1/3 of bank is generally highly erodible material • Plant/soil matrix compromised	[✓ • Bottom 1/3 of bank is generally highly resistant plant/soil matrix or material]	• Bottom 1/3 of bank is generally highly resistant plant/soil matrix or material
	• Channel cross-section is generally trapezoidally-shaped	[✓ • Channel cross-section is generally trapezoidally-shaped]	• Channel cross-section is generally V- or U-shaped	• Channel cross-section is generally V- or U-shaped
Point range	☐ 0 ☐ 1 ☐ 2	☑ 3 ☐ 4 ☐ 5	☐ 6 ☐ 7 ☐ 8	☐ 9 ☐ 10 ☐ 11

Channel Scouring/ Sediment Deposition	• > 75% embedded (> 85% embedded for large mainstem areas)	• 50-75% embedded (60-85% embedded for large mainstem areas)	[✓ • 25-49% embedded (35-59% embedded for large mainstem areas)]	• Riffle embeddedness < 25% sand-silt (< 35% embedded for large mainstem areas)
	• Few, if any, deep pools • Pool substrate composition >81% sand-silt	[✓ • Low to moderate number of deep pools • Pool substrate composition 60-80% sand-silt]	• Moderate number of deep pools • Pool substrate composition 30-59% sand-silt	• High number of deep pools (> 61 cm deep) (> 122 cm deep for large mainstem areas) • Pool substrate composition <30% sand-silt
	• Streambed streak marks and/or "banana"-shaped sediment deposits common	• Streambed streak marks and/or "banana"-shaped sediment deposits common	• Streambed streak marks and/or "banana"-shaped sediment deposits uncommon	[✓ • Streambed streak marks and/or "banana"-shaped sediment deposits absent]
	• Fresh, large sand deposits very common in channel • Moderate to heavy sand deposition along major portion of overbank area	• Fresh, large sand deposits common in channel • Small localized areas of fresh sand deposits along top of low banks	• Fresh, large sand deposits uncommon in channel • Small localized areas of fresh sand deposits along top of low banks	[✓ • Fresh, large sand deposits rare or absent from channel • No evidence of fresh sediment deposition on overbank]
	• Point bars present at most stream bends, moderate to large and unstable with high amount of fresh sand	• Point bars common, moderate to large and unstable with high amount of fresh sand	• Point bars small and stable, well-vegetated and/or armoured with little or no fresh sand	[✓ • Point bars few, small and stable, well-vegetated and/or armoured with little or no fresh sand]
Point range	☐ 0 ☐ 1 ☐ 2	☐ 3 ☐ 4	☐ 5 ☑ 6	☐ 7 ☐ 8

Date:	2020-11-02	**Reach:**	GC-3	**Project Code:**	PN20048

Evaluation Category	**Poor**	**Fair**	**Good**	**Excellent**
Physical Instream Habitat	• Wetted perimeter < 40% of bottom channel width (< 45% for large mainstem areas)	• Wetted perimeter 40-60% of bottom channel width (45-65% for large mainstem areas)	[✓ • Wetted perimeter 61-85% of bottom channel width (66-90% for large mainstem areas)]	• Wetted perimeter > 85% of bottom channel width (> 90% for large mainstem areas)
	• Dominated by one habitat type (usually runs) and by one velocity and depth condition (slow and shallow) (for large mainstem areas, few riffles present, runs and pools dominant, velocity and depth diversity low)	[✓ • Few pools present, riffles and runs dominant. • Velocity and depth generally slow and shallow (for large mainstem areas, runs and pools dominant, velocity and depth diversity intermediate)]	• Good mix between riffles, runs and pools • Relatively diverse velocity and depth of flow	• Riffles, runs and pool habitat present • Diverse velocity and depth of flow present (i.e., slow, fast, shallow and deep water)
	• Riffle substrate composition: predominantly gravel with high amount of sand • < 5% cobble	• Riffle substrate composition: predominantly small cobble, gravel and sand • 5-24% cobble	[✓ • Riffle substrate composition: good mix of gravel, cobble, and rubble material • 25-49% cobble]	• Riffle substrate composition: cobble, gravel, rubble, boulder mix with little sand • > 50% cobble
	• Riffle depth < 10 cm for large mainstem areas	• Riffle depth 10-15 cm for large mainstem areas	[✓ • Riffle depth 15-20 cm for large mainstem areas]	• Riffle depth > 20 cm for large mainstem areas
	• Large pools generally < 30 cm deep (< 61 cm for large mainstem areas) and devoid of overhead cover/structure	[✓ • Large pools generally 30-46 cm deep (61-91 cm for large mainstem areas) with little or no overhead cover/structure]	• Large pools generally 46-61 cm deep (91-122 cm for large mainstem areas) with some overhead cover/structure	• Large pools generally > 61 cm deep (> 122 cm for large mainstem areas) with good overhead cover/structure
	• Extensive channel alteration and/or point bar formation/enlargement	• Moderate amount of channel alteration and/or moderate increase in point bar formation/enlargement	[✓ • Slight amount of channel alteration and/or slight increase in point bar formation/enlargement]	• No channel alteration or significant point bar formation/enlargement
	• Riffle/Pool ratio 0.49:1 ; ≥1.51:1	[✓ • Riffle/Pool ratio 0.5-0.69:1 ; 1.31-1.5:1]	• Riffle/Pool ratio 0.7-0.89:1 ; 1.11-1.3:1	• Riffle/Pool ratio 0.9-1.1:1
	• Summer afternoon water temperature > 27°C	• Summer afternoon water temperature 24-27°C N/A	• Summer afternoon water temperature 20-24°C	• Summer afternoon water temperature < 20°C
Point range	☐ 0 ☐ 1 ☐ 2	☐ 3 ☐ 4	☑ 5 ☐ 6	☐ 7 ☐ 8
Water Quality	• Substrate fouling level: High (> 50%)	• Substrate fouling level: Moderate (21-50%)	[✓ • Substrate fouling level: Very light (11-20%)]	• Substrate fouling level: Rock underside (0-10%)
	• Brown colour • TDS: > 150 mg/L	• Grey colour • TDS: 101-150 mg/L	• Slightly grey colour • TDS: 50-100 mg/L	[✓ • Clear flow • TDS: < 50 mg/L]
	• Objects visible to depth < 0.15m below surface	• Objects visible to depth 0.15-0.5m below surface	[✓ • Objects visible to depth 0.5-1.0m below surface]	• Objects visible to depth > 1.0m below surface
	• Moderate to strong organic odour	• Slight to moderate organic odour	[✓ • Slight organic odour]	• No odour
Point range	☐ 0 ☐ 1 ☐ 2	☐ 3 ☐ 4	☐ 5 ☑ 6	☐ 7 ☐ 8
Riparian Habitat Conditions	• Narrow riparian area of mostly non-woody vegetation	[✓ • Riparian area predominantly wooded but with major localized gaps]	• Forested buffer generally > 31 m wide along major portion of both banks	• Wide (> 60 m) mature forested buffer along both banks
	• Canopy coverage: <50% shading (30% for large mainstem areas)	[✓ • Canopy coverage: 50-60% shading (30-44% for large mainstem areas)]	• Canopy coverage: 60-79% shading (45-59% for large mainstem areas)	• Canopy coverage: >80% shading (> 60% for large mainstem areas)
Point range	☐ 0 ☐ 1	☐ 2 ☑ 3	☐ 4 ☐ 5	☐ 6 ☐ 7

Total overall score (0–42) = 23	**Poor (<13)**	[✓ **Fair (13-24)**]	**Good (25-34)**	**Excellent (>35)**

Completed by: BB Checked by: ________

Appendix E
Detailed Assessment Summary

Detailed Geomorphological Assessment Summary

Reach GCT1

Project Number:	PN21077	**Date:**	2021-08-26
Client:	Delmanor West Oak Inc.	**Length Surveyed (m):**	105.8
Location:	Oakville, ON	**# of Cross-Sections:**	8

Reach Characteristics

Drainage Area:	4.281	**Dominant Riparian Vegetation Type:**	Trees, herbaceous
Geology/Soils:	Clay to silt till, shale	**Extent of Riparian Cover:**	Continuos
Surrounding Land Use:	Residential	**Width of Riparian Cover:**	4-10 channel widths
Valley Type:	Confined	**Age Class of Riparian Vegetation:**	Mature
Dominant Instream Vegetation Type:	Herbaceous	**Extent of Encroachment into Channel:**	Minimal
Portion of Reach with Vegetation:	30	**Density of Woody Debris:**	Low

Hydrology

Measured Discharge (m^3/s):	0.00	**Calculated Bankfull Discharge (m^3/s):**	1.23
Modelled 2-year Discharge (m^3/s):	Not modelled	**Calculated Bankfull Velocity (m/s):**	1.64
Modelled 2-year Velocity (m/s):	Not modelled		

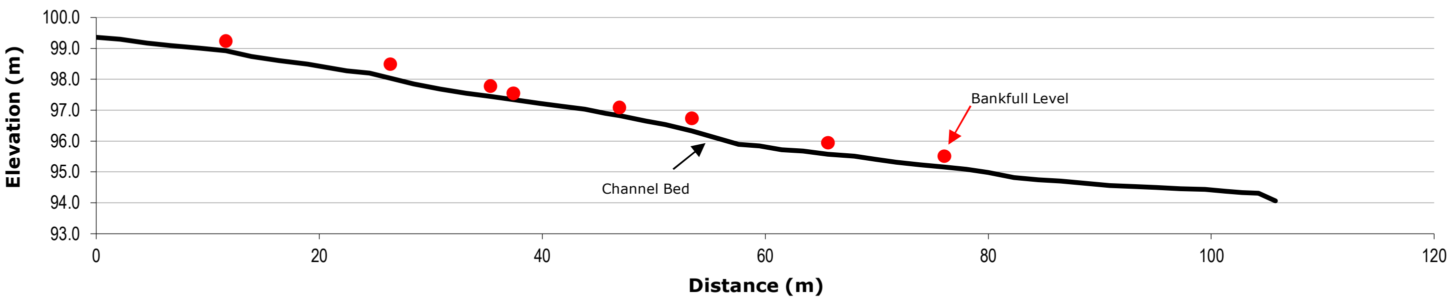
Profile Characteristics

Bankfull Gradient (%):	5.94
Channel Bed Gradient (%):	5.26
Riffle Gradient (%):	n/a
Riffle Length (m):	n/a
Riffle-Pool Spacing (m):	n/a

Planform Characteristics

Sinuosity:	1.32
Meander Belt Width (m):	Not measured
Radius of Curvature (m):	Not measured
Meander Amplitude (m):	Not measured
Meander wavelength (m):	Not measured

Longitudinal Profile



Bank Characteristics

	Minimum	Maximum	Average
Bank Height (m):	0.25	1.10	0.64
Bank Angle (deg):	0.6	90	58
Root Depth (m):	0.10	30.00	2.91
Root Density (%):	5	25	12
Bank Undercut (m):	0.05	0.06	0.06

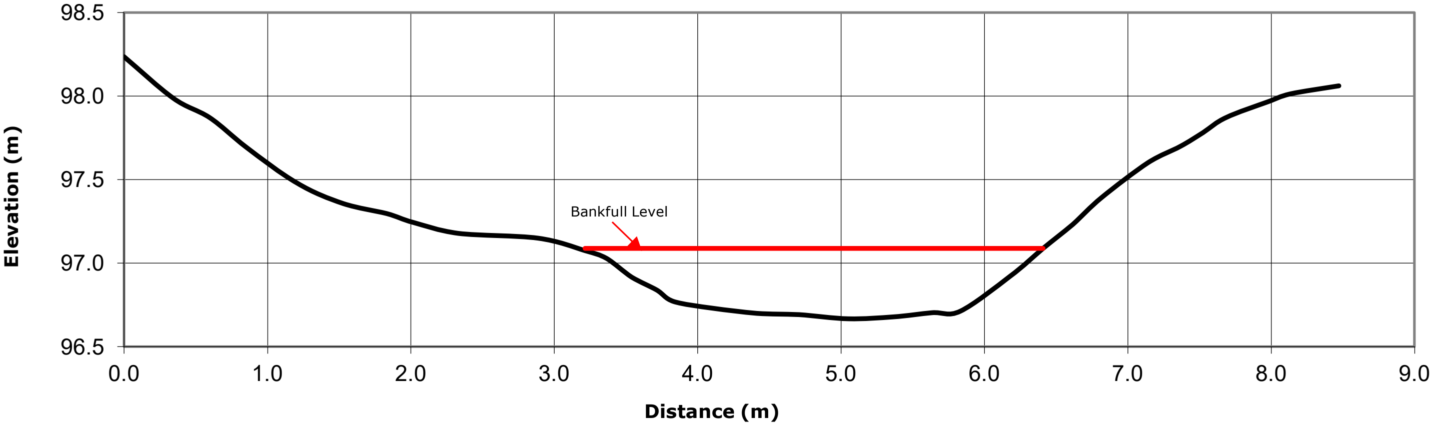
	Minimum	Maximum	Average
Torvane Value (kg/cm^2):		Not measured	
Penetrometer Value (kg/cm^3):		Not measured	
Bank Material (range):		Silty-clay loam, trace shale	

Cross-Sectional Characteristics

	Minimum	Maximum	Average
Bankfull Width (m):	2.33	3.50	3.08
Average Bankfull Depth (m):	0.19	0.32	0.24
Bankfull Width/Depth (m/m):	10	17	13
Wetted Width (m):	0.00	0.00	0.00
Average Water Depth (m):	0.00	0.00	0.00
Wetted Width/Depth (m/m):	n/a	n/a	n/a
Entrenchment (m):		Not measured	
Entrenchment Ratio (m/m):		Not measured	
Maximum Water Depth (m):	0.00	0.00	0.00
Manning's *n* :		0.058	

Photograph at cross section 5 (looking upstream)

Representative Cross-Section #5

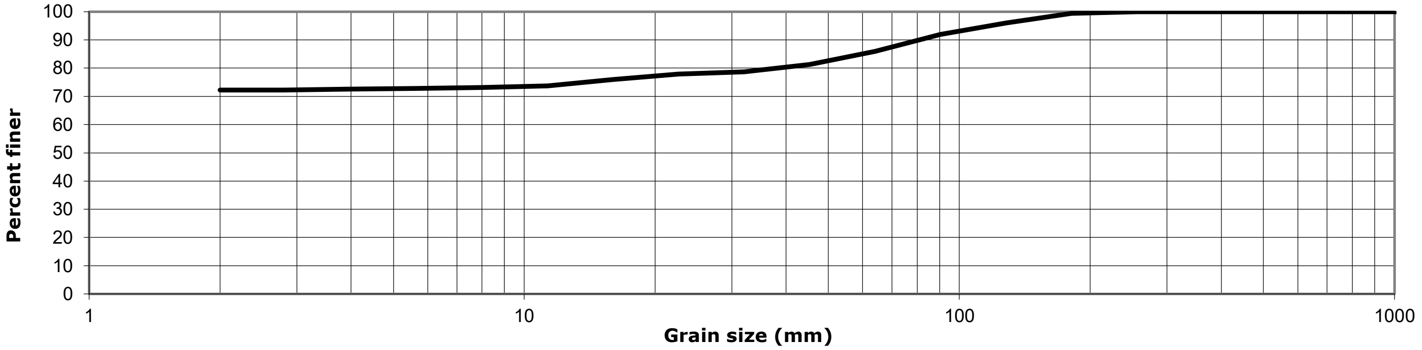


Substrate Characteristics

Particle Size (mm)	
D_{10} :	2.0
D_{50} :	2.0
D_{84} :	56.2

Subpavement:	Shale
Particle shape:	Sub-rounded, platy
Embeddedness (%):	20-60%
Particle range (riffle):	Silt to cobbles
Particle Range (pool):	Silt to gravel

Cumulative Particle Size Distribution



Channel Thresholds

Flow Competency (m/s):		**Tractive Force at Bankfull (N/m^2):**	142.34
for D_{50}:	0.27	**Tractive Force at 2-year flow (N/m^2):**	Not modelled
for D_{84}:	1.26	**Critical Shear Stress (D_{50}) (N/m^2):**	1.46
Unit Stream Power at Bankfull (W/m^2):	233.63		

General Field Observations

Channel Description

Reach GCT1 flows through the ravine central to the subject property. The channel follows a meandering planform, confined within the valley and making contact with the valley walls in several locations. Evidence of active erosion was minimal, with undercutting up to only 0.06 m noted at two cross-sections. The channel was dry during the time of assessment. The riparian zone is confined to the valley extent, and is characterized by mature trees. Approximately 30% of the channel bed was encroached by herbaceous and grassy vegetation. Average bankfull width and depth were 3.08 and 0.24 m, respectively. Bed substrate ranges from silt to platy cobbles, while the bank material is characterized as a silty-clay loam throughout.

Cross Section 6 - Facing Upstream

Appendix F
Hydrographs

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25 mm
event</td>
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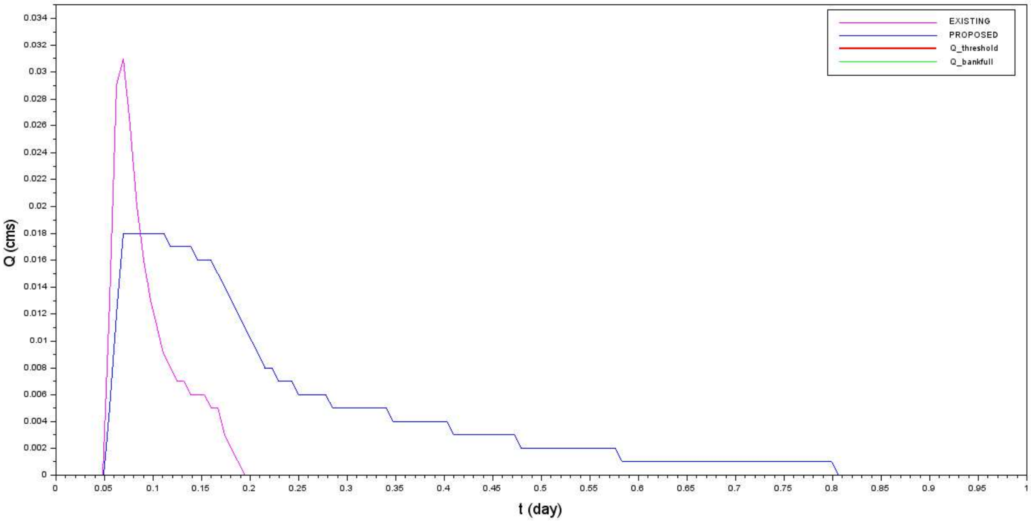

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2-year
event</td>
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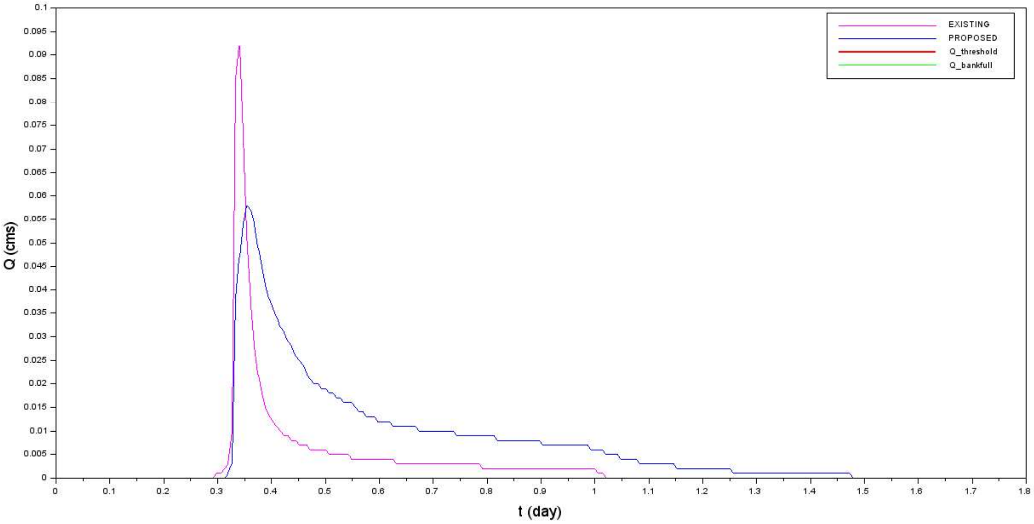

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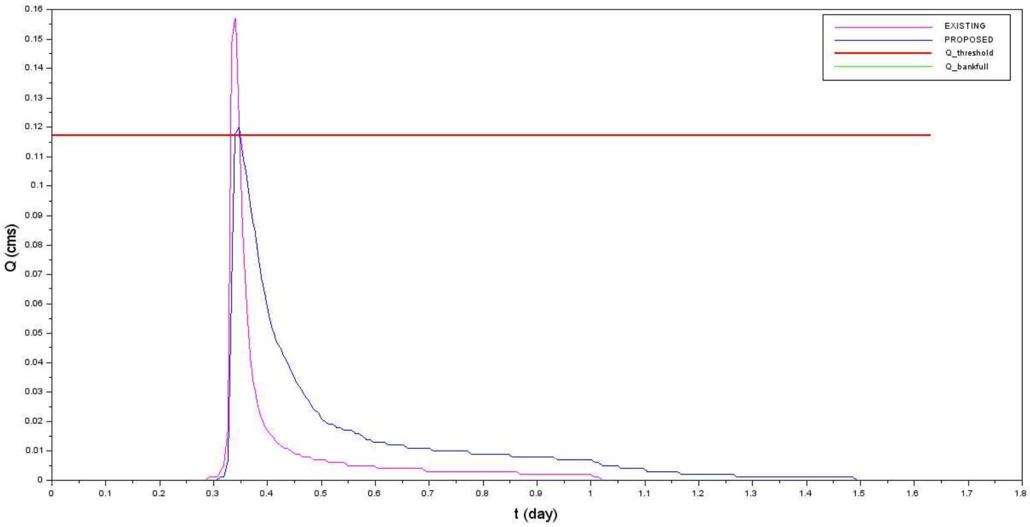
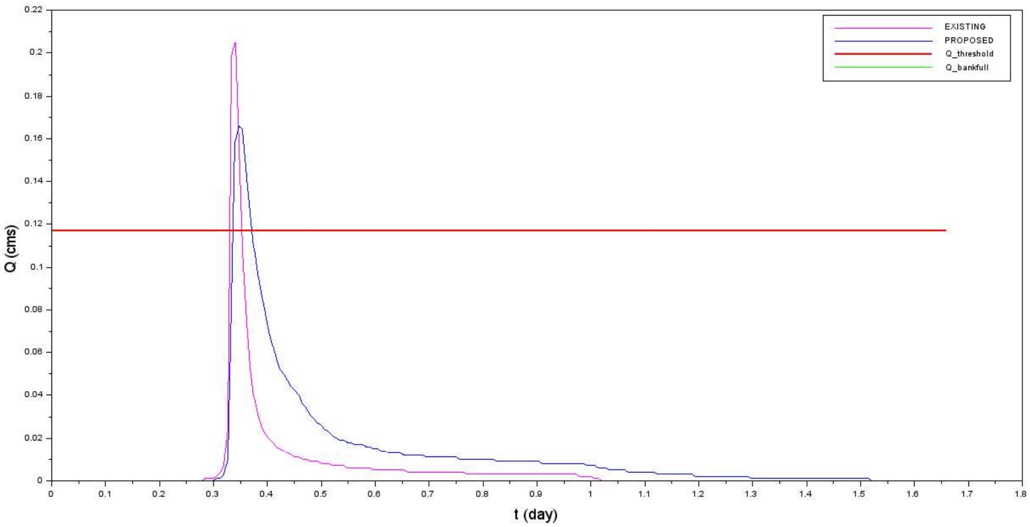
GCT-1 5-year event	
GCT-1 10-year event	

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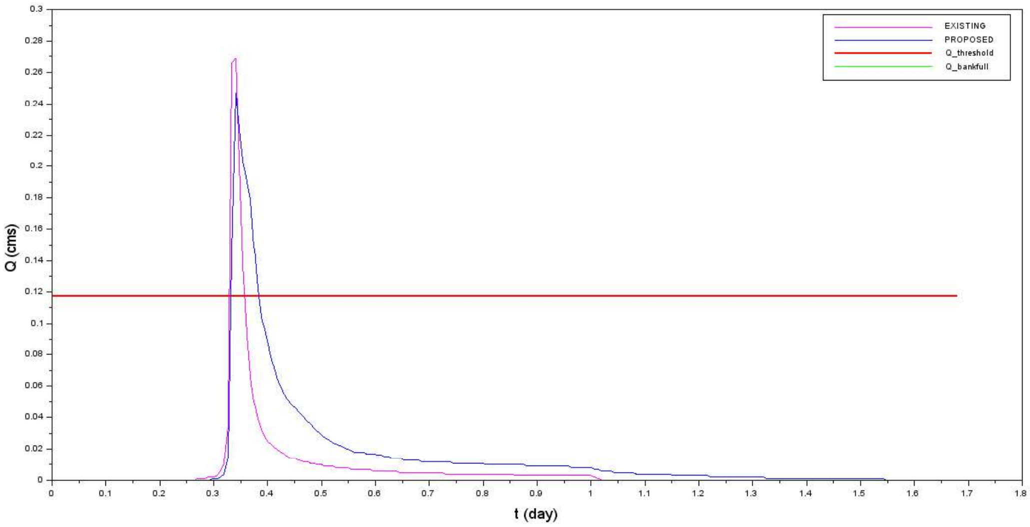

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50-year
event</td>
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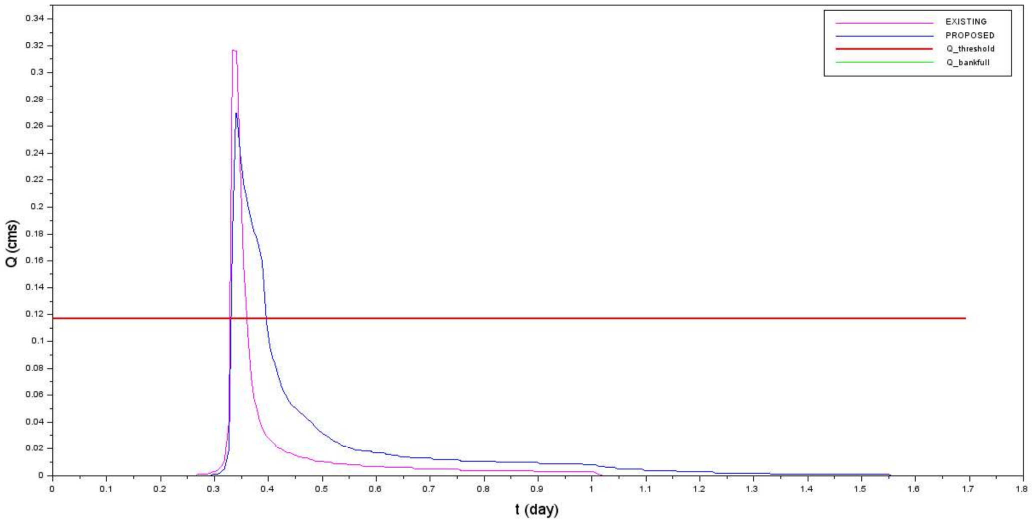

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GCT-1 100-year event