APPENDIX

L

GEOMORPHOLOGICAL REPORT

Geomorphological Report: Sixteen Mile Creek and Tributary NW-1-E

Steeles Avenue West, Municipal Class Environmental Assessment Study Town of Milton

Prepared for:
WSP
610 Chartwell Rd, Suite 300
Oakville, ON, L6J 4A5

April 27, 2022
Project No. PN18143a

GEO MORPHIX
Geomorphology
Earth Science
Observations

Report Prepared by:	GEO Morphix Ltd. 36 Main Street N. Campbellville, Ontario L0P 1B0
Report Title:	Geomorphological Report, Sixteen Mile Creek and Tributary NW-1-E, Steeles Avenue West MCEA, Milton
Project Number:	PN18143a
Status:	Final
Version:	2.0
First Submission Date:	September 10, 2021
Revision Date:	April 27, 2022
Prepared by:	Bryce Molder, M.Sc., P.Geo., CAN-CISEC
Approved by:	Paul Villard, Ph.D., P.Geo., CAN-CISEC, EP, CERP
Approval Date:	April 27, 2022

Table of Contents

List of Figures

List of Tables

Appendices

1 Introduction

A Municipal Class Environmental Assessment "MCEA" (Schedule C) led by WSP is underway to support transportation corridor improvements for Steeles Avenue, between Tremaine Road and Industrial Drive, in Milton, Ontario. The proposed improvements along Steeles Avenue will require the realignment and widening of the road at Sixteen Mile Creek and a tributary to Sixteen Mile Creek, denoted herein as **NW-1-E**. In addition, the Canadian National Railway (CNR) crossing of Sixteen Mile Creek was assessed for a complete understanding of geomorphology in the study area.

GEO Morphix Ltd. was retained by WSP to fulfill the geomorphological requirements of the MCEA within the study limits. This included completion of a geomorphological assessment to support proposed improvements to the Steeles Avenue West crossing over Sixteen Mile Creek, as well as the addition of a new crossing over the **NW-1-E** watercourse. The subject study limits and associated crossing locations are shown in **Figure 1**, for reference.

Figure 1: Steeles Avenue Municipal Class Environmental Assessment Study Limits (Google Earth Pro, 2018 Imagery)

Specifically, fluvial geomorphic input was required to assess the erosion hazard associated with Sixteen Mile Creek and **NW-1-E** in proximity to Steeles Avenue. The assessment involved an estimation of the lateral extent to which a channel has historically occupied and may likely occupy in the future. Such information is useful for informing crossing structure design (e.g., crossing location, orientation, and sizing), as the structure should accommodate for future adjustment to the channel's planimetric form. In support of the study, the following activities were completed

- A review of available background materials, including the Milton Heights Neighbourhood Subwatershed Impact Study (Beacon Environmental Ltd., 2014), and the Bronte Street MCEA – Sixteen Mile Creek Geomorphic Hazard Assessment (Geomorphic Solutions, 2012)

- A review of watershed characteristics that directly influence the local geomorphology
- A review of historical aerial imagery to determine past landuse changes and assess channel migration patterns
- Field investigation, including rapid field assessments to fully characterize the watercourse's existing form, evaluate channel stability, and determine stream 'health'
- Delineation of the channel meander belt width through a desktop review and verification through a modelling exercise
- Review of the existing and proposed crossing structures
- Identification of potential erosion hazards, and restoration opportunities within the channel

2 Background Review

2.1 Watershed Characteristics

Channel morphology and planform are largely governed by the flow regime and the availability and type of sediments (i.e., surficial geology) within the stream corridor. Physiography, riparian vegetation and land use also physically influence the channel. 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.

In the study area, Sixteen Mile Creek traverses through the Halton Till, which consists of a clayey silt till. The underlying bedrock consists of the Queenston Formation, which is predominantly a red fissile shale. The consolidated nature of these materials makes them generally resistant to erosion and therefore impact channel geomorphology. For example, channel migration or downcutting rates may therefore be inhibited by exposed deposits of till or bedrock located along the channel banks or beds.

The lands surrounding the study area have been extensively altered for agricultural purposes and to support land development. Changes include earth displacement (e.g., cutting and infilling) and watercourse modification. For instance, Sixteen Mile Creek displays evidence of channel straightening / bank armouring and valley alteration to accommodate the construction of Steeles Avenue and establishment of nearby residential and commercial lots. As the subwatershed becomes increasingly developed to support Milton's growing population, land modifications will contribute to changes in natural channel functioning. Typical catchment responses accompanying urbanization include more rapid flow conveyance following rainfall and increased potential for sediment exhaustion due to reduced availability of upstream sources. These factors generally contribute to channel instability.

2.2 Study Area History

A series of historical aerial images were reviewed to determine changes to surrounding lands as well as changes to channel planform. These changes were evaluated within the context of the larger watershed as 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. Aerial photographs from 1934, 1946, 1971, and satellite imagery from 2004, 2005, and 2013 - 2018 (Google Earth Pro) were reviewed to complete the historical assessment. Additionally, lower resolution imagery from 1978 was reviewed for general changes to landuse or adjustments in channel form.

Between 1934 and 1946, the surrounding landuse was predominantly agricultural in nature, with rural homes interspersed throughout the area. In the vicinity of Steeles Avenue, Sixteen Mile Creek intersected multiple farm fields. Naturally wooded / grassy sections of riparian buffer were narrow and characterized by localized gaps where farm fields extended to the channel top of bank. The creek followed a meandering planimetric form and was partially confined within a subtle valley (made evident by the lack of vegetative cover). Minor channel adjustments were observed throughout the period, including the outward progression of a meander bend situated immediately downstream of Steeles Avenue.

By 1978, residential lots were established along the west channel bank up- and downstream of Steeles Avenue. The lots were cleared and developed to the top of channel bank. Notably, an oxbow feature had formed where the channel avulsed through a particularly tight meander ~60 m downstream of the road. Beyond the feature, the channel appeared to have undergone a degree of realignment (e.g., straightening) as part of the lot development. Two pedestrian crossings were constructed over the realigned portion of channel. Upstream of Steeles Avenue, adjustments in channel form were difficult to evaluate due to the presence of vegetation which obscured the channel from view.

By 2004, a significant portion of the surrounding land to the east of the channel was developed. Land development included the addition of residential communities along Steeles Avenue and Peru Road, as well as the construction of Industrial Drive and the adjacent commercial lots. Additionally, the riparian area was further established with tree and shrub plantings, which augmented the canopy cover over the creek. The noted oxbow feature downstream of Steeles Avenue was partially overgrown with vegetation. The realigned channel maintained its general form. The only discernible difference in channel morphology was general widening.

Between 2004 and 2017 there were no significant changes in landuse or channel planimetric form, aside from minor variations in the wetland form east of Bronte Street. In late 2017, the widening of Steeles Avenue, immediately east of the Sixteen Mile Creek crossing was underway. The works included the construction of a SWM facility on the north side of the road. Overflow from the SWM facility was guided through a silt sock-inlaid drainage pathway along the road embankment to Sixteen Mile Creek.

In summary, Sixteen Mile Creek has undergone significant adjustments in planimetric form and general widening since 1934 in the vicinity of Steeles Avenue. This is evidenced by the presence of an overgrown oxbow feature located immediately downstream of Steeles Avenue. As a result, the channel was realigned in the 1970's to ensure stability. Over this time, landuse has changed from primarily agricultural practice to an increasingly urbanized setting. Finally, there was a noted increase in tree and shrub density throughout the valley corridor.

3 Geomorphic Assessment

3.1 Reach Delineation

Reaches are homogeneous segments of channel used in geomorphological investigations delineated based on changes in the channel's existing condition (e.g., channel planform, gradient, physiography, land cover, flow contributions, anthropogenic channel modifications, etc.). Reaches 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. This follows a scientifically defensible methodology proposed by Montgomery and Buffington (1997).

Reaches were first delineated as a desktop exercise using available data and information such as aerial photography, topographic maps, geology information and physiography maps. The results were then verified in the field. Within the study area, Two reaches were identified along **NW-1-E**, including one north and one south of Steeles Avenue. Three reaches were identified along the Sixteen Mile Creek. Reach **R1** (Sixteen Mile Creek) extends north of Steeles Avenue, with the Steeles Avenue crossing serving as a reach break. Reach **R2** extends south and east of Steeles Avenue to the CNR crossing over a distance of 415 m. Finally, **R3** extends east from the CNR. Channel reach extents match those identified by Geomorphic Solutions (2012) within the adjacent Bronte Street MCEA. The noted channel reaches are depicted in **Appendix A**.

3.2 Study Reach Characteristics

A geomorphic assessment of Sixteen Mile Creek and **NW-1-E** was carried out in the vicinity of Steeles Avenue on November 29th, 2018, to characterize current watercourse conditions to assist with informing crossing sizing and orientation, and to identify opportunities for restoration within the channels. Permission was not granted by the landowner to access **NW-1-E**, and as such the assessment of **NW-1-E** was limited to the road right-of-way. To support the general field observations, rapid stream assessments were completed to evaluate channel stability and stream health. Site photographs are provided in **Appendix B** and field notes are provided in **Appendix C**.

Sixteen Mile Creek

Field observations revealed a sinuous stream set within in a broad, expansive valley. North of Steeles Avenue, the channel hugged a residential / paved lot on the west side. The east floodplain was partly forested with localized gaps of open meadow. The dominant riparian vegetation consisted of dogwood and willow-type shrubs. South of Steeles Avenue, the channel intersected a lot occupied by the Milton Banquet Conference Centre. The immediate riparian area was wooded, although significant sections of the lot were groomed. The channel was partly-confined by the adjacent road and was observed to have encroached on the toe of the embankment slope near the CNR crossing.

The channel exhibited limited bed morphology. For instance, the channel was dominated by riffles and run features with fewer deep pools present. Bed substrates generally consisted of a range of gravels to boulders, which overlaid a bed of coarse sand. Intermittent stretches of till were observed where the bed materials had been scoured out. Bank materials consisted of a well-rooted cohesive loam with gravels. The channel exhibited several indicators corresponding to systematic adjustment, namely widening. Commonly observed indicators included exposed roots, leaning trees, and basal scouring. Channel widening processes were likely exacerbated by the presence of the relatively coarse substrates and erosion-resistant till on the channel bed, which would act to mitigate downcutting processes and redirect erosive forces towards the channel banks. Upstream of Steeles Avenue, channel bankfull width measurements ranged from 7.2 m to 14.0 m (average width = 10.0 m). Average bankfull depth was 0.88 m. Downstream of Steeles Avenue, channel bankfull width measurements ranged from 8.6 m to 15.1 m (average width = 10.4 m). Average bankfull depth was 0.94 m.

The Steeles Avenue crossing consisted of a 14.8 m concrete bridge structure, built in 1985. The crossing was partially degraded and undersized relative to the bankfull channel. For instance, the channel wetted width extended the full span of the crossing. The right bank leading up to the crossing was reinforced with a stone revetment. The opposite bank was vegetated and moderately stable. The right channel bank on the downstream side were gradually sloped, vegetated, and moderately stable. The left banks on both the upstream and downstream sides were relatively low-lying and therefore likely prone to flooding during rainfall events. Two additional pedestrian crossings, associated with the Milton Banquet and Conference property, were observed downstream of Steeles Avenue. The pedestrian crossings appeared dated with rotted logs and corroded rails. Erosion around the crossings and footings was limited.

The CNR crossing of Sixteen Mile Creek consisted of two 3 m by 4 m CSP culverts. The culverts were spaced several meters apart, forming a fork in the river. There was limited erosion around the culverts, although woody debris had collected between them at the head of the split in the river. The base of the culverts was partially embedded into the riverbed.

NW-1-E

The tributary **NW-1-E** was assessed within the Steeles Avenue right-of-way. At the time of the assessment, access onto the adjacent lands were not permitted. Upstream (south) of Steeles Avenue, **NW-1-E** flowed through a ~40 m wooded buffer set within an agricultural field. Channel conditions were not discernible from the road. At Steeles Avenue, **NW-1-E** veered east to follow the road embankment for approximately 50 m where it was then guided into a 750 mm corrugated plastic pipe (CPP) beneath the road. The roadside feature consisted of a swale, overgrown with emergent-type vegetation. The swale generally lacked a definitive form (e.g., no bankfull indicators) but was estimated to be around 2 m to 2.5 m in width. Downstream (north) of Steeles Avenue, the CPP pipe discharged into a small stone-lined plunge pool, which occupied the narrow space between the road and railway embankments. The plunge pool banks were supported with concrete and armourstone retaining walls that were eroded at the toe and in poor condition.

3.3 Rapid Geomorphological Assessments

Rapid Geomorphic Assessments were completed to generally evaluate channel stability and stream health for Sixteen Mile Creek. Channel instability was semi-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 (planform) adjustment. The index produces values that indicate whether the 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 and consider the ecological functioning 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 and the River Styles Framework (Brierley and Fryirs, 2005). The Downs Model describes successional stages of a channel as a result of 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 River Styles Framework (Brierley and Fryirs, 2005) provides a geomorphological approach to examining river character, behaviour, condition, and recovery potential.

A summary of the rapid assessment results is included in **Table 1**. Notably, the above reconnaissance level assessments were not applicable for **NW-1-E**, as it has undergone modification to function as a roadside ditch and did not exhibit a naturally meandering planimetric form in proximity to Steeles Avenue. The form and condition of **NW-1-E** should be reassessed within the adjacent lots once permission to enter the properties has been granted.

Table 1: Rapid Assessment Results

Reach	RGA (MOE, 2003)			RSAT (Galli, 1996)			Downs Channel Evolution Model (1995)
	Score	*Condition*	*Dominant Systematic Adjustment*	*Score*	*Condition*	*Limiting Features*	*Classification*
R1	0.21	In Transition	Widening, Planform adjustment	21	Fair	Instream habitat	"E" Enlarging
R2	0.27	In Transition	Widening, Planform adjustment	21	Fair	Instream habitat, Riparian conditions	"E" Enlarging

With a RGA score of 0.21, the reach immediately upstream of Steeles Avenue (**R1**) was assessed to be “in transition / stress” bordering on “in-regime”, with pronounced evidence of channel widening (e.g., leaning trees, exposed roots, and basal scouring). With regards to the RSAT, stream health was assessed to be “fair” with a score of 21. Channel scouring / sediment deposition and water quality conditions scored high, while in-stream habitat and stability scored relatively low.

With a RGA score of 0.27, the reach immediately downstream of Steeles Avenue (**R2**) was assessed to be “in transition / stress”, with pronounced evidence of channel widening (e.g., leaning trees, exposed roots, and basal scouring) and planimetric adjustment. With regards to the RSAT, stream health was assessed to be “fair” with a score of 21. Channel scouring / sediment deposition and water quality conditions scored high, while in-stream habitat and stability scored relatively low.

Application of the Downs channel evolution model suggests that Sixteen Mile Creek (**R1** and **R2**) is undergoing “enlargement”, in which scouring is occurring along the bed and widening is occurring along both banks. Such patterns are likely to persist as the channel seeks to establish a relative balance between hydrodynamic forces to attain a state of quasi-equilibrium (Cluer and Thorne, 2014). Channel enlargement, however, does not appear to be occurring rapidly as observations of active erosion were limited. The shallow, accessible floodplain helps to reduce erosion potential through flow attenuation in the broad overbank.

4 Meander Belt Width Delineation

4.1 Background

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 assessment estimates the lateral extent that a meandering channel has historically occupied and will likely occupy in the future. The assessment is therefore useful for informing the potential hazard to proposed activities in the vicinity of a stream as well as the need for supporting erosion mitigation measures. Meander belt widths were initially assessed for Sixteen Mile Creek downstream of Steeles Avenue as part of the 2012 Bronte Street Class MCEA by Geomorphic Solutions Inc. The meander belt widths have since been reviewed and refined accordingly at Steeles Avenue to account for current channel conditions.

4.2 Methodology

When defining the meander belt width for a creek system, unconfined and confined systems are treated differently (TRCA, 2004). Unconfined systems are those with poorly defined valleys or slopes well-outside where the channel could realistically migrate. In unconfined systems, the meander belt is broadly defined as the lateral extents within a floodplain in which the channel has historically occupied, plus an erosion setback to account for future channel migration and shifts in the meander belt axis (TRCA, 2004). With respect to the former, georeferenced historical aerial imagery is used to delineate past channel positions and the channel’s central tendency (or meander axis). Parallel lines are then drawn tangentially to the outside bends of the most laterally extreme meanders within the corresponding channel reach to form the preliminary meander belt. An erosion setback is applied to these delineated extents. For meander belts above 50 m, the setback is based on a safety factor, which is then verified through measurement of the historical progression of select channel meanders.

Sixteen Mile Creek

In the case of Sixteen Mile Creek, the channel has undergone multiple historical realignments within the study area and as such the current form is no longer representative of the natural meander belt. Moreover, migration of local channel meanders could not be reliably assessed due to tree cover, which obscured the channel from view in most available aerials. Similar constraints were documented by Geomorphic Solutions Inc. within the Bronte Street MCEA, who instead proposed an 88 m meander belt for **R2** based on the amplitude of a surrogate natural meander associated with a downstream reach. The proposed 88 m preliminary meander belt was reviewed against visible historical channel configurations and was deemed to be an acceptable alternative solution. Following the TRCA (2004) recommendations, the preliminary meander belt width is to be fitted with an additional factor of safety. However, the factor of safety was assessed to be overly conservative based on a visual evaluation of the belt limits in relation to the existing alignment of the channel as well as in consideration of the moderately stable form of the channel.

The meander belt width was verified through modelling following a modified Williams-Width (1986) approach. Additionally, the Ward-Width (2002) method was applied for comparison purposes. The modified Williams-Width (1986) approach is represented as:

$$B_w = \left(4.3{W_b}^{1.12} + W_b\right) * 1.2 \qquad \textbf{[Eq. 1]}$$

The Ward-Width (1986) approach is represented as:

$$B_w = \left(6{W_b}^{1.12}\right) * 1.2 \qquad \textbf{[Eq. 2]}$$

where B_w is meander belt width (m), and W_b is bankfull channel width (m). An additional 20% buffer, or factor of safety, was applied to the computed meander belt width values. This addresses issues of under-prediction and provides a factor of safety.

NW-1-E

As with Sixteen Mile Creek, an alternative approach is likely required to gauge the meander belt width for **NW-1-E**, given that the watercourse consists of a linear agricultural drainage feature and is largely obscured from view within available aerials. An estimate of the meander belt may be determined through application of **Equation 1** or **2**, or in using the modelled approach as outlined within the TRCA (2004) guidelines. However, in order to provide a reasonable estimate, channel dimensions should first be confirmed beyond the road right-of-way where the channel is better established.

4.3 Results

The results of the preliminary meander belt width (MBW) assessments are outlined in **Table 2** and **Appendix A**. The results herein are intended for planning purposes only. Meander belt widths are to be refined during detailed design to account for local constraints, including interaction with the valley wall, or the incorporation of additional safety factors.

Finally, the meander belt width only takes into consideration the hazard associated with the channel. To determine the full extent of the hazard the belt limits are to be augmented by the stable slope allowance, as determined by a geotechnical investigation, as required. Such factors were beyond the scope of this study.

Table 2: Preliminary Meander Belt Assessment Results

Channel Reach	Avg. Bankfull Width (m)	Williams[1] MBW (m)	Ward[2] MBW (m)	Preliminary MBW[3] (m)
R1 (upstream)	10.0	80.0	104	88
R2 (downstream)	10.4	83.6	114	88
NW-1-E†	2.5	17.4	23.2	-

†Channel dimensions to be confirmed beyond road right-of-way and meander belt width to be refined accordingly

[1] Preliminary meander belt width based on Williams (1986)

[2] Preliminary meander belt width based on Ward et al. (2002)

[3] Graphically-defined meander belt based on historical channel configuration and surrogate natural meander amplitude (additional factor of safety not applied)

In review of **Table 2**, the preliminary meander belt width based on the noted surrogate meander falls within the range of estimates provided through modelling.

5 Review of Crossings

Generally, culvert crossings are evaluated in the context of limiting or mitigating the impact to creek form and function. Crossings which are improperly sized can place infrastructure stability at risk due to potential channel adjustment (e.g., migration, widening, or downcutting). Similarly, crossings which are too small can impede aquatic and terrestrial passage due to the formation of in-channel or overbank barriers. Bearing in mind these considerations, crossing designs should achieve the following:

- Provide a span that is respectful of potential future channel erosion/migration, as informed by the erosion setback
- Mimic a natural bed morphology through the crossing
- Maintain sediment transport processes for frequent storm events
- Maintain velocity differentials through the culvert for frequent storm events
- Be placed away from actively migrating meanders

- Be placed along a stable and straight length of channel at a perpendicular angle to the watercourse

5.1 Sixteen Mile Creek

The condition of the existing Steeles Avenue crossings, when compared with the current geomorphic form of Sixteen Mile Creek, serves as a valuable reference to inform future crossing requirements in case of a replacement. Notably, the following observations were considered:

- The existing 14.8 m structure at Steeles Avenue and the 3 m x 4 m culverts at the CNR are undersized relative to the channel, as evidenced by the absence of channel banks (e.g., the channel wetted width spanned the full extent of the bridge openings). Despite the undersized condition, there was limited evidence of channel adjustment or erosion around the structures. For example, the upstream and downstream banks were gradually sloped and well-vegetated.
- The rapid geomorphic assessment findings support that the channel is "in-transition", which suggests that the channel is not fully stable or in-regime and is undergoing some degree of adjustment.
- The floodplain is low-lying relative to the channel and is thus relatively susceptible to overtopping and channelization or migration in the overbank area. This is supported by the presence of a remnant avulsion located immediately downstream of Steeles Avenue.

In summary, the existing structures are performing adequately well to convey and contain Sixteen Mile Creek. However, in their current form, the Steeles Avenue bridge and CNR culverts do not meet certain important geomorphological requirements. For example, the crossings do not account for future channel adjustment or offer energy dissipation (e.g., through provision of a functional floodplain). Furthermore, the CNR culverts, in particular, do not effectively mimic natural channel conditions and are a significant constraint with respect to aquatic and terrestrial passage.

5.2 NW-1-E

The **NW-1-E** crossing consists of a 750 mm CPP pipe. Based on an initial review of the channel, the crossing is functioning adequately to convey flows, as evidenced by the stable condition of the channel. However, the pipe is undersized relative to the ~2.5 m wide watercourse. This may lead to erosion issues in the future with further changes to the sub-catchment hydrological regime due to land development and/or climate change.

6 Crossing Recommendations

6.1 Sixteen Mile Creek

At this time, the existing 14.8 m bridge over Sixteen Mile Creek is proposed to be replaced with a relatively enlarged structure located approximately 50 m downstream (south) of the roadway.

The new road is positioned to cross the creek diagonally with skewed abutments that generally align with the channel.

From a geomorphological perspective, the position and orientation of the structure is not ideal. The skew of the road requires that additional length of channel be covered by the new structure, as compared with one that is oriented perpendicular to the channel. In addition, the bridge spans the channel at the location of a remnant avulsion that is likely activated under bankfull flow conditions. In following this plan, a significant degree of in-channel work is required to contain the watercourse within the crossing. Moreover, compensatory work is warranted to account for the loss of any potentially active channel footprint associated with the avulsion. It is understood that the alignment was developed bearing in mind numerous site constraints related to property ownership and infrastructure presence. Therefore, recognizing that the plan reflects a balance of societal, technical, and economical implications, preliminary crossing size and design recommendations are included below.

In keeping with the geomorphological recommendations set out in the opening paragraph of **Section 6**, the new crossing size should accommodate the bankfull channel plus an erosion setback to account for future channel migration. However, due to local site constraints a span recommendation on the lower end of acceptability is likely required to be a constructable and cost-viable option. As such, a crossing which spans the bankfull channel (approximately 10.4 m) plus a setback of 8 m applied to either side of the channel is likely appropriate, as it will permit the construction of bank treatment and a functional floodplain. The 8 m + 8 m setback reflects the 100-year toe erosion allowance for a channel undergoing erosion with cohesive soil and till based banks, as per MNR (2002) guidelines.

6.2 NW-1-E

Adoption of the new Steeles Avenue alignment will require the construction of a crossing over **NW-1-E**. The proposed crossing consists of a 6.5 m open bottom concrete box culvert.

At this time, the 6.5 m span is considered a suitable recommendation, given the favourable condition of the relatively undersized 750 mm CPP culvert at Steeles Avenue and the intermittent flow conditions of the watercourse. A 6.5 m span permits the incorporation of a ~2.5 m wide low flow channel with 2 m of overbank buffer to either side to serve as an erosion allowance and to maintain terrestrial passage opportunity within the culvert. This preliminary recommendation is contingent upon the confirmation of **NW-1-E** bankfull dimensions during the latter stages of planning or detailed design.

7 Channel Restoration Recommendations

The construction of new crossings over Sixteen Mile Creek and **NW-1-E** will require modification of the existing watercourses to promote stability in proximity to the roadway. Where possible, the geomorphological and ecological condition of the channels may be enhanced as a supplementary benefit to the work through bioengineering and / or realignment.

With respect to Sixteen Mile Creek, bioengineering (e.g., vegetated rock buttresses / offset protection) may be incorporated into the existing channel banks to combat erosive forces and help direct flows through the crossing. Vegetated rock buttresses consist of multiple lifts of stone with interspersed live woody plantings and are hydraulically-sized to withstand large flooding events. The plantings provide added stability through root generation in addition to providing shading benefits to the channel. Softer bank treatments solutions, such as root wad bank enhancement or brush mattressing, are also available. However, such woody-based treatments are more susceptible to erosional forces and ice scouring and are potentially not suitable for implementation in Sixteen Mile Creek, which is characterized by a moderate gradient and rapid flow.

At the new **NW-1-E** crossing, a low flow channel will be required within the culvert. Provision of a morphologically-diverse channel, such as a riffle-pool or cascade typology, is appropriate as it would essentially replicate a natural fluvial system while also promoting stability within the crossing. In addition, the roadwork provides an opportunity to redefine the existing altered condition of **NW-1-E** near Steeles Avenue. Realignment of the watercourse in the vicinity of the existing roadway applying natural channel design standards can improve connectivity with downstream reaches, enhance hydrologic function, and promote aquatic habitat and passage conditions.

Implementation of the channel restoration works will require additional planning and coordination, to be undertaken as part of detailed design. This will include completion of additional site investigations and analyses to support the design, namely:

- Detailed channel surveys to determine bankfull channel characteristics (e.g., discharge, velocity, stream power, tractive forces, and flow competency of channel substrates)
- Scour assessment
- Determination of the channel-forming or design discharge and hydraulic sizing of the channel
- Hydraulic sizing of channel substrates
- Planform, profile, and cross section drawings
- Development of a post-construction monitoring program

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
Director, Principal Geomorphologist

Bryce Molder, M.Sc., P.Geo, CAN-CISEC
Geomorphologist

8 References

Cluer, B. and Thorne, C.R. 2014. A stream evolution model integrating habitat and ecosystem benefits. River Research and Applications 30: 135-154.

Conservation Halton (CH). 2021. Culverts and Bridges – Complete Application Checklist. 8 pp.

Galli, J. 1996. Rapid stream assessment technique, field methods. Metropolitan Washington Council of Governments. 36pp.

Geomorphic Solutions. 2012. Bronte Street Class MCEA. Geomorphic Hazard Assessment – Sixteen Mile Creek Watershed. May 2012. 35 pp.

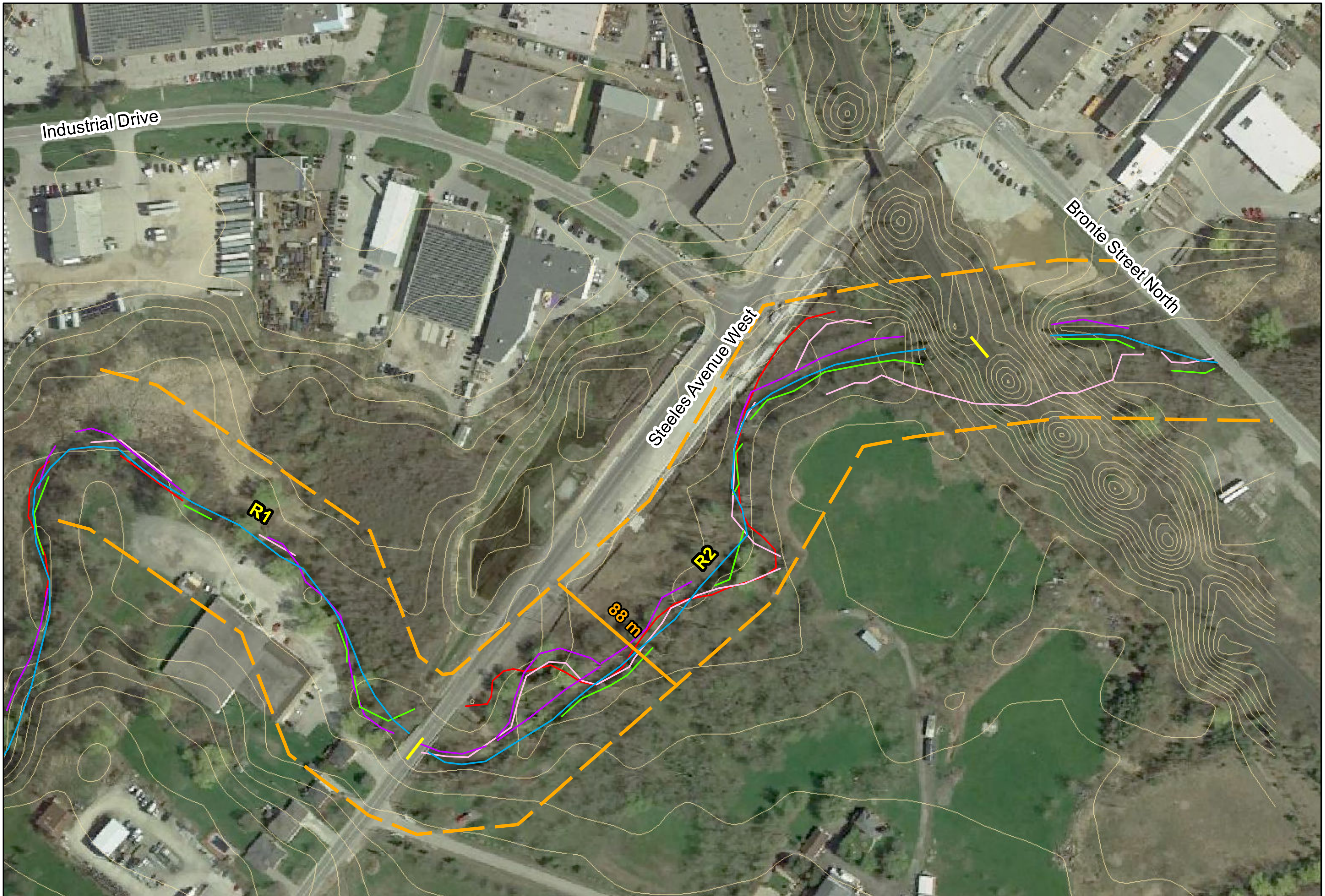
Ministry of the Environment. 2003. Stormwater Management Planning and Design Manual. March 2003. 379 pp.

Toronto and Region Conservation Authority (TRCA). 2004. Belt Width Delineation Procedures. 90 pg.

Ward, A., et al. 2002. Sizing Stream Setbacks to Help Maintain Stream Stability. 2002 ASAE Annual International Meeting. 35 pp.

Williams, G.P. 1986. River Meanders and Channel Size. Journal of Hydrology, 88: 147-164.

Appendix A
Meander Belt Width Delineation



Legend

- Reach Break and ID
- Preliminary Meander Belt Width (88 m)
- Contour (1 m)
- 2018 Watercourse
- 2004 Watercourse
- 1971 Watercourse
- 1946 Watercourse
- 1934 Watercourse

Sixteen Mile Creek, Steeles Avenue West, Milton

Historical Reach Delineation and Meander Belt Width

N

0 25 50

Metres

Imagery: GEP, May, 2018.
Contours: MNRF, 2021. Meander Belt Width: GHD, 2011, GEO Morphix Ltd. 2021.
Historical Watercourse Delineation: GEO Morphix Ltd., 2021.
Print Date: August 2021. PN18143a. Drawn By: B.M., M. O.

Legend

- Reach Break and Label (NW-1-E)
- Preliminary Meander Belt Width
- Watercourse
- Contour (1 m)

Reach NW-1-E
Steeles Avenue West, Milton

MBW Delineation

0 25 50
Metres

GEO MORPHIX™

Imagery: GEP, May, 2018.
Contours: MNRF, 2021.
Watercourse, Meander Belt Width: GEO Morphix Ltd. 2021.
Print Date: September 2021. PN18143a. Drawn By: B.M., M. O.

Appendix B
Site Photographs

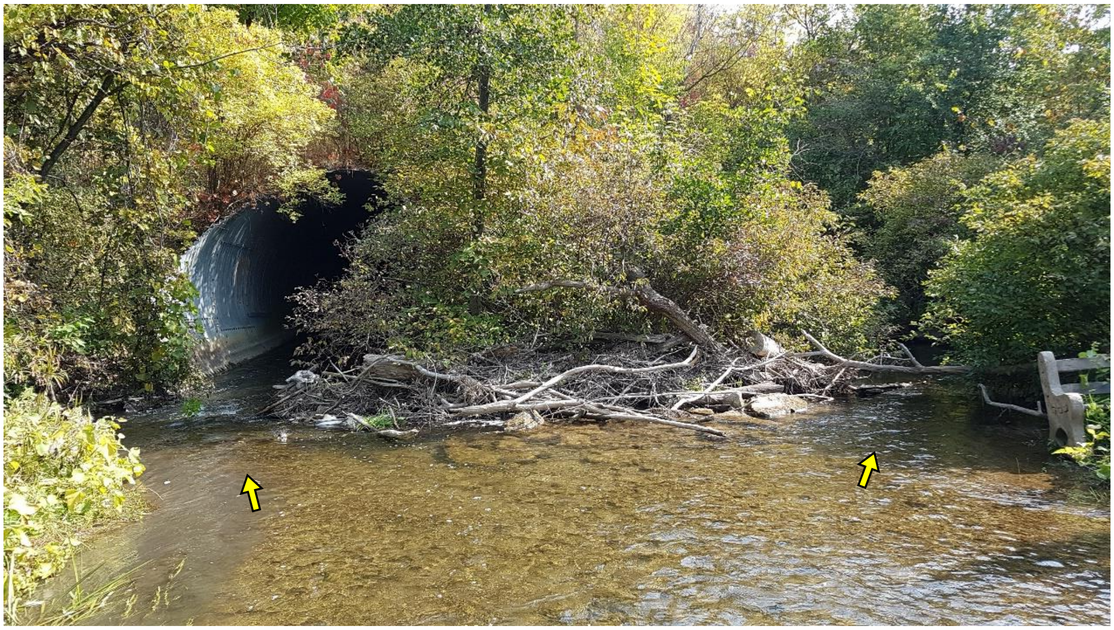
Reach R1 - Photo 1	 Upstream (North) of Steeles Avenue West, Sixteen Mile Creek was wide, relatively shallow, and dominated by riffle and run features.
Reach R1 - Photo 2	 The riparian area on the west side of the channel consisted of a narrow, forested buffer next to a residential lot.

Reach R1 - Photo 3	
	The east riparian area was wooded with a high density of shrubs. Red Osier Dogwood was particularly abundant. Some shrubs were inundated as a result of channel widening.
Reach R1 - Photo 4	
	The run-dominant reach extended to the Steeles Avenue crossing. Bed substrates consisted of range of coarse sands to small subangular boulders.

Reach R1 - Photo 5	
	View of the upstream valley corridor from Steeles Avenue.
Reach R2 - Photo 6	
	The Steeles Avenue crossing was undersized relative to the channel. The channel wetted width extended the full span of the crossing.

Reach R2 - Photo 7	 The homogenous bed morphology persisted downstream of the crossing. There was limited erosion observed around the crossing.
Reach R2 - Photo 8	 The east bank was relatively shallow and partially inundated. A remnant channel avulsion was observed within the floodplain.

Reach R2 - Photo 9	
	100 m downstream of the crossing, there was a wooden bridge associated with the Milton Banquet and Conference Centre lot. The bridge was partially-rotted, though not displaced.
Reach R2 - Photo 10	
	Short segments of exposed till were observed along the channel bed, indicative of widening processes. Channel banks were gradually sloped and vegetated. The adjacent floodplain was relatively low-lying.

Reach R2 - Photo 11	 An additional wooden bridge was noted 180 m downstream of the Steeles Avenue crossing. The adjacent channel banks were vegetated and moderately stable.
Reach R2 - Photo 12	 The CNR crossing of Sixteen Mile Creek consisted of two 3 m x 4 m culverts. Woody debris had collected along the bank between the culverts.

Reach R2 - Photo 13	
	The culverts were slightly embedded into the riverbed.
Reach R2 - Photo 14	
	The two culverts fed into an overwidened pool on the opposite side of the CNR crossing. Channel banks were vegetated and stable. Minor scouring was observed along the pool bed.

NW-1-E - Photo 15	
	NW-1-E consisted of a 2.5 m wide, well-vegetated swale, which extended from the adjacent farm field and followed the Steeles Avenue embankment.
NW-1-E - Photo 16	
	NW-1-E was conveyed beneath Steeles Avenue within a 750 mm diameter corrugated plastic pipe. The channel fed into a stone-lined plunge pool at the base of the road / rail embankment.

NW-1-E - Photo 17	
	The supporting headwall and concrete retaining walls of the plunge pool were degraded and in poor condition.

Appendix C
Field Notes

GEO | MORPHIX

Geomorphology
Earth Science
Observations

General Site Characteristics

Project Code: 18143

Date:	2018, Nov 11	**Stream/Reach:**	R2 - DS of Steeles
Weather:	1°C	**Location:**	Steeles + Peru
Field Staff:	BM.	**Watershed/Subwatershed:**	16 MC

Features

- Reach break
- Cross-section
- Flow direction
- Riffle
- Pool
- Medial bar
- Eroded bank
- Undercut bank
- Rip rap/stabilization/gabion
- Leaning tree
- Fence
- Culvert/outfall
- Swamp/wetland
- Grasses
- Tree
- Instream log/tree
- Woody debris
- Station location
- Vegetated island

Flow Type

H1	Standing water
H2	Scarcely perceptible flow
H3	Smooth surface flow
H4	Upwelling
H5	Rippled
H6	Unbroken standing wave
H7	Broken standing wave
H8	Chute
H9	Free fall

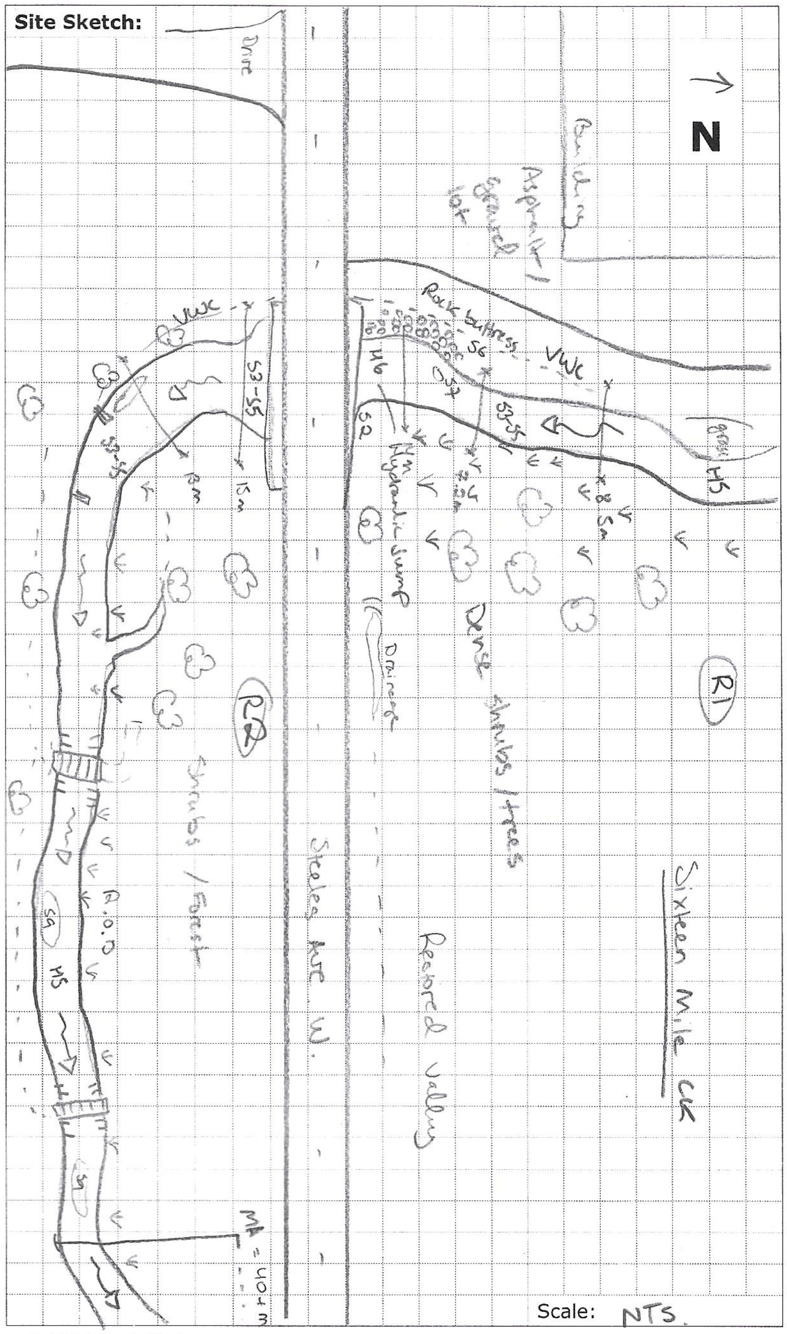
Substrate

S1	Silt	**S6**	Small boulder
S2	Sand	**S7**	Large boulder
S3	Gravel	**S8**	Bimodal
S4	Small cobble	**S9**	Bedrock/till
S5	Large cobble		

Other

BM	Benchmark	**EP**	Erosion pin
BS	Backsight	**RB**	Rebar
DS	Downstream	**US**	Upstream
WDJ	Woody debris jam	**TR**	Terrace
VWC	Valley wall contact	**FC**	Flood chute
BOS	Bottom of slope	**FP**	Flood plain
TOS	Top of slope	**KP**	Knick point

Site Sketch:



Scale: NTS.

Additional Notes:

Completed by: BM. Checked by: PV

GEO | MORPHIX
Geomorphology Earth Science Observations

Reach Characteristics

Project Code: 18143

Date:	Nov 11 2018	**Stream/Reach:**	US of Steeles R1
Weather:	1°C	**Location:**	Steeles + Penn
Field Staff:	BM	**Watershed/Subwatershed:**	16MC
UTM (Upstream)	43°30'51 79°54'34	**UTM (Downstream)**	43° 30 '43 79° 54' 11

Land Use (Table 1): 1/7 | **Valley Type** (Table 2): 3 | **Channel Type** (Table 3): 7 | **Channel Zone** (Table 4): 2 | **Flow Type** (Table 5): 1 | ☐ Groundwater | Evidence: NA

Riparian Vegetation

Dominant Type: (Table 6) 1/2

Species: Red Osier Dogwood

Coverage: ☐ None ☑ Fragmented ☐ Continuous

Channel widths: ☑ 1-4 RB ☑ 4-10 LB ☐ > 10

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

Encroachment: (Table 7) 1

Aquatic/Instream Vegetation

Type (Table8) 2 | Coverage of Reach (%) 5

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

Density of WD: ☑ Low ☐ Moderate ☐ High | WDJ/50m: 1

Water Quality

Odour (Table 16): 1

Turbidity (Table 17): 2

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): 2 | **Type of Bank Failure** (Table 14): 1 | **Downs's Classification** (Table 15): R

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

Bankfull Width (m)	7.2	8.5	14 10.2	**Wetted Width (m)**	6.1	6.4	7.9
Bankfull Depth (m)	1.0	0.75	1.0 0.73	**Wetted Depth (m)**	0.3	0.25	0.4

Riffle/Pool Spacing (m) NA | **% Riffles:** 95 | **% Pools:** 5 | **Meander Amplitude:** ~60 m

Pool Depth (m) 1 | **Riffle Length (m)** continuous | **Undercuts (m)** 0.15

Velocity (m/s) 1.5 | 2 | | Wiffle ball / ADV / Estimated

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

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

Comments: Reach walk limited to ~150 m N of Steeles.

Notes:

Completed by: BM. Checked by: PV

GEO | MORPHIX

Rapid Geomorphic Assessment **Project Code:** PN18143a

Date:	Nov 11, 2018	**Stream/Reach:**	R1
Weather:	1°C	**Watershed/Subwatershed:**	16 MC
Field Staff:	BM.	**Location:**	US of Steeles

Process	No.	Geomorphological Indicator Description	Present? Yes	Present? No	Factor Value
Evidence of Aggradation (AI)	1	Lobate bar		✓	
	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 =	0	7	0
Evidence of Degradation (DI)	1	Exposed bridge footing(s)		✓	
	2	Exposed sanitary / storm sewer / pipeline / etc.		✓	
	3	Elevated storm sewer outfall(s)	NA		
	4	Undermined gabion baskets / concrete aprons / etc. VRB		✓	
	5	Scour pools downstream of culverts / storm sewer outlets		✓	
	6	Cut face on bar forms		✓	
	7	Head cutting due to knickpoint 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	7	0.22
Evidence of Widening (WI)	1	Fallen / leaning trees / fence posts / etc.	✓		
	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.		✓	
	7	Length of basal scour >50% through subject reach		✓	
	8	Exposed length of previously buried pipe / cable / etc.		✓	
	9	Fracture lines along top of bank		✓	
	10	Exposed building foundation	NA		
		Sum of indices =	3	6	0.33
Evidence of Planimetric Form Adjustment (PI)	1	Formation of chute(s)		✓	
	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 =	2	5	0.29

Additional notes: Run/Riffle dominated.

Stability Index (SI) = (AI+DI+WI+PI)/4 = 0.21

Condition	**In Regime**	**In Transition/Stress**	**In Adjustment**
SI score =	☐ 0.00 - 0.20	☑ 0.21 - 0.40	☐ 0.41

Completed by: BM. Checked by: PV

Rapid Stream Assessment Technique

Project Code: 19143

Date:	Nov 11, 2018	**Stream/Reach:**	US of Steeles R1
Weather:	1°C	**Location:**	Steeles & Peru.
Field Staff:	BM	**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:	Nov 11, 2018	Reach:	R1	Project Code:	18143

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	• 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) = 21	Poor (<13)	Fair (13-24)	Good (25-34)	Excellent (>35)

Completed by: CM Checked by: PV

GEO | MORPHIX
Geomorphology Earth Science Observations

Reach Characteristics

Project Code: 18143

Date:	Nov 11, 2018	**Stream/Reach:**	DS of Steeles R2
Weather:	1°C	**Location:**	Steeles Ave & Peru Rd
Field Staff:	BM	**Watershed/Subwatershed:**	16 Mc
UTM (Upstream)	43° 30' 48 / 79° 54' 10	**UTM (Downstream)**	43° 30' 55 79° 53' 58

Land Use (Table 1): 1/7 | **Valley Type** (Table 2): 1 | **Channel Type** (Table 3): 7 | **Channel Zone** (Table 4): 2 | **Flow Type** (Table 5): 1 | ☒ Groundwater | Evidence: N/A

Riparian Vegetation

Dominant Type: (Table 6) 1/2
Species: ROD

Coverage:
- ☐ None
- ☑ Fragmented
- ☐ Continuous

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

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

Encroachment: (Table 7) 1

Aquatic/Instream Vegetation

Type (Table8) 2 | Coverage of Reach (%) <5

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

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

WDJ/50m: 1

Water Quality

Odour (Table 16): 1
Turbidity (Table 17): 2

Channel Characteristics

Sinuosity (Type) (Table 9): 2 | **Sinuosity (Degree)** (Table 10): 2/3 | **Gradient** (Table 11): 2 | **Number of Channels** (Table 12): 1

Entrenchment (Table 13): 2 | **Type of Bank Failure** (Table 14): 1 | **Downs's Classification** (Table 15): E

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

Bankfull Width (m): 8.6, 9.7, 10.2, 15, 8.5 | **Wetted Width (m)**: 6.0 | 5.7 | 6.3

Bankfull Depth (m): 0.82, 0.95, 0.90, 1.05, 1.0 | **Wetted Depth (m)**: 0.40 | 0.30 | 0.50

Riffle/Pool Spacing (m): NA | **% Riffles:** 100 | **% Pools:** NA | **Meander Amplitude:** ~50

Pool Depth (m): NA ~0.8 | **Riffle Length (m)**: continuous | **Undercuts (m)**: 0.10 | **Comments:**

Velocity (m/s): 1 | 1.3 | 2 | **Wiffle ball / ADV / Estimated**

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

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

Notes:

Completed by: BM Checked by: PV

GEO | MORPHIX

Rapid Geomorphic Assessment **Project Code:** 18143a

Date:	Nov 11, 2018	**Stream/Reach:**	R2
Weather:	1°C	**Watershed/Subwatershed:**	16MC
Field Staff:	BM	**Location:**	DS of Steeles

Process	No.	Description	Present? Yes	Present? No	Factor Value
Evidence of Aggradation (AI)	1	Lobate bar		✓	
	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 =	0	7	0
Evidence of Degradation (DI)	1	Exposed bridge footing(s)		✓	
	2	Exposed sanitary / storm sewer / pipeline / etc.		✓	
	3	Elevated storm sewer outfall(s)	NA		
	4	Undermined gabion baskets / concrete aprons / etc. URB		✓	
	5	Scour pools downstream of culverts / storm sewer outlets		✓	
	6	Cut face on bar forms		✓	
	7	Head cutting due to knickpoint 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	7	0.22
Evidence of Widening (WI)	1	Fallen / leaning trees / fence posts / etc.	✓		
	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.		✓	
	7	Length of basal scour >50% through subject reach		✓	
	8	Exposed length of previously buried pipe / cable / etc.		✓	
	9	Fracture lines along top of bank		✓	
	10	Exposed building foundation	NA		
		Sum of indices =	4	5	0.44
Evidence of Planimetric Form Adjustment (PI)	1	Formation of chute(s)		✓	
	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:
Avulsion DS of XSing.
Run/Riffle dominated

Stability Index (SI) = (AI+DI+WI+PI)/4 = 0.27

Condition	**In Regime**	**In Transition/Stress**	**In Adjustment**
SI score =	☐ **0.00 - 0.20**	☒ **0.21 - 0.40**	☐ **0.41**

Completed by: BM Checked by: PV

GEO | MORPHIX

Rapid Stream Assessment Technique **Project Code:** 18143

Date:	Nov 11 2019	**Stream/Reach:**	DS of Steeles R2
Weather:	1°C	**Location:**	Steeles & Peru.
Field Staff:	BM	**Watershed/Subwatershed:**	F6 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:	Nov 11, 2018	Reach:	R2	Project Code:	18143

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	• 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) = 21	Poor (<13)	Fair (13-24)	Good (25-34)	Excellent (>35)

Completed by: BM Checked by: PV

GEO | MORPHIX
Geomorphology
Earth Science
Observations

General Site Characteristics

Project Code: 18143a

Date:	Nov 11, 2018	**Stream/Reach:**	NW1-E
Weather:	1°C	**Location:**	Steeles Ave.
Field Staff:	BM.	**Watershed/Subwatershed:**	16 MC

Features
- Reach break
- Cross-section
- Flow direction
- Riffle
- Pool
- Medial bar
- Eroded bank
- Undercut bank
- Rip rap/stabilization/gabion
- Leaning tree
- Fence
- Culvert/outfall
- Swamp/wetland
- Grasses
- Tree
- Instream log/tree
- Woody debris
- Station location
- Vegetated island

Flow Type

H1	Standing water
H2	Scarcely perceptible flow
H3	Smooth surface flow
H4	Upwelling
H5	Rippled
H6	Unbroken standing wave
H7	Broken standing wave
H8	Chute
H9	Free fall

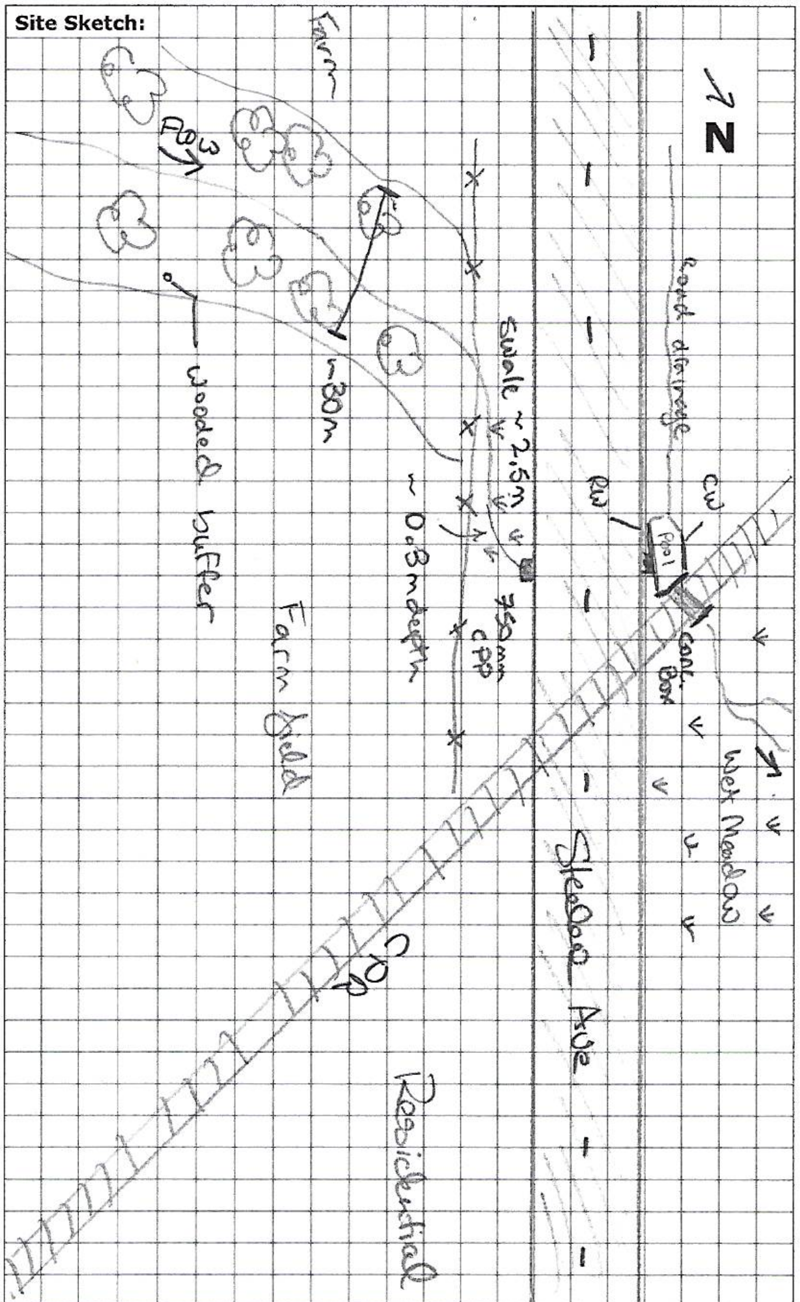
Substrate

S1	Silt	**S6**	Small boulder
S2	Sand	**S7**	Large boulder
S3	Gravel	**S8**	Bimodal
S4	Small cobble	**S9**	Bedrock/till
S5	Large cobble		

Other

BM	Benchmark	**EP**	Erosion pin
BS	Backsight	**RB**	Rebar
DS	Downstream	**US**	Upstream
WDJ	Woody debris jam	**TR**	Terrace
VWC	Valley wall contact	**FC**	Flood chute
BOS	Bottom of slope	**FP**	Flood plain
TOS	Top of slope	**KP**	Knick point

Site Sketch:

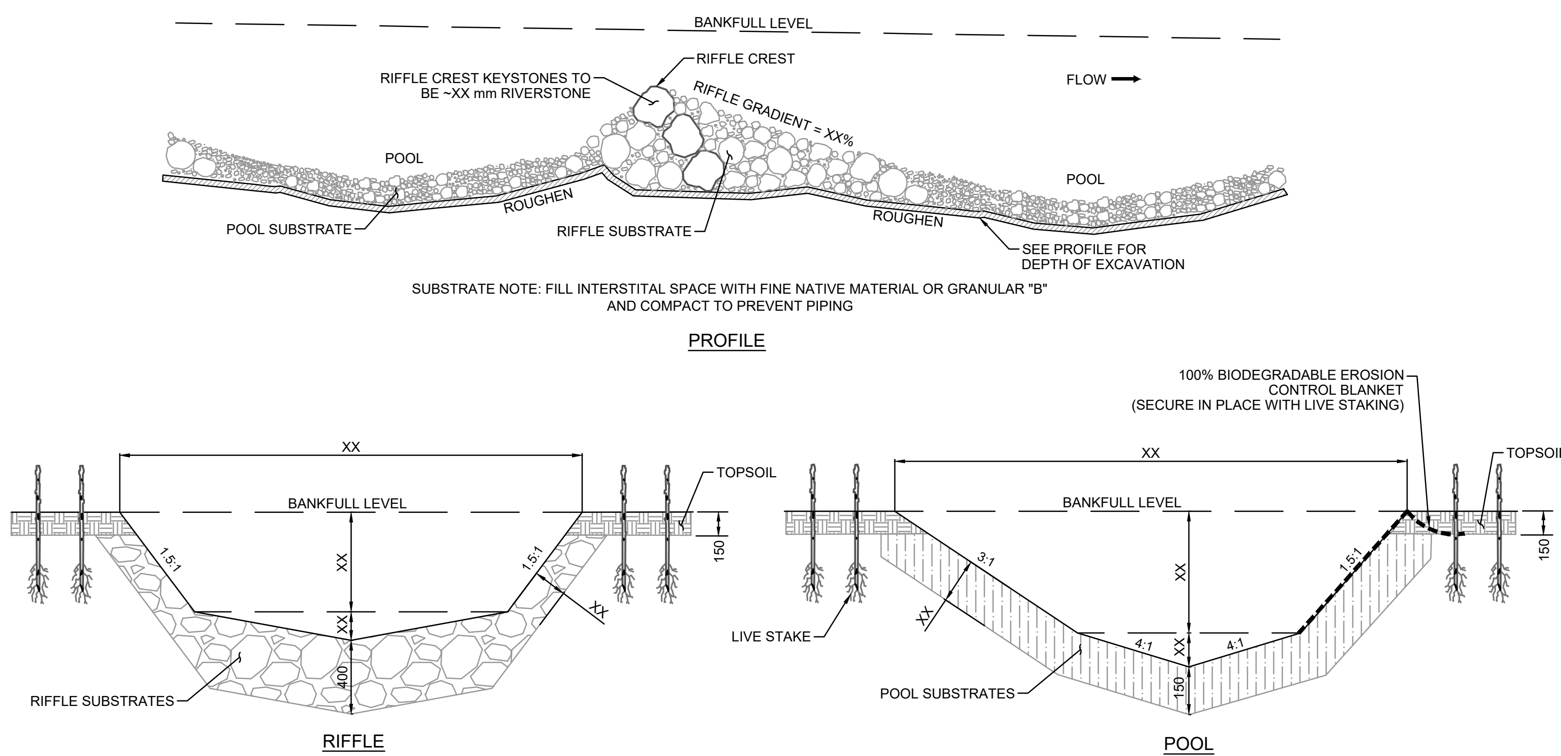


Scale: NTS.

Additional Notes: Vegetated feature.
NO ACCESS to feature beyond ROW.

Completed by: BM Checked by: PU.

Appendix D
Fluvial Design Concepts



SUBSTRATE NOTE: FILL INTERSTITAL SPACE WITH FINE NATIVE MATERIAL OR GRANULAR "B" AND COMPACT TO PREVENT PIPING

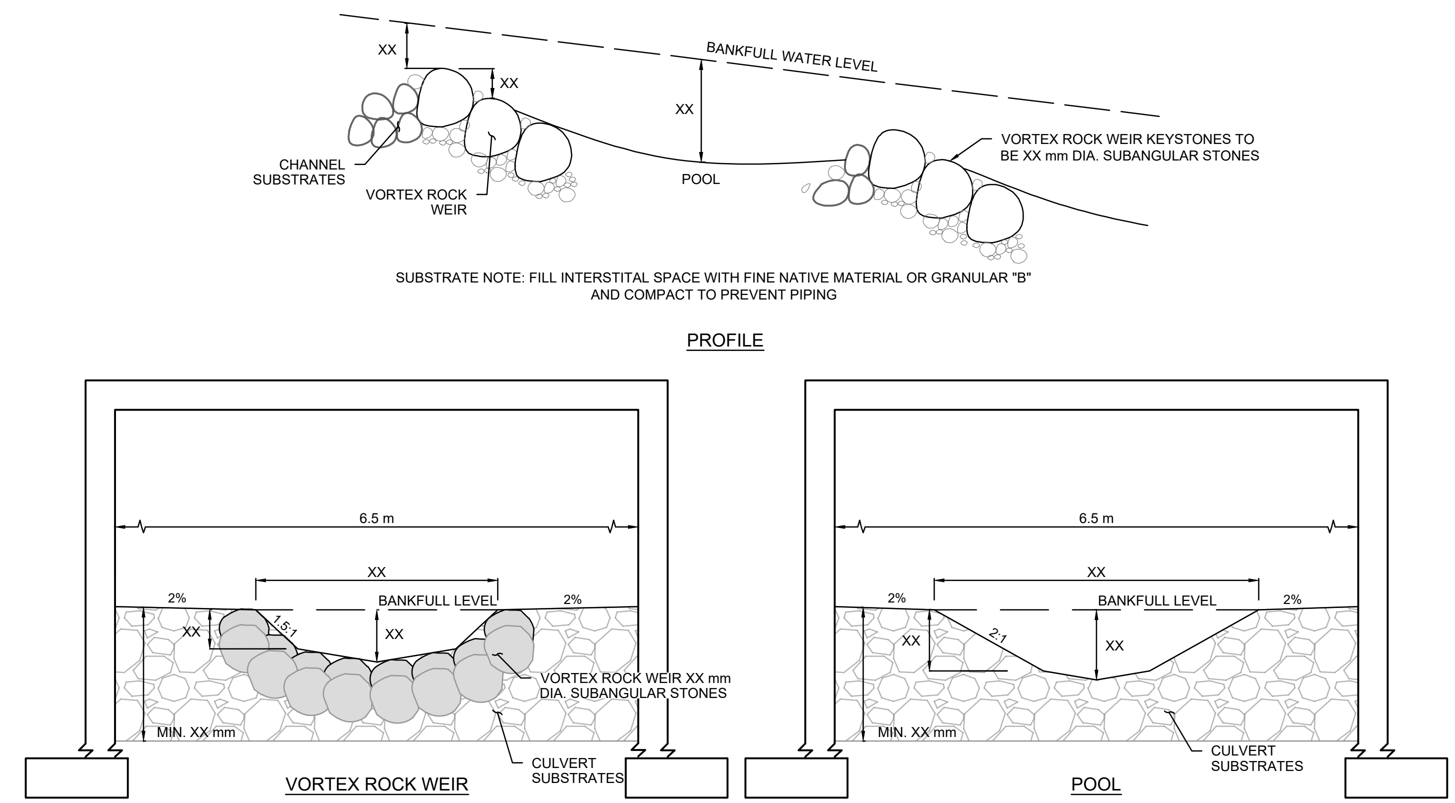
PROFILE

RIFFLE

POOL

CHANNEL DESIGN DISCHARGE AND ASSOCIATED GEOMETRIES TO BE EVALUATED DURING DETAILED DESIGN
CHANNEL SUBSTRATES TO BE HYDRAULICALLY-SIZED

NATURAL CHANNEL DESIGN SECTIONS
N.T.S.



SUBSTRATE NOTE: FILL INTERSTITAL SPACE WITH FINE NATIVE MATERIAL OR GRANULAR "B" AND COMPACT TO PREVENT PIPING

PROFILE

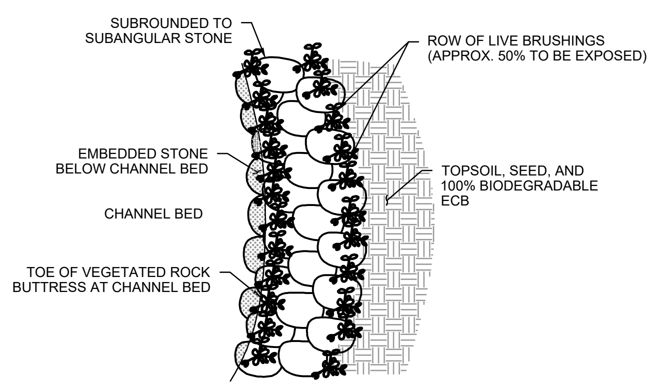
VORTEX ROCK WEIR

POOL

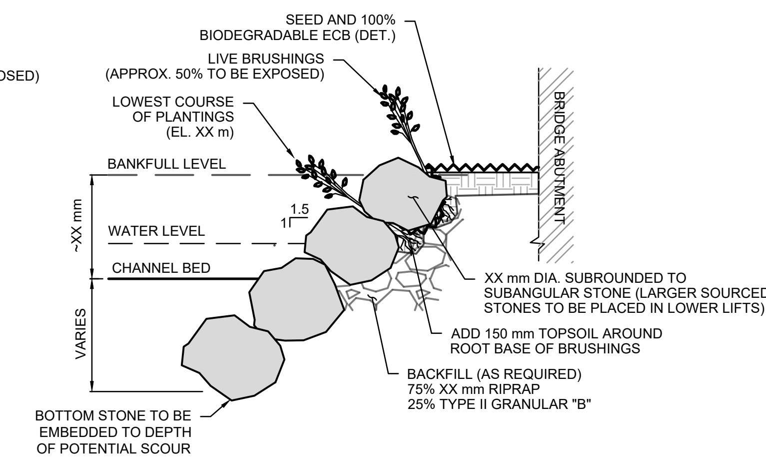
CHANNEL DESIGN DISCHARGE AND ASSOCIATED GEOMETRIES TO BE EVALUATED DURING DETAILED DESIGN
CHANNEL SUBSTRATES TO BE HYDRAULICALLY-SIZED

CASCADE (IN CULVERT)
N.T.S.

NW-1-E



PLAN



CROSS SECTION

CONSTRUCTION NOTES

- VEGETATED ROCK BUTTRESS TO BE INSTALLED IN LIFTS, WITH LARGER SOURCED STONES PLACED ALONG THE TOE OF THE TREATMENT.
- TOE STONES TO BE EMBEDDED INTO CHANNEL BED TO A MINIMUM DEPTH OF XX m OR A MAXIMUM DEPTH ELEVATION OF XX m.
- STONES TO BE SUBROUNDED IN SHAPE
- LIVE BRUSHINGS / PLANTINGS, TO BE INSTALLED INTO LIFTS OF BUTTRESS DURING CONSTRUCTION AND NOT AT A LATTER DATE.

SEQUENCE OF CONSTRUCTION

LOWER LIFTS:

1. EMBED LOWEST LIFTS OF STONE, BACKFILLING AS NEEDED WITH PROPOSED RIPRAP / GRANULAR MIX. COMPACT.

MIDDLE TO UPPER LIFTS:

2. INSTALL SINGLE LIFT OF STONE, BACKFILLING AS NEEDED WITH PROPOSED RIPRAP / GRANULAR MIX. COMPACT.
3. INSTALL CONTINUOUS ROW OF LIVE BRUSHINGS / PLANTINGS OVERTOP OF NEWLY PLACED STONE LIFT AND ADD 150 mm LAYER OF TOPSOIL AROUND BASE OF BRUSHINGS.
4. REPEAT STEPS 2-3 FOR ADDITIONAL LIFTS TO TOP OF BANK.

POTTED PLANTINGS SPECIFICATIONS

COMMON NAME	SCIENTIFIC NAME	QTY	CONDITION
RED-OSIER DOGWOOD	*Cornus sericea*	XX	1 m, LIVE BRUSHINGS
PEACH-LEAVED WILLOW	*Salix amygdaloides*	XX	1 m, LIVE BRUSHINGS
BEBB'S WILLOW	*Salix bebbiana*	XX	1 m, LIVE BRUSHINGS
PUSSY WILLOW	*Salix discolor*	XX	1 m, LIVE BRUSHINGS

NOTE: LIVE BRUSHINGS TO BE REPLACED WITH CONTAINER GROWN (POTTED) PLANTINGS IF PLANTING TO OCCUR OUTSIDE THE DORMANT PERIOD (FALL / WINTER)

VEGETATED ROCK BUTTRESS
N.T.S.

SIXTEEN MILE CREEK

CHANNEL RESTORATION CONCEPTS

NOT FOR CONSTRUCTION

GEO MORPHIX
Geomorphology
Earth Science
Observations

36 Main Street North, PO Box 205
Campbellville, Ontario L0P 1B0

T: 416.920.0926
www.geomorphix.com