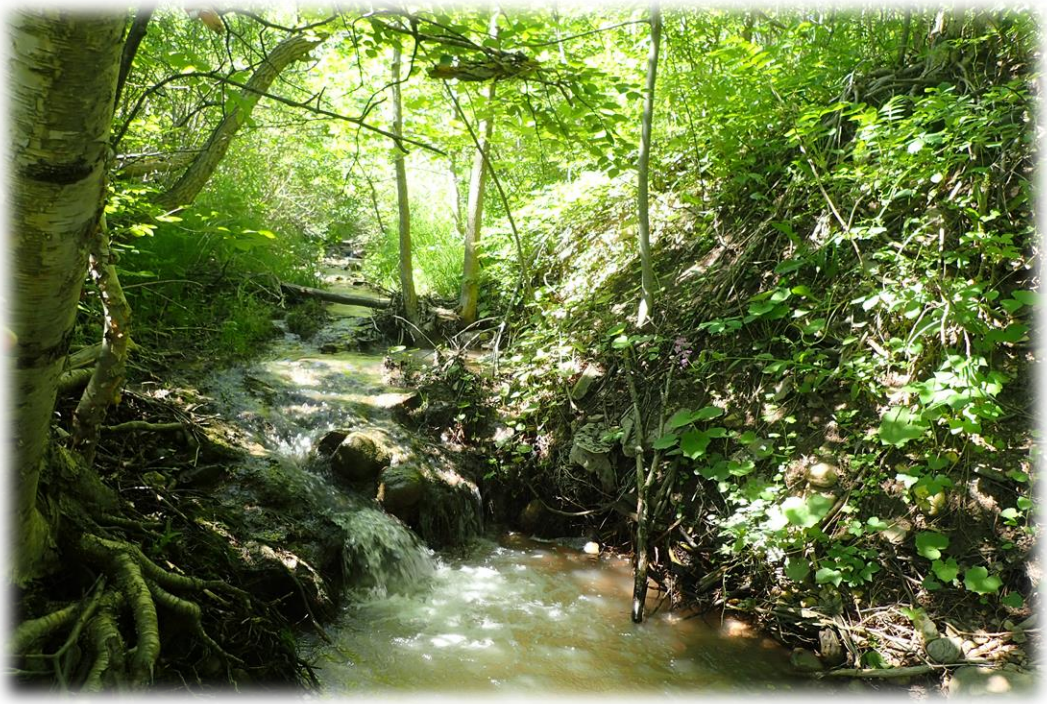
Geomorphological Assessment and Stabilization Recommendations

Watercourse 9 – Craigleith Proposed Residential Development



Prepared for:

Parkbridge Lifestyle Communities Inc.
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Wasaga Beach, Ontario L9Z 1X7

September 11, 2020
PN20058

GEO MORPHIX
Geomorphology
Earth Science
Observations

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1 Introduction

GEO Morphix was retained by Parkbridge Lifestyle Communities Inc. to complete a geomorphological assessment of Watercourse 9 to support a proposed residential development in the Town of The Blue Mountains, Ontario. The proposed residential development will cross Watercourse 9 in three (3) locations and receive flows from stormwater management (SWM) facilities at two (2) locations. Due to these proposed activities, and their potential impact on Watercourse 9, the Grey Sauble Conservation Authority (GSCA) provided comments to ensure all natural hazards are considered in the planning and development phases.

To satisfy the fluvial geomorphological assessment, and address comments from GSCA, the following activities were completed:

- Review available background reports and mapping (e.g., watershed/subwatershed reporting, geology, and topography) related to channel form and function and controlling factors related to fluvial geomorphology
- Delineate watercourse reaches through a desktop assessment
- Complete rapid geomorphological assessments on a reach basis to document channel conditions and verify the desktop assessment
- Document any areas of significant erosion, collect instream measurements of bankfull channel dimensions, and characterize bed and bank material composition and structure
- Delineate limits of the meander belt width/erosion hazard on a reach basis using field observations and historical aerial photography
- Develop recommendations for erosion protection and bank stability associated with the proposed watercourse crossings and SWM outfalls to ensure that natural hazards are addressed from a fluvial geomorphological perspective
- Prepare a report and mapping product to characterize the watercourse, provide erosion protection and bank stability recommendations, and summarize all findings

1.1 Background Information

Watercourse 9 is characterized as a drainage feature which originates from the escarpment (shore bluff) associated with the southern shoreline of Georgian Bay. Watercourse 9 enters the subject property west of Grey County Road 19 at a stormwater management (SWM) facility. It flows south west to north east through the subject property, beneath Lakeshore Road East and Highway 26, and eventually discharges to Georgian Bay. Watercourse 9 is located entirely within the Craigleith-Camperdown Subwatershed and is regulated by the Grey Sauble Conservation Authority (GSCA).

Associated with the proposed residential development adjacent to Watercourse 9, three (3) watercourse crossings and two (2) outfalls from the stormwater management (SWM) ponds were proposed. To stabilize the crossing and outfall locations, riprap was recommended to be installed along channel banks. It was requested that a geomorphological assessment be completed to review the proposed stabilization measures, and further, inform the erosion potential of Watercourse 9.

1.2 Geology and Physiography

Geology and physiography act as constraints to channel development and tendency. These factors determine the nature and quantity of the availability and type of sediment. Secondary variables that affect the channel include land use and riparian vegetation. These factors are explored as

they not only offer insight into existing conditions, but also potential changes that could be expected in the future as they relate to a proposed activity.

Watercourse 9 is characterized by a range of surficial geological landscapes and a variety of physiographic regions and features. This is important to consider in reach delineation, as the diversity in geologic and physiographic factors influence channel and floodplain form and function. Moving from upstream to downstream, Watercourse 9 is characterized by ice-contact stratified deposits (composed of sand and gravel, minor silt, clay, and till), shore bluff (escarpment), coarse-textured glaciolacustrine deposits (composed of sand, gravel, minor silt and clay, foreshore and basinal deposits), and Paleozoic bedrock (OGS, 2010). The subject lands are within the Simcoe Lowlands physiographic region and include three (3) main physiographic landforms from upstream to downstream: clay plains, beaches, and sand plains (Chapman and Putnam, 2007).

1.3 Historical Assessment

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.

Various aerial photographs and satellite images from 1954 to 2019 were reviewed to complete the historical assessment and inform the erosion hazard delineation. Specifically, aerial photographs from 1954 (University of Toronto) and 2006 (Grey County) were reviewed using open source data. Additionally, satellite images from 2011 and 2019 (Google Earth Pro) were reviewed and are provided in **Appendix A**, for reference.

In 1954, the subject property and surrounding lands were dominated by agricultural land use. Due to the resolution of the aerial photograph, many of the details associated with the channel and floodplain were not discernable. The general planform of the watercourse is sinuous, with slight meandering through the upstream extent, and straight through the downstream extent. The location of the Nipissing Ridge is identifiable, which is consistent with the minor change in sinuosity. Dense vegetation within the riparian zone is also observed particularly through the upstream extent of the watercourse.

By 2006, several residential developments were established west of Grey County Road 19, and single-family dwellings were constructed east of Grey County Road 19 and north of Lakeshore Road East. To support the residential lands, two (2) SWM facilities were constructed west of Grey County Road 19. One (1) SWM facility was constructed immediately upstream from Watercourse 9, which likely altered the flow characteristics of the drainage feature particularly during high rainfall events. The subject property remained occupied by agriculture, with an increase in forested lands. Mature vegetation was established surrounding Watercourse 9 and the Nipissing Ridge. The extent and maturity of vegetation within the riparian zone reduced the visibility of the channel planform, however, the sinuosity of the watercourse is generally consistent with its previous form.

The satellite image captured in 2011 was taken during the winter season (February), and as such, the majority of vegetation was dormant and the planform of the channel was visible. At the upstream extent of Watercourse 9, the channel flows through dense vegetation and exhibits an irregular meandering planform. Due to the maturity of the tree species within the riparian zone, it is evident that the channel was not previously modified. Moving downstream from the Nipissing Ridge, Watercourse 9 exhibits a straight sinuosity. The riparian zone through the downstream extent of Watercourse 9 is less extensive, however mature vegetation indicates there were likely no historical modifications to the channel planform. Land use through the study site remained dominated by agricultural practices.

In 2019, the planform of Watercourse 9 was not visible through the extent of the riparian zone and mature tree species surrounding the channel. The extent of residential development increased surrounding the subject property, however the lands in close proximity to Watercourse 9 remained occupied by agriculture and forest.

Despite changes in land use and drainage (SWM facilities) over time, Watercourse 9 was not modified and maintained its general planform from 1954 to 2019. Additionally, the riparian zone and extent of vegetation increased and matured over time. These observations suggest that the system is generally stable.

2 Watercourse Characteristics

2.1 Reach Delineation

Reaches are homogeneous segments of channel used in geomorphological investigations. Reaches are studied semi-independently as each is expected to function in a manner that is at least slightly different from adjoining reaches. This method 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 typically delineated based on changes in the following:

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

Reach delineation follows scientifically defensible methodology proposed by Montgomery and Buffington (1997), Richards et al. (1997), and the Toronto and Region Conservation Authority (2004) as well as others. Reaches were preliminarily identified as **WC9-1**, **WC9-2**, **WC9-3** (reaches downstream from Nipissing Ridge), **WC9-4**, **WC9-5**, and **WC9-6** (reaches upstream from Nipissing Ridge).

2.2 General Reach Observations

Field investigations were completed on June 19, 2020, and included the following:

- Descriptions of riparian conditions
- Estimates of bankfull channel dimensions
- Determination of bed and bank material composition and structure
- Observations of erosion, scour, or deposition
- Collection of photographs to document the watercourses, riparian areas and/or valley, surrounding land use, and channel disturbances such as crossing structures

These observations and measurements are summarized below. The descriptions are supplemented and supported with representative photographs, which are included in **Appendix C**. Field sheets, including those completed for rapid assessments, are provided in **Appendix D**.

Reaches WC9-1, WC9-2, and WC9-3 flow southwest to northeast through the subject property and extend from the Nipissing Ridge to the furthest downstream extent of the subject property, where the watercourse flows beneath Lakeshore Road East and ultimately outlets to Georgian Bay. There are four (4) proposed features to support the residential development through **Reaches WC9-1, WC9-2, and WC9-3.** This includes one (1) outfall through **WC9-1,** one (1) watercourse crossing through **WC9**-**2**, and one (1) outfall and one (1) watercourse crossing through **WC9-3.** These features are identified on the preliminary reach map, provided in **Appendix B.**

Reaches WC9-1, WC9-2, and WC9-3 were situated within an unconfined valley setting. The channel exhibited a sinuous planform with low sinuosity, ranging from 1.06 to 1.30. The surrounding land use consisted of forest and pasture, and the reaches were located within a transfer zone. The riparian buffer zone was approximately 1 to 4 channel widths in size and had continuous coverage. The dominant type of riparian vegetation was established (5 to 30 years) and mature (greater than 30 years) tree and shrub species. There was minimal encroachment of vegetation into the channel. The reaches had perennial flow with a moderate gradient. Riffle pool spacing was approximately 5 m, with 60% of the watercourse occupied by riffles and 40% occupied by pools. Riffle substrate consisted of gravel and cobble, and pool substrate consisted of sand, gravel, and cobble. Flow was clear and odourless, however, there was evidence of groundwater inputs through observations of iron staining. Aquatic vegetation occupied approximately 15% of the channel and consisted of attached algae. There was a high density of woody debris jams present in the cutbank and channel, with approximately 5 woody debris jams per 50 m of the watercourse.

Average bankfull width and depth were 2.3 m and 0.5 m, respectively. Average wetted width and depth on the day of assessment were 1.9 m and 0.3 m, respectively. Bank angles ranged from 60° to 90° and consisted of clay/silt and sand. Evidence of erosion was observed through 30 to 60% of channel, with bank undercuts measuring up to 0.47 m in depth.

Reaches WC9-4 and **WC9-5** flow southwest to northeast through the subject property and extend from the existing farm crossing to the Nipissing Ridge. There is one (1) proposed feature to support the residential development through **Reaches WC9-4, and WC9-5.** This includes one (1) watercourse crossing at the upstream extent of **WC9-5.** This feature is identified on the preliminary reach map, provided in **Appendix B.**

Reaches WC9-4 and **WC9-5** were situated within a confined valley setting. The channel exhibited a meandering planform with irregular meanders and degree of sinuosity ranging from 1.31 to 3.0. The surrounding land use consisted of forest and pasture, and the reaches were located within a transfer zone. The riparian buffer zone was approximately 4 to 10 channel widths in size and had continuous coverage. The dominant type of riparian vegetation was established (5 to 30 years) and mature (greater than 30 years) tree species. There was moderate encroachment of vegetation into the channel. The reaches had perennial flow with a high gradient. Riffle pool spacing was approximately 5 m, with 50% of the watercourse occupied by riffles and 50% occupied by pools. Riffle substrate consisted of gravel, cobble, and boulders, and pool substrate consisted of gravel and cobble. Flow was clear and odourless, however, there was evidence of groundwater inputs through observations of iron staining. Aquatic vegetation occupied approximately 10% of the channel and consisted of attached algae. There was a moderate density of woody debris jams present in the cutbank and channel, with approximately 2 woody debris jams per 50 m of the watercourse.

Average bankfull width and depth were 4.95 m and 0.7 m, respectively. Average wetted width and depth on the day of assessment were 2.8 m and 0.17 m, respectively. Bank angles ranged

from 60° to 90° and consisted of clay/silt and sand. Evidence of erosion was observed through 30 to 60% of channel, with bank undercuts measuring up to 0.47 m in depth.

Reach WC9-6 extends from Grey Road 19 (the upstream limit of the subject property) to the existing farm crossing. A defined channel was not observed through **Reach WC9-6.** Rather, backwatering from the culvert at the existing farm crossing resulted in water pooling with multiple flow pathways. Additionally, there was heavy encroachment of vegetation within the system. Given there was no defined channel, the RGA and RSAT were not deemed appropriate.

2.3 Rapid Assessments

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.

These observations and measurements are summarized below. The descriptions are supplemented and supported with representative photographs, which are included in **Appendix C**. Field sheets, including those completed for RGA and RSAT assessments, are provided in **Appendix D**. All RGA and RSAT results for **Reaches WC9-1, WC9-2, WC9-3, WC9-4,** and **WC9-5** are summarized in **Table 1**. Given the lack of defined channel associated with **Reach WC9-6**, the RGA and RSAT were deemed not appropriate.

Reaches WC9-1, WC9-2, and **WC9-3** were assigned an RGA score of 0.28, indicating the reaches were *in transition/stress*. The dominant geomorphological indicator was evidence of widening by the observations of fallen/leaning trees and fence posts, exposed tree roots, basal scour on both sides of channel through the riffles, and the length of basal scour greater than 50% through the reaches. **Reaches WC9-1, WC9-2,** and **WC9-3** had an RSAT score of 30, or *good*. There was one limiting factor, including riparian habitat conditions, which was attributed to the riparian area being predominantly wooded with major localized gaps.

Reaches WC9-4 and **WC9-5** were assigned an RGA score of 0.44, indicating the reaches were *in adjustment*. The dominant geomorphological indicator was evidence of widening by the observations of fallen/leaning trees and fence posts, exposed tree roots, basal scour on both sides of channel through the riffles, the length of basal scour greater than 50% through the reaches and exposed length of previously buried pipe and water lines. **Reaches WC9-4** and **WC9-5** had an RSAT score of 31, or *good*. There was one limiting factor, including riparian habitat conditions, which was attributed to the riparian area being predominantly wooded with major localized gaps.

Moving upstream from the existing farm crossing, backwatering was observed, and no defined channel was visible through **WC9-6.** As such, the RGA and RSAT were deemed not appropriate.

Table 1. Summary of Rapid Assessment Results

Reach	RGA (MOE, 2003)			RSAT (Galli, 1996)		
	Score	Condition	Dominant Systematic Adjustment	Score	Condition	Limiting Feature(s)
WC9-1	0.28	In Transition/Stress	Widening	30	Good	Riparian Habitat Conditions
WC9-2	0.28	In Transition/Stress	Widening	30	Good	Riparian Habitat Conditions
WC9-3	0.28	In Transition/Stress	Widening	30	Good	Riparian Habitat Conditions
WC9-4	0.44	In Adjustment	Widening	31	Good	Riparian Habitat Conditions
WC9-5	0.44	In Adjustment	Widening	31	Good	Riparian Habitat Conditions
WC9-6	Not applicable – no defined watercourse					

3 Meander Belt Width and Erosion Hazard Limit Delineation

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

When defining the erosion hazard for a watercourse, Ministry of Natural Resources and Forestry (MNRF, 2002) guidelines treat unconfined and confined systems differently. Unconfined systems are those with poorly defined valleys or slopes well outside where the channel could realistically migrate. Confined systems are those where the watercourse is contained within a defined valley, where valley wall contact is possible. Based on field observations, **Reaches WC9-1, WC9-2,** and **WC9-3** are within an unconfined valley system, whereas **Reaches WC9-4** and **WC9-5** are within a confined valley system. Given there was no defined channel observed through **Reach WC9-6**, an erosion hazard was delineated based on available topographical information.

In unconfined systems, the meander belt boundaries centre along the general valley orientation and are defined as parallel lines drawn tangentially to the outside bends of the most laterally extreme meanders within the reach (TRCA, 2004). Georeferenced historical aerial imagery can be used to examine past positions and configurations of the channel planform and to delineate the channel centreline, and its central tendency (i.e., meander belt axis). In this case, historical aerial photographs were reviewed, but the channel planform was not discernable due to the density of vegetation surrounding both left and right banks.

Given that **Reaches WC9-1, WC9-2,** and **WC9-3** are within an unconfined valley, and changes to channel geometry and planform is not visible through available aerial imagery, a modelling approach was be used to determine a meander belt width. Specifically, empirical relations from

Williams (1986) were applied using average bankfull channel dimensions measured in the field by GEO Morphix to estimate the meander belt width (B_w) such that:

$$B_w = 4.3{W_b}^{1.12} + W_b \quad \text{[Eq. 1]}$$

Where W_b is average bankfull channel width (m). This modelling approach resulted in a meander belt width of 16.3 m for **Reaches WC9-1, WC9-2,** and **WC9-3**. An additional 20% buffer, or factor of safety, is included in these results to address issues of under prediction. The meander belt width for **Reaches WC9-1, WC9-2,** and **WC9-3** are graphically displayed in **Appendix B**.

To provide a supplementary analysis, the meander belt width was calculated based on TRCA's (2004) empirical model:

$$B_w = -14.827 + 8.319\ln(\rho g Q S * DA) \quad \text{[Eq. 2]}$$

where ρ is water density (1000 kg/m^3), g is acceleration due to gravity (9.8 m/s^2), Q is discharge (m^3/s), S is channel slope (m/m), and DA is drainage area (km^2). The TRCA meander belt width was determined using a drainage area of 0.02 km^2 and a 2-year discharge of 1.36 m^3/s. These values were provided by the Project Engineer (Crozier and Associates). A channel gradient of 0.064 m/m was used as well, which was determined based on available topographic data (Google Earth Pro). This modelling approach resulted in a meander belt width of 17.5 m for **Reaches WC9-1, WC9-2,** and **WC9-3**. An additional 20% buffer, or factor of safety, is included in these results to address issues of under prediction.

Based on the results of the meander belt width analysis, it is recommended that a 17 m meander belt width be applied through the downstream extent of Watercourse 9, particularly through **Reaches WC9-1, WC9-2,** and **WC9-3**. The meander belt width for **Reaches WC9-1, WC9-2,** and **WC9-3** are graphically displayed in **Appendix B**.

Reaches WC9-4 and **WC9-5** are within a confined valley, and therefore, require an alternate approach to delineating the erosion hazard. Where the watercourse is within 15 m of the valley toe of slope, the erosion hazard for **Reaches WC9-4** and **WC9-5** was delineated by implementing an erosion setback from the delineated toe of slope. An appropriate erosion setback was determined based the type of bed and bank substrate, and the level of active erosion observed. This approach is consistent with the protocol outlined by MNRF (2002).

Based on the stiff/hard cohesive soil (clays, clay silt) and coarse granular material (gravels), as well as evidence of active erosion observed through the confined sections of **Reaches WC9-4** and **WC9-5**, the minimum toe erosion allowance was identified as 5 to 8 m (MNRF, 2002). Given the size of the channel and its general overall stability, a 5 m toe erosion allowance is recommended. Based on MNRF's guidelines for minimum toe erosion allowance, this is an appropriate approach to the erosion hazard delineation.

It is important to note that the stable top of slope includes a combination of the erosion setback and the geotechnically defined stable top of slope (stable slope identified as 2.5:1). Further, for all locations through Watercourse 9 that are characterized by channel banks greater than 2.5 m in height, the erosion hazard is defined by the stable top of slope and erosion setback. In these locations, where the watercourse is within 15 m of the toe of slope, a 5 m erosion setback should be applied.

In some sections of **Reach WC9-4**, Watercourse 9 is greater than 15 m from the valley toe of slope. As such, a toe erosion allowance is not required. Rather, the erosion hazard is defined as the geotechnically stable top of slope (MNRF, 2002).

A defined watercourse was not observed through **Reach WC9-6.** Due to backwatering from the downstream culvert, the system exhibited various flow paths and locations of pooling water. Additionally, there was extreme encroachment of vegetation (mature shrubs and trees). There were no observations of active erosion through this reach, and as such, a 1 m erosion setback is recommended from the stable top of slope.

4 Recommendations for Erosion Protection and Bank Stability at Proposed Crossing Locations

It is understood that three (3) stormwater outfalls and two (2) watercourse crossings are proposed over Watercourse 9 within the subject property. Particularly at the proposed stormwater outfall locations, it is recommended that all outfalls avoid disturbance to forested valley slopes and adjacent wooded or wetland habitats, avoid erosion prone areas, and avoid disturbance to the low-flow channel. Additionally, reinforcement measures surrounding the outfall location (e.g. hydraulically sized materials) are recommended to reduce erosive velocities.

To address erosion protection and bank stability at the proposed watercourse crossing locations, channel form and function would be enhanced if a natural channel design approach was taken to restore the watercourse. The natural channel design approach would include the construction of resting pools upstream and downstream from each crossing, bioengineering to stabilize banks, and either a riffle-pool sequence or cascade pool geometries in the high gradient sections of channel. These restoration efforts, in combination with watercourse crossings sized appropriately based on hydraulic requirements, would provide erosion control, support fish habitat and refuge where current obstructions exist, and further, alleviate GSCA's concerns with regards to stabilization.

Before finalized measures for erosion protection and channel stabilization are provided to review Agencies, a meeting with the Project Team should be held to discuss potential impacts associated with the crossing size and type.

5 Summary and Conclusions

Watercourse 9 is a drainage feature originating from the escarpment (shore bluff) and flowing southwest to northeast towards Georgian Bay, within the Town of The Blue Mountains. The upstream extent of Watercourse 9 flows within a confined valley system, whereas the downstream extent of Watercourse 9 flows within an unconfined valley system. Through aerial photograph interpretation, it was determined that the channel planform has remained unchanged since the 1950s. This differs from land use, which was converted from primarily agricultural areas to residential areas. Currently, the subject property is occupied by agricultural and forested lands. This property is proposed for residential development, which will include two (2) stormwater outfall facilities and three (3) watercourse crossings.

Given the direct impact on Watercourse 9, and to address concerns from the GSCA, a fluvial geomorphological and erosion hazard assessment was completed. A field investigation was conducted on June 19, 2020 and included a rapid geomorphological assessment for **Reaches WC9-1, WC9-2, WC9-3, WC9-4,** and **WC9-5.** No defined channel was observed through **Reach WC9-6**, and as such, the RGA and RSAT were not deemed appropriate. Given the evidence of widening in select locations, **Reaches WC9-1, WC9-2, WC9-3** were identified as being *'in transition/stress'* with *'good'* overall conditions. Upstream, **Reaches WC9-4** and **WC9-5** were identified as being *'in adjustment'*, with *'good'* overall conditions.

A meander belt width and erosion setback were delineated for **Reaches WC9-1, WC9-2, WC9-3, WC9-4,** and **WC9-5**. Based on a review of aerial imagery, the available topographic survey, and collected site observations, two approaches to addressing the erosion hazard were applied. A modelling approach, including empirical relations from Williams (1986) and TRCA (2004), was applied to the unconfined system associated with Watercourse 9 (**Reaches WC9-1, WC9-2,** and **WC9-3**). This approach applied the average bankfull channel dimensions measured in the field by GEO Morphix to estimate the meander belt width. Results provided a meander belt width of 17 m. An additional 20% buffer, or factor of safety, was included in these results to address issues of under prediction.

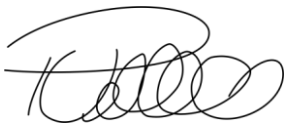
Additionally, the MNRF (2002) guidelines for erosion hazard delineation were applied to delineate an erosion hazard limit through the confined system associated with Watercourse 9 (**Reaches WC9-4** and **WC9-5**). Specifically, a 5 m toe erosion allowance was recommended to address the erosion hazard associated with the sections of **Reaches WC9-4** and **WC9-5** within 15 m from the valley toe of slope**.** The recommended setback is appropriate based on the MNRF (2002) guidelines for erosion hazard delineation. In sections of **Reach WC9-4** where Watercourse 9 was greater than 15 m from the valley toe of slope, a toe erosion allowance was not required. Rather, the erosion hazard is based on the geotechnically stable top of slope.

Given there was no defined channel or active erosion observed through **Reach WC9-6**, an erosion setback of 1 m is recommended. This erosion setback should be applied from the geotechnically stable top of slope.

Recommendations were provided to address erosion protection and bank stability at the proposed watercourse crossing and outfall locations. Resting pools upstream and downstream from each crossing, bioengineering to stabilize channel banks, and either a riffle-pool sequence or cascade pool geometries in the high gradient sections of channel were recommended. These restoration efforts, in combination with watercourse crossings sized appropriately based on hydraulic requirements, would provide erosion control, support fish habitat and refuge where current obstructions exist, and further, alleviate GSCA's concerns with regards to stabilization.

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

Respectfully submitted,



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Josie Mielhausen, M.Sc.
Junior Environmental Scientist

6 References

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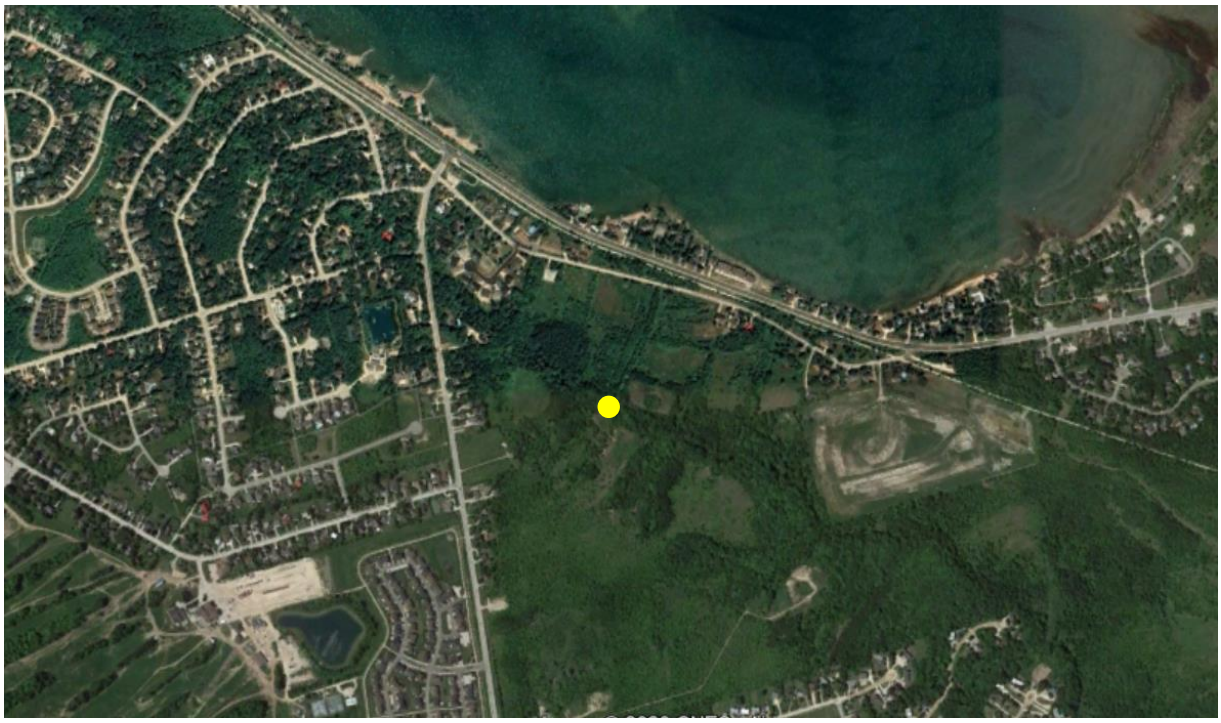
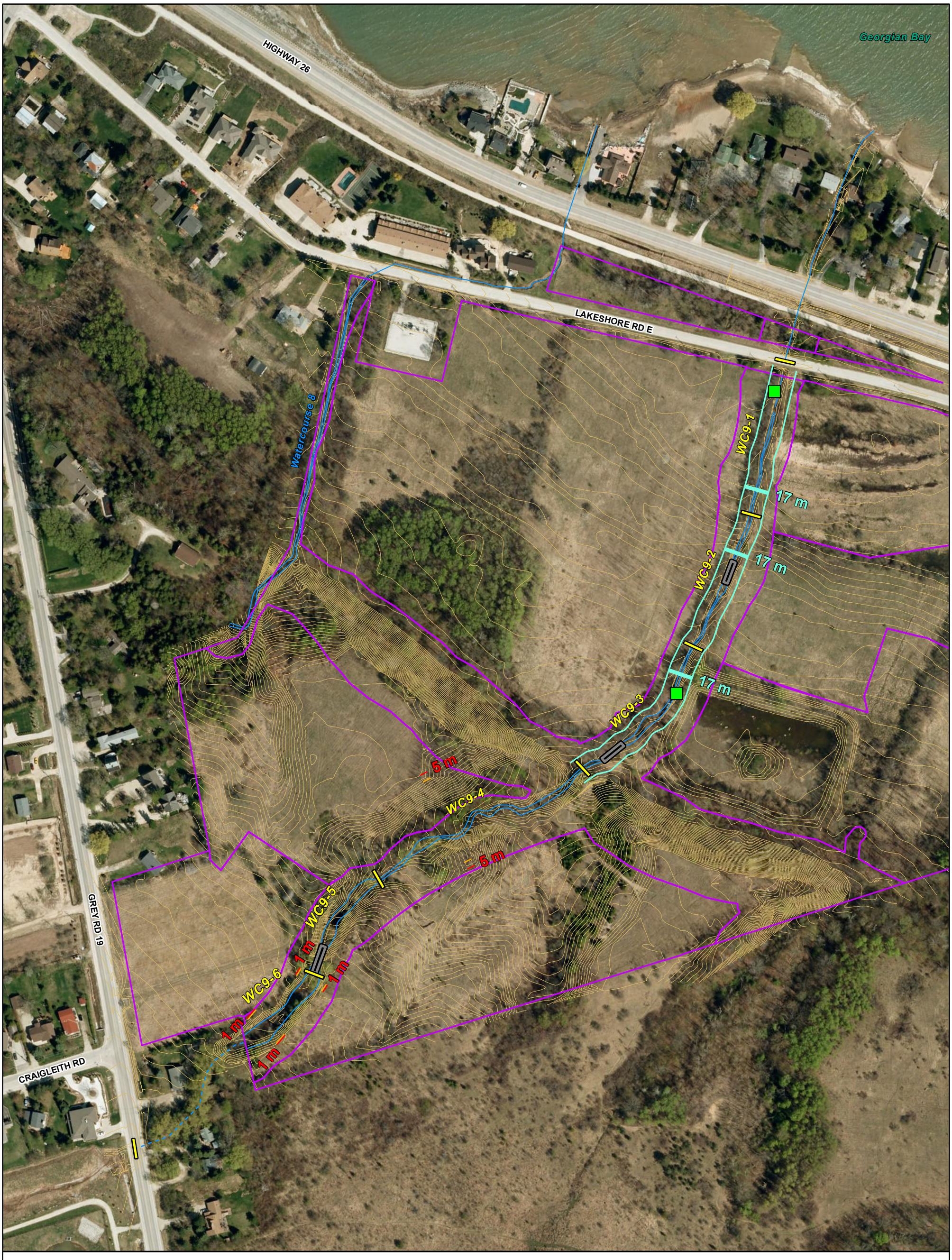
Appendix A
Historical Aerial Photographs

Location: Watercourse 9, Craigleith, Ontario (yellow dot)
Year: 2011
Source: Google Earth Pro (GEP)



Location: Watercourse 9, Craigleith, Ontario (yellow dot)
Year: 2019
Source: Google Earth Pro (GEP)

Appendix B
Reach Delineation and Erosion Hazard Mapping



Legend

- Reach break
- Proposed outfall location (approx.)
- Proposed crossing location (approx.)
- Watercourse
- Contour (50 cm)
- Stable top of slope (2.5:1)
- Erosion setback (1 m or 5 m)
- Meander belt width (17 m)
- Zoning setback

Meander Belt Width and Erosion Hazard Delineation

Watercourse 9

Craigleith Proposed Residential Development
Town of The Blue Mountains, Ontario

N

0 50
Metres

GEO MORPHIX™

Imagery: Maxar, 2014.
Reach break, Stable top of slope, Erosion setback, and Meander belt width: GEO Morphix Ltd., 2020.
Proposed outfall and crossing locations, Watercourse, Contour, and Zoning setback: C.F. Crozier & Associates Inc., 2020.

Appendix C
Photographic Record

Photo 1 Reach WC9 DS – Town of the Blue Mountains, Ontario	 Looking downstream at the furthest downstream extent of the reach and proposed outfall location. Watercourse 9 flows through a mix of forested and pasture lands, with mature tree species continuously occupying the riparian zone.
Photo 2 Reach WC9 DS – Town of the Blue Mountains, Ontario	 Riffle substrate ranged from gravel to cobble, with low embeddedness of coarse materials. Basal scour was present on both sides of the channel through riffles and is evident of channel of widening.

Photo 3 Reach WC9 DS – Town of the Blue Mountains, Ontario	 Bars were poorly formed and reworked throughout the reach. Poor longitudinal sorting of bed materials was observed.
Photo 4 Reach WC9 DS – Town of the Blue Mountains, Ontario	 There was a high density of woody debris present in the channel and cut bank. There were approximately 5 woody debris jams per 50 m of the reach.

Photo 5 Reach WC9 DS – Town of the Blue Mountains, Ontario	 Leaning and fallen trees were frequently noted through the extent of the reach. Leaning and fallen trees, as well as undercutting, provided evidence of channel widening.
Photo 6 Reach WC9 DS – Town of the Blue Mountains, Ontario	 Bank erosion was present through 30 to 60% of the reach and was observed through scouring of the channel banks. Basal scour was observed along more than 50% of total length.

Photo 7 Reach WC9 DS – Town of the Blue Mountains, Ontario	
	Thalweg alignment was out of phase with meander form and was observed in conjunction with poorly formed/reworked/removed bar forms.
Photo 8 Reach WC9 DS – Town of the Blue Mountains, Ontario	
	There was a good mix between riffles, runs and pools through the subject reach providing good physical instream habitat. Siltation in pools (circled) was indicative of aggradation.

Photo 9 Reach WC9 DS – Town of the Blue Mountains, Ontario	 A rooted knickpoint was observed with apparent head-cutting due to knickpoint migration upstream.
Photo 10 Reach WC9 DS – Town of the Blue Mountains, Ontario	 The wetted perimeter of the channel occupied > 85% of the bottom channel width. This improved physical instream habitat conditions.

Photo 11 Reach WC9 DS – Town of the Blue Mountains, Ontario	 Young exposed tree roots were common throughout the reach. Moving upstream, the outer bank height increased to greater than 1 – 2 m above the stream bank, contributing to instability.
Photo 12 Reach WC9 DS – Town of the Blue Mountains, Ontario	 The reach was a defined, single thread channel with low sinuosity and a moderate gradient. Substrate size and bed load increased moving upstream, as observed by small to large boulders.

Photo 13 Reach WC9 DS – Town of the Blue Mountains, Ontario	
	Looking downstream at the approximate location of a proposed watercourse crossing.
Photo 14 Reach WC9 DS – Town of the Blue Mountains, Ontario	
	Valley wall contact was common through the upstream sections of the reach. Bank materials consisted of silt, sand, gravel, and cobble.

Photo 15 Reach WC9 DS – Town of the Blue Mountains, Ontario	 A transitional zone is pictured here, with substantial variation in gradient commonly observed throughout the upstream portion of the reach.
Photo 16 Reach WC9 DS – Town of the Blue Mountains, Ontario	 Banks were densely vegetated with a mix of trees, shrubs, and herbaceous species.

Photo 17 Reach WC9 DS – Town of the Blue Mountains, Ontario	 Looking downstream at the approximate location of an additional proposed outfall. Valley wall contact was observed at the right bank.
Photo 18 Reach WC9 DS – Town of the Blue Mountains, Ontario	 Undercutting was the dominant type of bank failure with undercuts measured up to 0.47 m. Young and old exposed tree roots were common.

Photo 19 Reach WC9 DS – Town of the Blue Mountains, Ontario	 Iron staining along the channel bed and banks indicated there were groundwater contributions through the system.
Photo 20 Reach WC9 DS – Town of the Blue Mountains, Ontario	 The reach was a defined, single-thread channel, with developed riffle pool sequencing. Forested canopy coverage provided > 80% shading throughout, enhancing riparian habitat conditions.

Photo 21 Reach WC9 US – Town of the Blue Mountains, Ontario	 Photograph taken looking upstream from the downstream extent of Reach WC9-US. A preliminary reach break was established based on field observations.
Photo 22 Reach WC9 US – Town of the Blue Mountains, Ontario	 The valley was partially confined at the downstream extent of the reach and was evident by frequent valley wall contact.

Photo 23 Reach WC9 US – Town of the Blue Mountains, Ontario	 Basal scour observed on both sides of the channel through riffles was indicative of widening processes.
Photo 24 Reach WC9 US – Town of the Blue Mountains, Ontario	 There was a moderate density of woody debris present in the channel and cut bank. In some cases, woody debris was observed as fallen trees (pictured here). There were approximately 2 woody debris jams per 50 m of reach.

Photo 25 Reach WC9 US – Town of the Blue Mountains, Ontario	
	Bank erosion was present through 30 to 60% of the reach and was observed through scouring of the channel banks and undercutting (circled).
Photo 26 Reach WC9 US – Town of the Blue Mountains, Ontario	
	Looking upstream at the approximate location of a proposed watercourse crossing, where an all-terrain vehicle trail currently exists.

Photo 27 Reach WC9 US – Town of the Blue Mountains, Ontario	 Moving upstream, the valley transitioned to confined and outer bank heights increased to greater than 1 to 2 m above the stream bank, contributing to bank instability.
Photo 28 Reach WC9 US – Town of the Blue Mountains, Ontario	 Bank failure was present along outside meander bends. Undercuts up to 0.9 m were observed and exacerbated by leaning tree root systems.

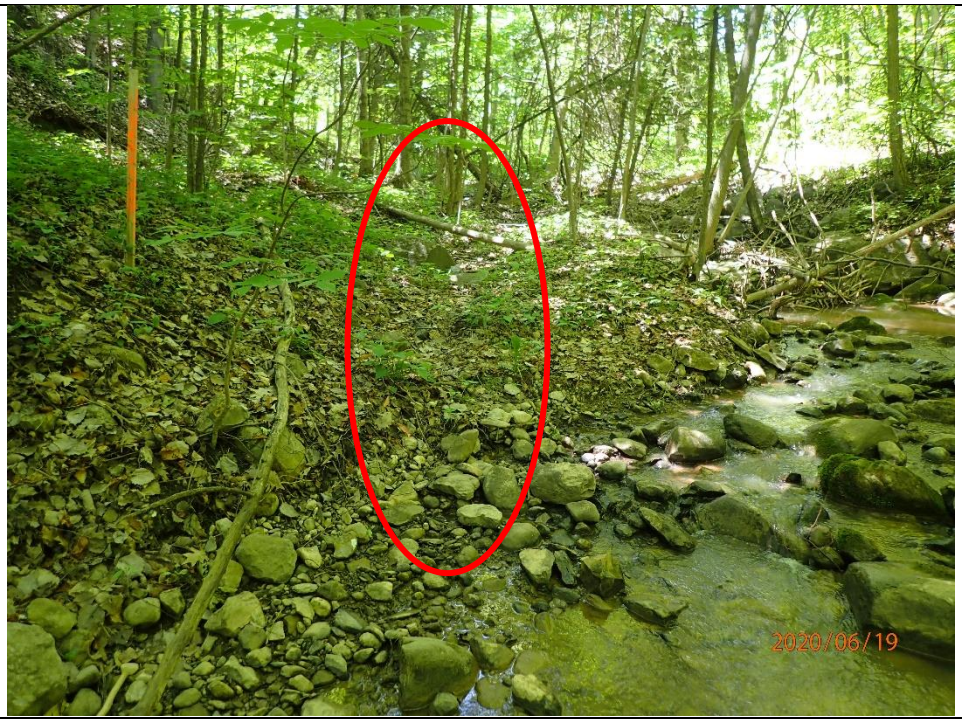
Photo 29 Reach WC9 US – Town of the Blue Mountains, Ontario	
	Bar forms were poorly formed or reworked, and the thalweg was out of phase with meander form indicating planimetric form adjustment processes.
Photo 30 Reach WC9 US – Town of the Blue Mountains, Ontario	
	Formation of a chute (circled) was observed providing further evidence of planimetric form adjustment.

Photo 31 Reach WC9 US – Town of the Blue Mountains, Ontario	 Throughout the reach there were multiple points of valley wall contact. In this area, the base of the valley wall showed evidence of undercutting, and bank failure/fallen trees showed evidence of widening.
Photo 32 Reach WC9 US – Town of the Blue Mountains, Ontario	 Bank materials through the reach ranged from clay to sand. Bank failure was present frequently.

Photo 33 Reach WC9 US – Town of the Blue Mountains, Ontario	 An exposed storm sewer and length of previously buried pipe was located at the upstream extent of the reach. Surrounding bank erosion and undercutting was present. This is indicative of both degradation and widening at this location.
Photo 34 Reach WC9 US – Town of the Blue Mountains, Ontario	 Banks were densely vegetated with trees, shrubs, and herbaceous species providing canopy coverage of > 80% shading throughout most of the reach.

Photo 35 Reach WC9 US – Town of the Blue Mountains, Ontario	 An elevated outfall was observed at the downstream extent of an existing watercourse crossing. A scour pool was present immediately downstream, indicative of degradation.
Photo 36 Reach WC9 US – Town of the Blue Mountains, Ontario	 Looking downstream at the existing crossing, where a future crossing is proposed. A rapid change in gradient was apparent.

Photo 37 Reach WC9 US – Town of the Blue Mountains, Ontario	 Downstream view at the upstream extent of the reach. Evidence of widening and degradation were the key geomorphic indicators of channel stability through the reach.
Photo 38 Upstream Wetland – Town of the Blue Mountains, Ontario	 Watercourse 9 was predominantly a wetland environment in the headwater zone where the channel originates.

Photo 39 Upstream Wetland – Town of the Blue Mountains, Ontario	 Downstream view of the system at the upstream study limits. Pooling was present in the wetland dominated area (circled). No defined banks were observed.
Photo 40 Upstream Wetland – Town of the Blue Mountains, Ontario	 Looking upstream at the upstream study limits. There was no defined channel or surface water observed.

Appendix D
Field Assessment Sheets

GEO MORPHIX
Geomorphology Earth Science Observations

General Site Characteristics

Project Code: PN20058

Date:	June 19, 2020	**Stream/Reach:**	Watercourse 9 (D/S) WC9-1/2/3
Weather:	Sunny 28°C	**Location:**	Craigleith (Blue Mountain)
Field Staff:	BB + JM	**Watershed/Subwatershed:**	Craigleith - Camperdown

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

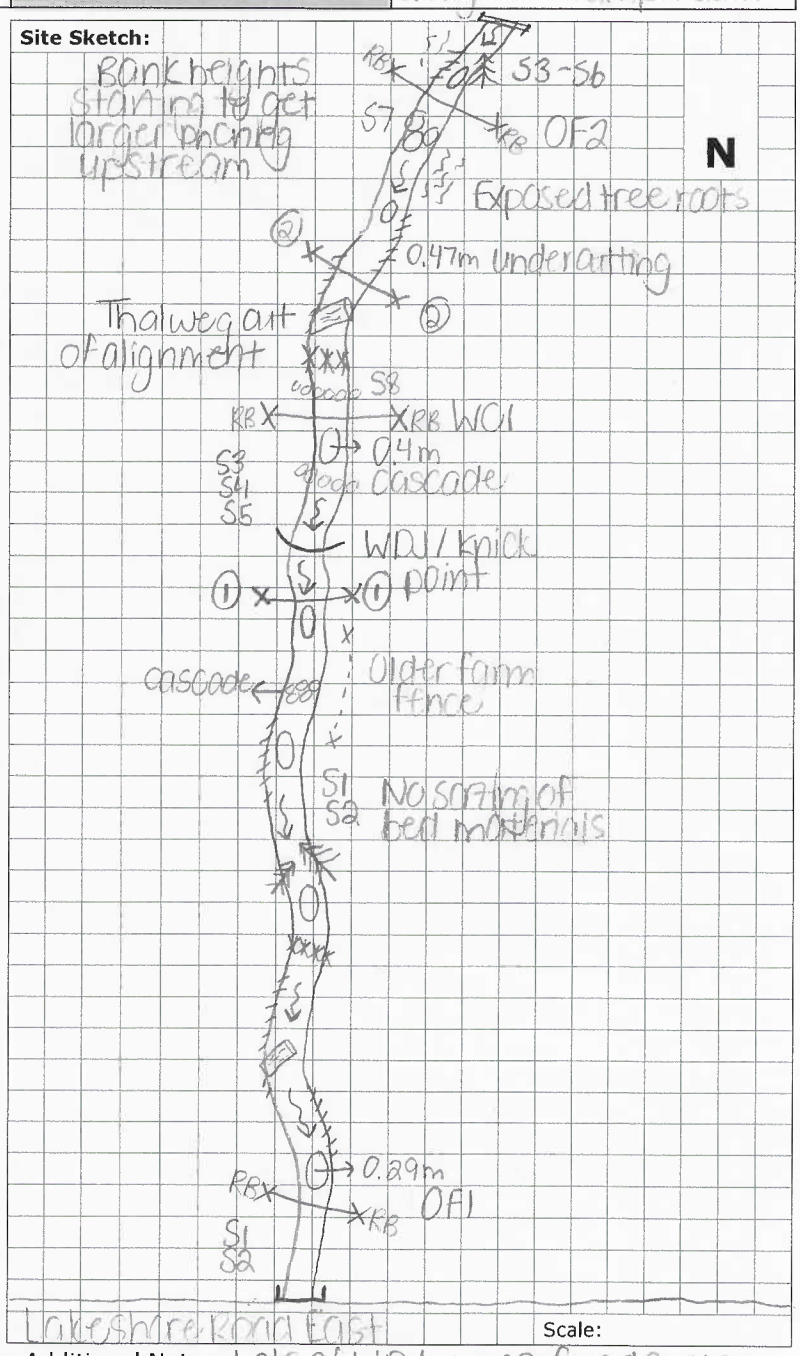
Substrate

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:



Additional Notes: Lots of WDJ, unconfined system flowing into confined system, dense vegetation throughout, monumented cross-sections established at crossing + outfall locations, velocity measurements collected at crossing + outfall locations.

Completed by: JM Checked by: _____

GEO MORPHIX
Geomorphology Earth Science Observations

Reach Characteristics

Project Code: PN20058

Date:	June 19, 2020	**Stream/Reach:**	Watercourse 9 (DIS) WC9-1/2/3
Weather:	Sunny 28°C	**Location:**	Craigleith (Town of Blue Mountain)
Field Staff:	JM + BB	**Watershed/Subwatershed:**	Craigleith - Camperdown
UTM (Upstream)	553998.22mE, 4929892.65mN	**UTM (Downstream)**	554108.11mE, 4930153.36mN

Land Use (Table 1): 112 | **Valley Type** (Table 2): 1 | **Channel Type** (Table 3): 7 | **Channel Zone** (Table 4): 2 | **Flow Type** (Table 5): 1 | ☑ Groundwater | Evidence: Iron staining

Riparian Vegetation

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

Aquatic/Instream Vegetation

Type (Table8): 6 | **Coverage of Reach (%):** 15

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): 1 | **Sinuosity (Degree)** (Table 10): 2 | **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): M

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

Bankfull Width (m)	2.7	2.0	2.3	**Wetted Width (m)**	2.0	1.7	1.9
Bankfull Depth (m)	0.5	0.6	0.4	**Wetted Depth (m)**	0.3	0.37	0.12

Riffle/Pool Spacing (m): 5 | **% Riffles:** 60 | **% Pools:** 40 | **Meander Amplitude:** 5

Pool Depth (m): 0.29 | **Riffle Length (m):** 2 | **Undercuts (m):** 0.21, 0.47 | **Comments:** _____

Velocity (m/s): 0.07 | 0.2 | 0.55 | **Wiffle ball / ADV / Estimated**

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

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

Notes:
→ Minnows observed thraigh reach
→ Dense vegetation within the riparian buffer

Completed by: JM | Checked by: _____

GEO | MORPHIX

Rapid Geomorphic Assessment **Project Code:** PN20058

Date:	June 19, 2020	**Stream/Reach:**	Watercourse 9 (DIS) WC9-1/2/3
Weather:	Sunny 28°C	**Watershed/Subwatershed:**	Craigleith - Camperdown
Field Staff:	BB + JM	**Location:**	Craigleith (Blue Mountain)

Process	Geomorphological Indicator		Present?		Factor Value
	No.	Description	Yes	No	
Evidence of Aggradation (AI)	1	Lobate bar		X	2/7
	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 =	2	5	0.28
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 knickpoint 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	7	0
Evidence of Widening (WI)	1	Fallen / leaning trees / fence posts / etc.	X		4/7
	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.	N/A		
	7	Length of basal scour >50% through subject reach	X		
	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 =	4	3	0.57
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 =	2	5	0.28

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: JM Checked by: _____

Rapid Stream Assessment Technique

Project Code: PN20058

Date:	June 19, 2020	**Stream/Reach:**	Watercourse 9 (DIS) WC9-1/2/3
Weather:	Sunny 28°C	**Location:**	Craigleith (Blue Mountain)
Field Staff:	BB + JM	**Watershed/Subwatershed:**	Craigleith - Camperdown

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**

WC9-1/2/3

Date:	June 19, 2020	Reach:	Watercourse 9/D	Project Code:	PN20058

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) = 30	Poor (<13)	Fair (13-24)	Good (25-34)	Excellent (>35)

Completed by: JM Checked by: _____

GEO MORPHIX
Geomorphology Earth Science Observations

General Site Characteristics

Project Code: 20058

Date:	June 19, 2020	**Stream/Reach:**	Watercourse 9 (UIS) WC9-4/5
Weather:	Sunny 28°C	**Location:**	Craigleith (Blue Mountains)
Field Staff:	BB + JM	**Watershed/Subwatershed:**	Craigleith - Camperdown

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

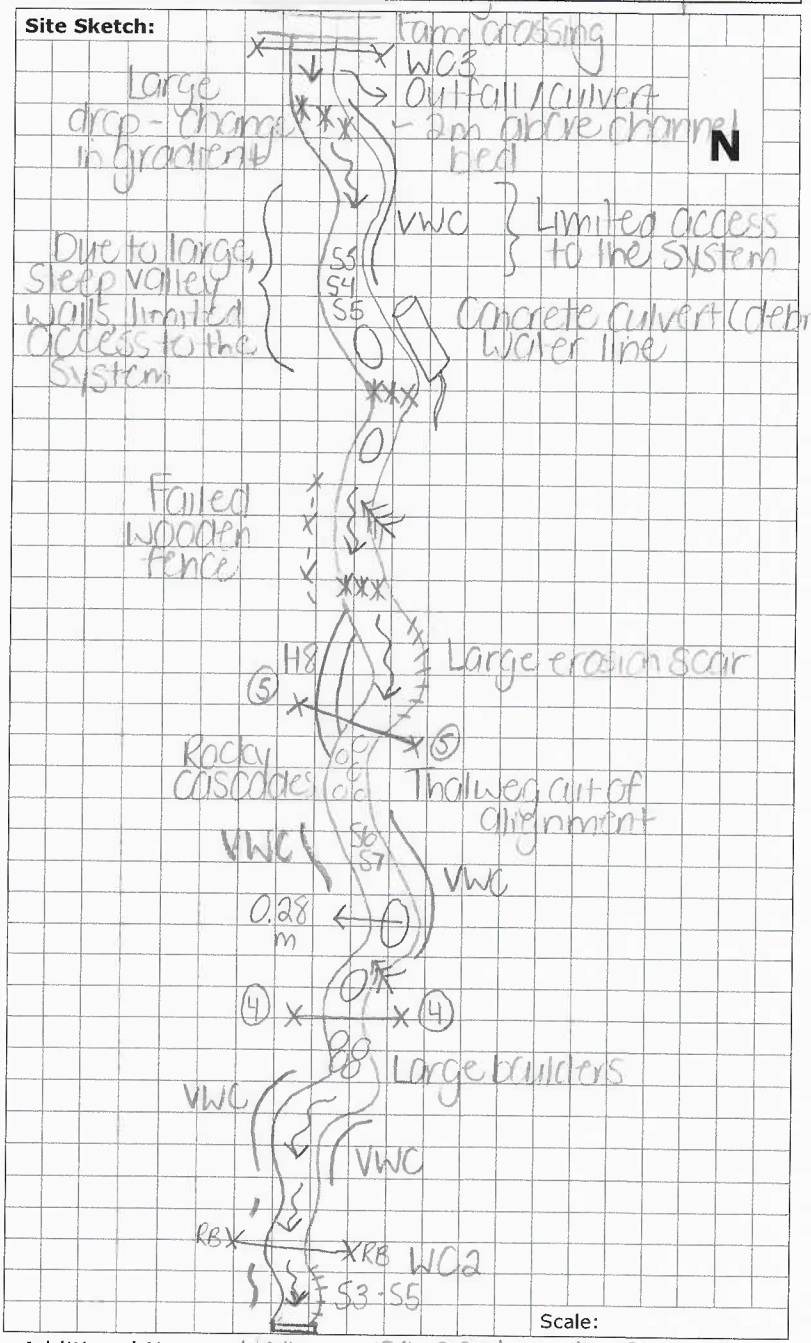
Substrate

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:



Additional Notes: Valley wall contact through the reach, limited access upstream due to steep valley walls, large drops/changes in gradient, fish passage obstructions, opportunities for improved connectivity

Completed by: JM Checked by: _____

GEO MORPHIX
Geomorphology Earth Science Observations

Reach Characteristics

Project Code: PN20058

Date:	June 19 2020	**Stream/Reach:**	Watercourse 9 (UIS) WC9-4/5
Weather:	Sunny 28°C	**Location:**	Craigleith (Town of Blue Mountains)
Field Staff:	BB + JM	**Watershed/Subwatershed:**	Craigleith - Comperdown
UTM (Upstream)	553781.61mE, 4929749.98mN	**UTM (Downstream)**	553992.90 mE, 4929882.44mN

Land Use (Table 1): 1/2 | **Valley Type** (Table 2): 2 | **Channel Type** (Table 3): 8 | **Channel Zone** (Table 4): 2 | **Flow Type** (Table 5): 1 | ☑ Groundwater | Evidence: Iron staining

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): 6 | **Coverage of Reach (%):** 10

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

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

WDJ/50m: 2

Water Quality

Odour (Table 16): 1

Turbidity (Table 17): 1

Channel Characteristics

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

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

Bankfull Width (m)	4.5	5.1	5.2	**Wetted Width (m)**	2.7	4.1	1.6
Bankfull Depth (m)	0.57	0.58	0.95	**Wetted Depth (m)**	0.12	0.15	0.25

Riffle/Pool Spacing (m): 5 | **% Riffles:** 50 | **% Pools:** 50 | **Meander Amplitude:** 8.3

Pool Depth (m): 0.28 | **Riffle Length (m):** 2.5 | **Undercuts (m):** 0.9

Velocity (m/s): 0.06 | 0.37 | 0 | **Wiffle ball / (ADV) / Estimated**

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

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

Comments: Undercutting present along outside meander bends

Notes:
→ Several rocky + wood cascades
→ Minnow sp. throughout the reach
→ Several instances of valley wall contact

→ Steep banks limited access at some locations
→ Several locations with banks > 5m in height

Completed by: JM | Checked by: _____

GEO | MORPHIX

Rapid Geomorphic Assessment

Project Code: PN20058

Date:	June 19, 2020	**Stream/Reach:**	Watercourse 9 (U/S) WC9-4/5
Weather:	Sunny 28°C	**Watershed/Subwatershed:**	Craigleith - Camperdown
Field Staff:	BB + JM	**Location:**	Craigleith (Blue Mountains)

Process	No.	Geomorphological Indicator	Present? Yes	Present? No	Factor Value
Evidence of Aggradation (AI)	1	Lobate bar		X	2/7
	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 =	2	5	0.28
Evidence of Degradation (DI)	1	Exposed bridge footing(s)		X	4/9
	2	Exposed sanitary / storm sewer / pipeline / etc.	X		
	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 knickpoint 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 =	4	5	0.44
Evidence of Widening (WI)	1	Fallen / leaning trees / fence posts / etc.	X		5/8
	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.	N/A		
	7	Length of basal scour >50% through subject reach	X		
	8	Exposed length of previously buried pipe / cable / etc.	X		
	9	Fracture lines along top of bank		X	
	10	Exposed building foundation	N/A		
		Sum of indices =	5	3	0.63
Evidence of Planimetric Form Adjustment (PI)	1	Formation of chute(s)	X		3/7
	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 =	3	4	0.43

Additional notes:

Stability Index (SI) = (AI+DI+WI+PI)/4 = 0.44

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

Completed by: JM Checked by: _____

Rapid Stream Assessment Technique

Project Code: PN20058

Date:	June 19, 2020	**Stream/Reach:**	Watercourse 9 (VIS) WC9-4/5
Weather:	Sunny 28°C	**Location:**	Craigleith (Town of Blue Mountains)
Field Staff:	BR + JM	**Watershed/Subwatershed:**	Craigleith - Camperdown

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

WC9-4/5

Date:	June 19, 2020	Reach:	Watercourse 9 (WC9)	Project Code:	PN20058

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) = 31	Poor (<13)	Fair (13-24)	Good (25-34)	Excellent (>35)

Completed by: JM Checked by: _____