APPENDIX

K FLUVIAL GEOMORPHOLOGY

ENVIRONMENTAL ASSESSMENT STUDY OF ARTERIAL ROADS WITHIN HIGHWAY 427 INDUSTRIAL SECONDARY PLAN AREA (AREA 47) – PART A

CITY OF BRAMPTON

FLUVIAL GEOMORPHIC COMPONENT

Prepared for:
WOOD ENVIRONMENT & INFRASTRUCTURE SOLUTIONS

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APPENDICES

1 INTRODUCTION

Wood Environment & Infrastructure Solutions retained Matrix Solutions Inc. to provide fluvial geomorphic support for the environmental assessment (EA) of the arterial roads within the Highway 427 Industrial Secondary Plan (Area 47) in the City of Brampton. This study is being completed as part of a Municipal Class EA (Phases 3 and 4) for arterial roads in Area 47. Area 47 is bound by Mayfield Road to the north, Castlemore Road to the south, The Gore Road to the west, and Regional Road 50 to the east (Figure 1). This report serves as an update to the fluvial geomorphic assessment completed by Matrix, titled *Environmental Assessment Study of Arterial Roads within Highway 427 Industrial Secondary Plan Area (Area 47), City of Brampton, Fluvial Geomorphic Component* (Matrix 2020), in October 2020. This report contains information only pertaining to the Part A Study Corridor and fluvial geomorphic concepts for the two road crossings have been included.

As part of the Highway 427 Industrial Secondary Plan (Area 47) Transportation Master Plan, the City of Brampton identified locations for new arterial roads as well sites for widening and other improvements for existing roads. As such, within the study area, new north-south and east-west arterial roads are proposed along with the proposed widening of existing Countryside Drive, Clarkway Drive, and Coleraine Drive. The Class EA consists of two parts: Part A includes the proposed Arterial A2 and improvements and realignment of Coleraine Drive and Part B includes improvements to Countryside Drive and Clarkway Drive, as well as the proposed East-West Arterial Road. The focus of this report will be to outline the fluvial geomorphic findings related to the Part A Study Corridor.

The proposed works to the Part A Study Corridor will modify and/or create two watercourse crossings of West Humber tributary Rainbow Creek (Figure 1). Such activities require a fluvial geomorphic assessment of all proposed and existing watercourse crossings to mitigate the impact to watercourses and inform the design of crossing structures and road designs. This report reflects the tasks that have been completed through the geomorphic assessment to meet the requirements of the Class EA for the Part A Study Corridor. A subsequent report summarizing fluvial geomorphic findings for the Part B Study Corridor will be issued separately at a later time.

1.1 Aims and Objectives

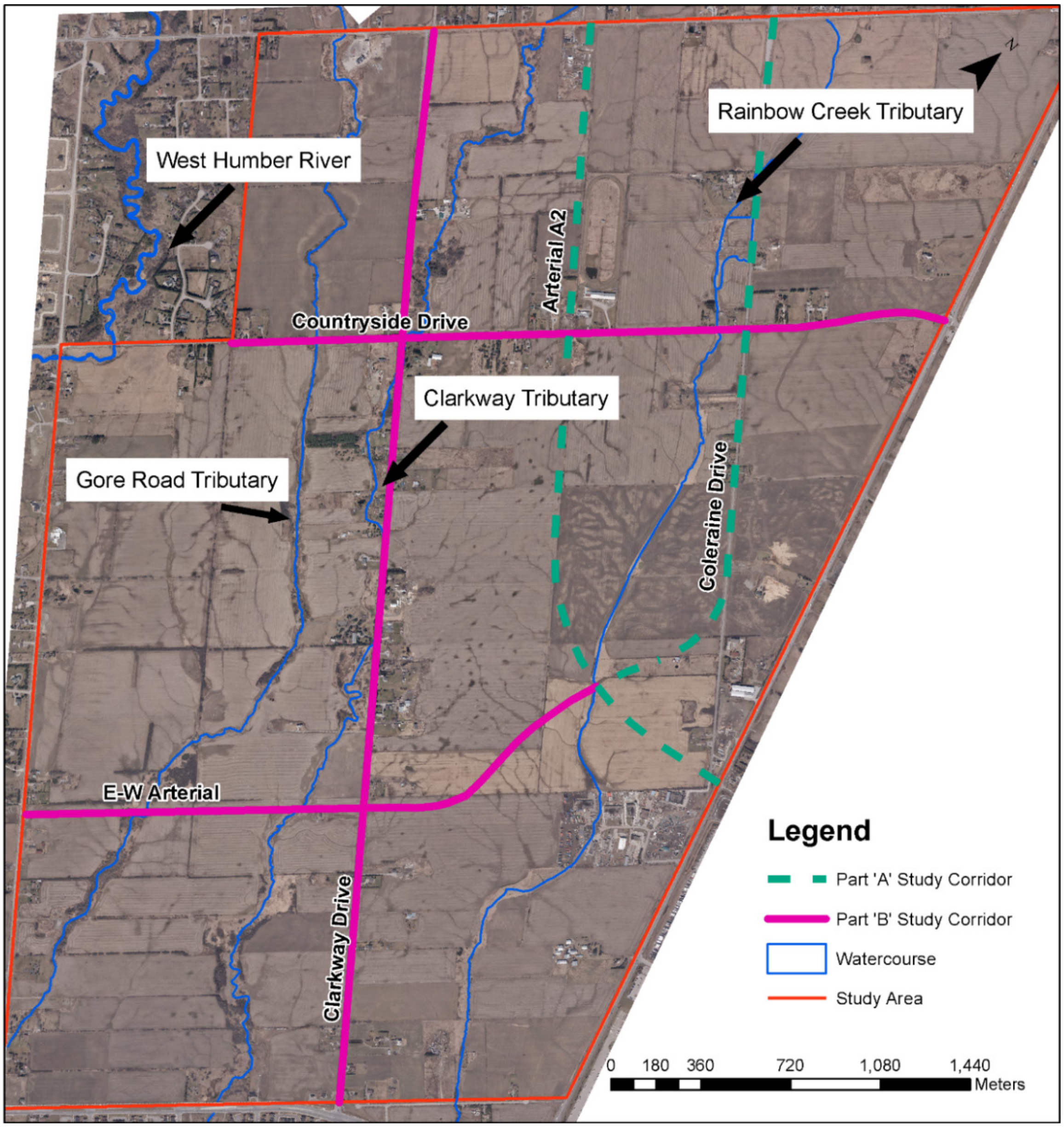
Watercourse crossings are typically evaluated through a risk-based approach, which collectively reviews geomorphic processes and stability within the vicinity of each crossing and identifies risks associated with the placement, sizing, and structure type at each location. In order to evaluate each of the two watercourse crossings and estimate appropriate structure sizes, the following tasks were completed:

- collecting and reviewing relevant background information, including topographic mapping, historic aerial imagery, the *Master Environmental Servicing Plan: Highway 427 Industrial Secondary Plan Area ("Area 47")* completed by Aquafor Beech Limited (2016) and various other reports.

- delineating meander belt widths and 100-year erosion rates based on existing and historical planform and empirical relations

- completing a field investigation to characterize channel geometry and document existing fluvial geomorphic conditions and stability

- providing comments and recommendations in relation to the location, size, and configuration of the road crossings using a risk-based approach



*Location and alignments of East-West (E-W) Arterial and Arterial A2 have been updated based on the revised block plan.
**Alignment of E-W Arterial Road subject to change as per preliminary preferred design

FIGURE 1 Area 47 Study Area with Part 'A' and Part 'B' Study Corridors

2 BACKGROUND REVIEW

2.1 Study Area

The Highway 427 Industrial Secondary Plan (Area 47) study area consists of approximately 1,200 ha in the northeast portion of the City of Brampton and is bound by Mayfield Road to the north, Castlemore Road to the south, The Gore Road to the west, and Regional Road 50 to the east. The study area lies within portions of the Humber River watershed and includes sections of Rainbow Creek, The Gore Road Tributary, and Clarkway Tributary, all of which have general north-south alignments (Figure 1).

The study area is located on portions of the South Slope and Peel Plain physiographic regions, south of the Oak Ridges Moraine. Topography across the study area consists of gently-rolling, drumlinized terrain, sloping south toward Lake Ontario, which is comprised of till plains, primarily consisting of clay- to silt-textured material with inclusions of sand and gravel (Chapman and Putnam 2007). Bedrock geology consists of shale, limestone, dolostone, and siltstone from the Georgian Bay and Blue Mountain formations. Note that bedrock does not outcrop in the watercourse valley or channel. Existing land use is primarily agricultural, rural-residential, and mixed industrial/commercial.

2.1.1 The Gore Road Tributary

The Gore Road Tributary originates in the Town of Caledon, north of the study area. The corridor is well defined through the study area, flowing in a general north-south alignment from Mayfield Road to The Gore Road, just north of Castlemore Road.

2.1.2 Clarkway Tributary

Clarkway Tributary also originates in the Town of Caledon. Within the study area the corridor is generally well defined with vegetation and valley walls; however, there are some reaches where valley extents become ill defined.

2.1.3 Rainbow Creek Tributary

The Rainbow Creek Tributary is an intermittent watercourse that originates in the Town of Caledon, north of the study area. The tributary flows southwest through the study area through an ill-defined valley corridor. The tributary drains to the main branch of Rainbow Creek and then to its confluence with the Humber River. Watercourse crossings within the Part A Study Corridor are all within Rainbow Creek.

2.1.4 Robinson Creek Tributary

In addition to the primary watercourses within the study area listed above, portions of the eastern limits of the study area drain headwater drainage features (HDFs) associated with Robinson Creek. These features drain southeast across Regional Road 50 in the area of Countryside Drive.

2.1.5 West Humber River

A relatively short reach of the West Humber River is located toward the western limit of the study area, extending for approximately 270 m upstream from The Gore Road to Countryside Drive. This reach is not expected to be impacted as a result of road widening nor arterial road construction. The widening of Countryside Drive will begin approximately 700 m east of The Gore Road; therefore, the existing crossings of the West Humber River will not be affected by the proposed improvements to Countryside Drive.

2.2 Previous Reports

Review of relevant background studies and assessments for the study area provides insight on channel characteristics and overall geomorphic setting. Studies reviewed include the Master Environmental Servicing Plan: Highway 427 Industrial Secondary Plan Area ("Area 47") (Aquafor Beech 2016), the Peel-Highway 427 Extension Area Transportation Master Plan (Region of Peel 2009) and various other environmental studies

The MESP, completed by Aquafor Beech (2016), includes characterization of existing conditions within the Area 47 study area specific to watercourses, hydrology, hazard lands, and natural heritage. The report contains a fluvial geomorphic study of all watercourses within the study area and outlines watercourse reach breaks, meander belt widths, and rapid assessment scores aimed at characterizing the overall stability of watercourse features and dominant channel processes.

This report will build on the Area 47 2016 MESP findings and provide recommendations and geomorphic characterization specific to watercourse crossings within the Part A Study Corridor.

3 DESKTOP ASSESSMENT

3.1 Reach Delineation

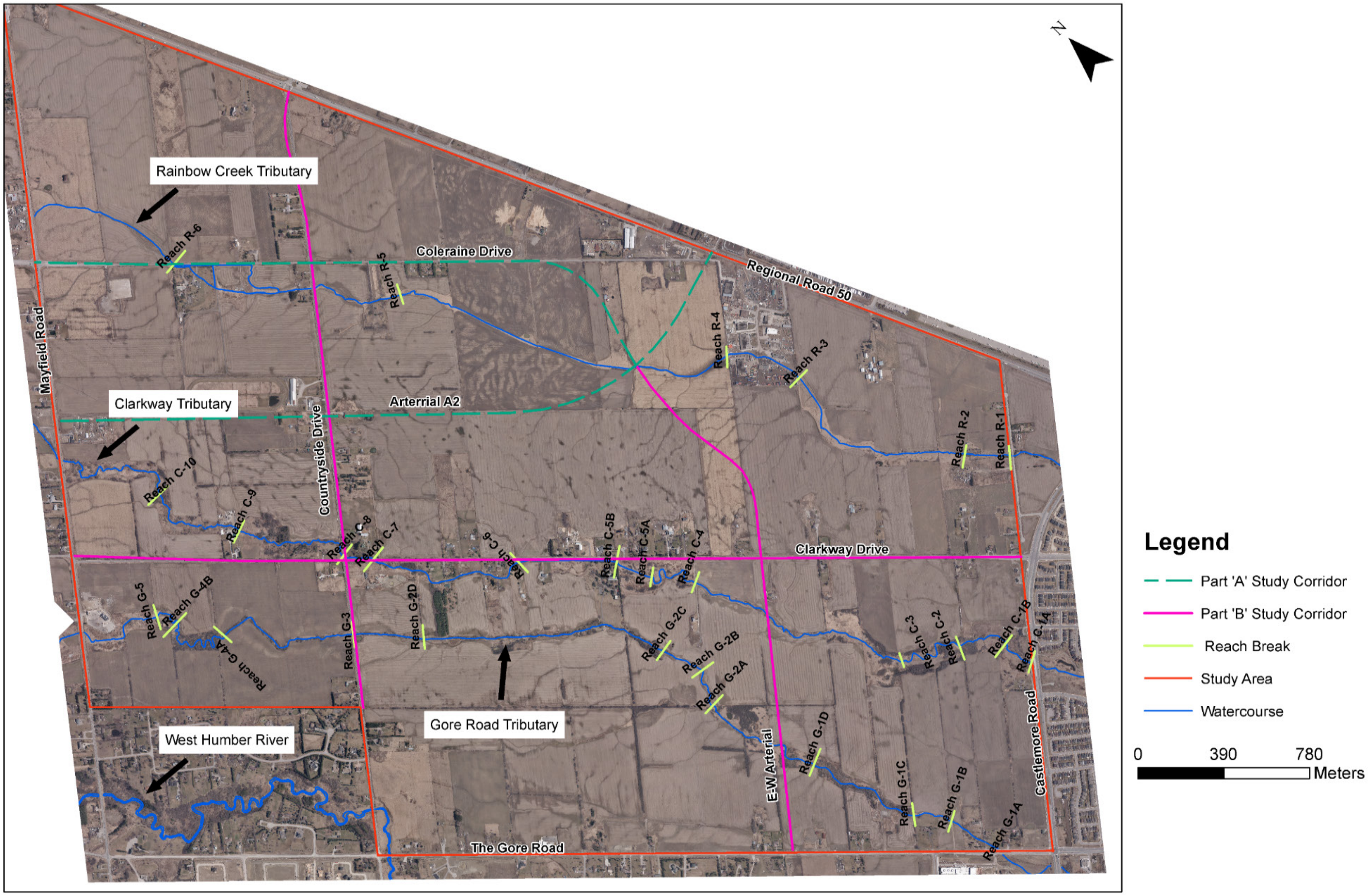
Reaches are lengths of channel (typically 200 m to 2 km in length) that display similarity with respect to valley setting, gradient, hydrology, local geology, vegetation, and other similar characteristics. Therefore, the controlling and modifying influences within a reach are assumed to be similar and are relatively consistent geomorphic form, function, and processes within the reach. For the purposes of this assignment, reaches were delineated in the vicinity of the crossings and follow the same nomenclature as the 2016 MESP (Aquafor Beech 2016). Road crossings often serve as reach breaks due to impacts from the crossing structure or changes in land use on either side of the road that impact channel morphology. Reaches are illustrated in Figure 2.

3.2 Identification of Crossing Locations

Existing and proposed stream crossings were initially identified using current aerial photography and topographic mapping resources and were subsequently refined based on field reconnaissance and updated road alignment designs. Two watercourse crossing locations of Rainbow Creek were identified in the Part ‘A’ Study Corridor (Table 1). Several other crossing locations were identified and correspond to HDFs, swales, or roadside drainage ditches that ultimately join to one of the major watercourses within the study area. Crossing recommendations for HDFs would be deferred to hydraulic flow conveyance requirements as there would be no fluvial geomorphic conditions to maintain. Therefore, these features are not included in subsequent recommendations. Crossing locations are identified in Figure 3.

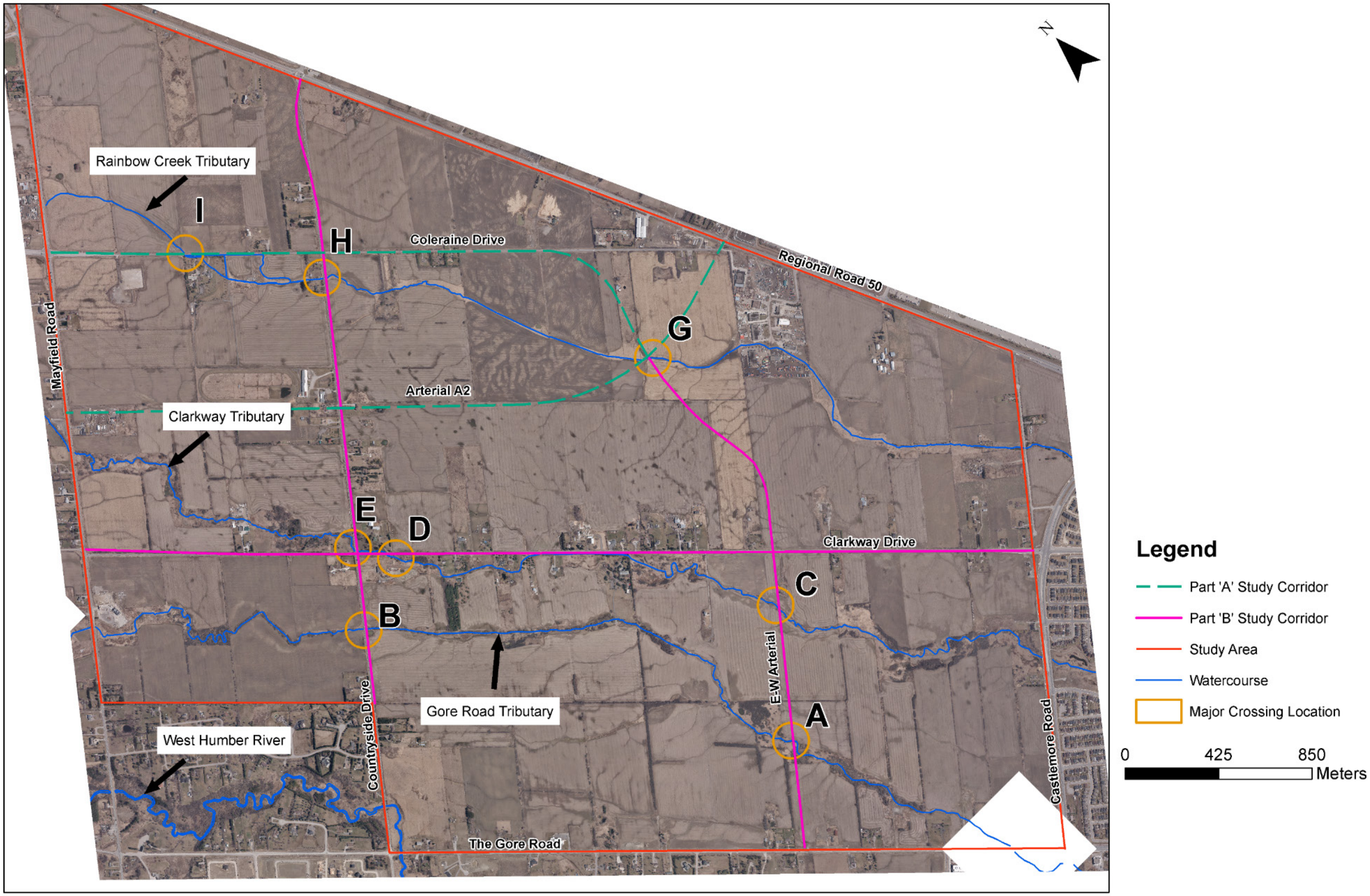
TABLE 1 Watercourse Crossing Locations within Part ‘A’ Study Corridor

Watercourse	Reach Name	Crossing ID	Crossing Location	
			Easting	Northing
Rainbow Tributary	R-4	G	605641	4852528
	R-6	I	604479	4854343



**Alignment of E-W Arterial Road subject to change as per preliminary preferred design

FIGURE 2 Area 47 Watercourse Reach Breaks



**Alignment of E-W Arterial Road subject to change as per preliminary preferred design

FIGURE 3 Area 47 Watercourse Crossing Locations

4 HISTORICAL ASSESSMENT

Streams are dynamic features which naturally adjust their configuration and position within the floodplain as a result of meander evolution and development and channel migration processes. These lateral and down-valley planform adjustments can be observed and often quantified by reviewing historical aerial photographs. Depending on photograph quality and scale of the channel of interest, erosion rates may be determined by measuring the distance from known control points to a governing meander bend over the available historical record and then projected to determine an erosion limit (e.g., 100-year limit).

In the context of this study, historical aerial photographs were analyzed to determine changes in surrounding land use, which may have directly and indirectly impacted channel migration. For the study area, aerial photographs from 1954, 1978, and 2015, spanning a time period of 61 years, were georeferenced and reviewed for changes in land use and planform. Historical planforms of the watercourses were traced in order to determine channel migration rates. Upon reviewing the historical images, land use is predominantly agricultural and rural-residential and has changed minimally over the past 60 years. Historical images are presented in Appendix A and results of the historic assessment are outlined below:

- Land use has remained predominantly rural with scattered dwellings since 1954. Residential dwellings were present northwest of the study area in 1954 and were greater in number in 1978. However, since 1978, residential development has also begun to encroach south of the study area.

- Castlemore Road was widened and realigned between 1978 and 2004. At this time, the Clarkway Tributary crossing, which had a span of approximately 7 m as measured from the 1987 imagery, was replaced with a larger approximate 13 m span structure. Between 1999 and 2013, Castlemore Road was further widened to six lanes, and the crossing was extended.

- Between 1978 and 2004, many industrial developments within the study area have impacted the watercourses, including development of Highway 50, which channelized Rainbow Creek Reach R-3, and light-industrial development on Clarkway Drive has impacted the channel morphology at Reach C-9.

- The stream crossings on Clarkway Drive, Countryside Drive, and Coleraine Drive appear in 1954 at the existing locations.

5 FIELD RECONNAISANCE

5.1 Methodology

Following the desktop assessment, field reconnaissance was undertaken at each of the Part A stream crossing locations where property access was granted. At each location, the following assessments were undertaken as required:

- Rapid Geomorphic Assessment (RGA)
- Rapid Stream Assessment Technique (RSAT)
- Stream Crossing Assessment

Results of the field assessments are described for each study reach in Section 5.2. A photographic inventory of study reaches is displayed in Appendix C.

5.1.1 Rapid Geomorphic Assessments

The RGA is a semi-quantitative technique, developed by the Ontario Ministry of the Environment (currently the Ministry of Environment, Conservation and Parks; MOE 2003) to document indicators of channel instability. Observations are quantified using an index that identifies channel sensitivity based on the presence or absence of aggradation, degradation, channel widening, and planform adjustment at the reach scale. Overall, the index produces values that indicate whether the channel is “stable” or “in regime” (score of less than or equal to 0.20), “transitional” or “stressed” (score of 0.21 to 0.40), or “adjusting” (score of 0.41 or greater) (Table 3). A stable score indicates that the channel morphology is within a range of variance for streams of similar characteristics. Any evidence of instability is isolated or associated with normal river meander propagation processes. A transitional score indicates that the channel morphology is within the range of variance of streams of similar hydrographic characteristics, but the evidence of instability is more frequent. An adjusting score indicates that the channel morphology is not within the range of variance, and evidence of instability is widespread

The RSAT was developed by the Metropolitan Washington Council of Governments (Galli 1996) and provides a more qualitative and broader assessment of the overall health and functions of a reach. This system integrates visual estimates of channel conditions and numerical scoring of stream parameters using six categories:

- channel stability
- erosion and deposition
- instream habitat
- water quality
- riparian conditions
- biological indicators

Once a condition is assigned a score, to the tool produces an overall rating based on a 50-point scoring system, divided into three classes:

- <20 Low
- 20 to 35 Moderate
- >35 High

During the rapid assessments, bankfull channel dimensions are identified. In natural, stable streams, the bankfull channel area often represents the maximum capacity of the channel before flow spills into the floodplain, and the discharge at this stage is referred to as the bankfull discharge. Field indicators of bankfull flow elevation include obvious breaks or inflections in the cross-section profile, the top elevation of point bars, and changes in vegetation.

5.1.2 Stream Crossing Assessment

The stream crossing assessment collects data specific to the channel and crossing structure within the vicinity of the road crossing. Information recorded includes crossing type, material, shape, dimensions, structural condition, as well as an assessment of potential issues relating to the channel near the crossing (e.g., bank erosion, bed scour, debris trapping, and fish passage).

5.2 Existing Geomorphic Conditions Within Part 'A' Study Corridor

In general, watercourses within the study area have been historically straightened or have been highly impacted due to agricultural purposes. In some locations, natural channel processes have occurred causing the streams to regain a sinuous planform through local erosion and meander development. This observation is documented in the RGA stability score with many of these reaches classified as transitional. This indicates that the channels are showing signs of instability but have not destabilized overall. Therefore, to avoid further degradation, these reaches should be considered as sensitive to future adjustments to the prevailing discharge and sediment regimes.

The dominance of agricultural land use has had impacts on stream health as reflected in the RSAT scores. Generally, reaches are considered to be in moderate stream health where instream habitat, riparian conditions, and water quality are the limiting factors.

5.2.1 Rainbow Creek

5.2.1.1 Reach R-4

This reach generally follows a moderately sinuous planform and flows through agricultural fields. The channel contains poorly defined banks, making it difficult to accurately determine bankfull dimensions. Banks are likely poorly defined as a result of channel disturbance through ploughing and farming practices. Average channel dimensions were 1.2 m in width and 0.3 m in depth and no water was present at the time of the field assessment. Channel substrate consisted of clay and silt, with some coarser substrate (i.e., gravels, cobbles) likely sourced from the adjacent farm fields. Pool-riffle morphology was absent and there was no evidence of channel migration. Rapid assessments resulted in an RGA score of 0.13 and RSAT score of 28, indicating that the watercourse is in regime/stable and contains moderate stream health. Overall, no major signs of erosion were observed.

5.2.1.2 Reach R-6

Coleraine Drive crosses reaches R-6 of the Rainbow Creek Tributary within the Part ‘A’ Study Corridor. Reach R-6 originates approximately 650 m upstream of the Coleraine Drive Road crossing. The channel flows through agricultural fields and follows a straight to slightly meandering planform. At the road crossing, the channel flows through a concrete box culvert where the road embankment to the right is beginning to fail. The culvert entrance also contains abundant cattails and instream vegetation. Standing water was present at the culvert crossing; however, upstream of the crossing, the channel was less defined and dry. Average bankfull channel dimensions were 1.5 m in width and 0.2 m in depth. Pool-riffle morphology was absent.

Rapid assessments resulted in an RGA score of 0.13 and RSAT score of 28, indicating that the watercourse is in regime/stable and contains moderate stream health. Overall, the only signs of erosion observed were at the upstream culvert crossing location where the channel is eroding toward the road embankment.

5.2.2 Rapid Assessment Summary - Part ‘A’ Study Corridor

Tables 2, 3, and 4 summarize the results of the rapid assessments for the study reaches.

TABLE 2 General Channel Characteristics Observed During Rapid Assessments

Reach	Bankfull Width (m)	Bankfull Depth (m)	Entrenchment Ratio*	Gradient	Sinuosity	Bank Height (m)	Bank Angle (degrees)
R-4	1.2	0.3	n/a Not Entrenched	Low	<1.0 Straight	0.30	20 to 30
R-6	1.5	0.2	n/a Not Entrenched	Low	<1.0 Straight	0.12	20 to 40

*Entrenchment ratio is equal to two times the bankfull depth divided by the bankfull width.

TABLE 3 Summary of Rapid Geomorphic Assessment Scores

Reach	Crossing	Factor Value				Stability Index	Condition
		Aggradation	Degradation	Widening	Planimetric Adjustment		
R-4	G	0.11	0.14	0.13	0.14	0.14	Stable/In Regime
R-6	I	0.11	0.14	0.13	0.14	0.14	Stable/In Regime

TABLE 4 Summary of Rapid Stream Assessment Technique Scores

Reach	Crossing	Factor Value						Overall Score	Condition
		Channel Stability	Scour/ Deposition	Instream Habitat	Water Quality	Riparian Condition	Biological Indicators		
Maximum Score		**11**	**8**	**8**	**8**	**7**	**8**	**50**	-
R-4	G	7	7	3	4	4	3	28	Moderate
R-6	I	7	7	3	4	4	3	28	Moderate

6 MEANDER BELT WIDTH ASSESSMENT

When meanders change shape and position, the associated erosion and depositional processes that enable these changes to occur can cause loss or damage to private property and infrastructure. For this reason, when development or other activities are contemplated near a watercourse, it is desirable to designate a corridor that is projected to contain all of the natural meander and migration tendencies of the channel. Outside of this corridor, it is assumed that private property and structures will be safe from the erosion potential of the watercourse. The extent that a meandering watercourse occupies on its floodplains commonly referred to as the meander belt.

6.1 Methodology

Meander belt width (MBW) assessments were completed for all existing and potential crossings within the study following *The Belt Width Delineation Procedure* (PARISH 2004). The procedure is applicable to unconfined systems and follows a process-based methodology for determining the MBW based on background information, historic data (including aerial photography), degree of valley confinement, and channel planform. First, the meander belt axis, which follows the general down-valley orientation of the meander pattern, is identified and drawn. The MBW is centred on this axis. To establish the meander belt, lines are drawn parallel to the governing outermost meanders of the channel planform, following the meander axis. Surrounding topography is also considered in this step. The distance between the two lines is measured and used to represent the width of the preliminary meander belt.

To account for long-term adjustments in channel planform, as well as potential post-development changes in hydrologic regime, the 100-year channel migration rate is applied to either side of the MBW as a factor of safety. The 100-year migration rate quantifies the lateral and downstream movement of meander features expected to occur within a 100-year time period and was delineated using georeferenced historical aerial images. For each reach, channel centrelines were drawn from the imagery in GIS. Offsets between the 2015 channel banks and the delineated banks from the historic photographs were measured at the apex of major bends in order to calculate average migration rates. Typically, where the 100-year migration rate can not be accurately quantified due to poor resolution or lack of aerial imagery, a factor of safety is applied to each side of the belt width. In the current study, a factor of safety of 10% to 20% was used and assessed based on meander development and the potential for lateral channel migration.

MBWs can be further verified using empirical relationships where aerial coverage of the watercourse is poor/non-existent or when channels have been historically modified from their natural state. Empirical equations predict the MBW as a function of the geometry of the existing channel (i.e., bankfull width).

6.2 Analysis and Results

MBWs have previously been assigned to the watercourses within the study area as part of the Area 47 MESP report ((Aquafor Beech 2016). The MBWs reported used a combination of traditional mapping procedures and empirical relationships to calculate preliminary estimates of the MBWs. Empirical methods were used on reaches where channel straightening and artificial channelization occurred. Since the majority of reaches are highly impacted due to farming practices, a governing meander of the existing channel planform in each reach was used to determine the MBW, as a more practical assessment of existing planform conditions. Where reaches have been fully straightened/channelized, empirical relationships were used provided there was no appropriate analogue or reference reach. Historical traces were also digitized and examined for occurrences of lateral channel migration. Where channel migration rates could be calculated, the migration rate was used as the factor of safety to determine a final MBW. MBWs summarized in Table 5 are compared against results reported in Aquafor Beech (2016). **The reassessed MBWs in the current report are considered to be more practical "engineering" erosion hazard limits, but do not necessarily supersede the Aquafor Beech (2016) values which are considered to be the long-term "geomorphic" MBWs. The MBWs presented for this report are specifically to assist in the evaluation of erosion risks to future road crossings and to inform the crossing recommendations in Section 7. The reassessed MBWs in this report are not to be used for any other purpose.**

The method used in determining the MBW factor of safety varies by reach, where either the migration rate setback or a certain percentage was applied to either side of the preliminary belt width to delineate the extent of the final MBW. For reaches R-4 and R-6channel migration rates could not be measured due to historical channel straightening. As a result, a 10% factor of safety was applied to the preliminary MBWs as channel migration will occur, however, to a lesser extent, since the channel is limited to migrating within a small, highly-impacted corridor between farm fields.

Results from this analysis, including the preliminary MBW, migration rate setback, and final MBW are presented in Table 5. MBW mapping is presented in Appendix B.

TABLE 5 Summary of Meander Belt Width Delineation - Part 'A' Study Corridor

Column		A	B	C	Column A +2C	D
Reach	Crossing	Preliminary MBW (m)	Method Used for Factor of Safety	Factor of Safety (m)	Final MBW (m)*	Area 47 2016 MESP MBW (m)
R-4	G	36	10%	3.6	**40**	58
R-6	I	20	10%	2.0	**22**	58

MBW - meander belt width
MESP - Master Environmental Service Plan
*Final MBWs have been rounded up to the nearest whole number.

7 CROSSING RECOMMENDATIONS

Fluvial geomorphic recommendations regarding roadway improvements and crossing structure upgrades/replacements have been developed based on the results of the desktop assessment, field investigation results, and geomorphic analysis to inform the preferred design option at the crossings. Recommendations for crossing span and skew are provided to address risks associated with lateral and downstream channel migration; however, it is understood that Wood has based their selection of the preferred crossing design from a hydraulic and flooding perspective. The determination of preliminary fluvial geomorphic crossing span recommendations follow the process outlined in Figure 4, and involve the evaluation of specific criteria:

- **MBW:** the MBW defines the area that a meandering watercourse has previously occupied, currently occupies, and is expected to occupy in the future. This value has been used by regulatory agencies for corridor delineation associated with natural hazards and the MBW is typically of a similar dimension to the regulatory floodplain. This criterion represents a very conservative approach for crossing span recommends and considers the long-term migratory tendencies of the watercourse. Where it is not possible for the crossing to accommodate the MBW, alternative criteria are evaluated.

- **Meander geometry**: the meander amplitude and wavelength are important parameters to ensure that channel processes and functions can be maintained within the crossing. The use of the meander belt width for structure sizing had been established as a criterion for some regulatory agencies. This criterion represents a very conservative approach for crossing design and is promoted as the most sustainable long-term management strategy where feasible.

- **100-year migration rate:** migration rates are estimated using historical aerial photography. Higher migration rates indicate a more unstable system and higher geomorphic risk. Due to historical channel straightening, 100-year migration rates could not be estimated. With reference to established provincial and regulatory guidelines, a generic factor of safety equivalent to 20% (10% for each side) of the preliminary belt width was used in lieu of the 100-year migration rate.

RGA: the RGA score provides a measure of the channel stability. Channels that are unstable tend to be actively adjusting and thus are sensitive to the possible effects of the proposed crossing. The channels along the crossings were assessed to be stable or poorly defined and were not actively adjusting.

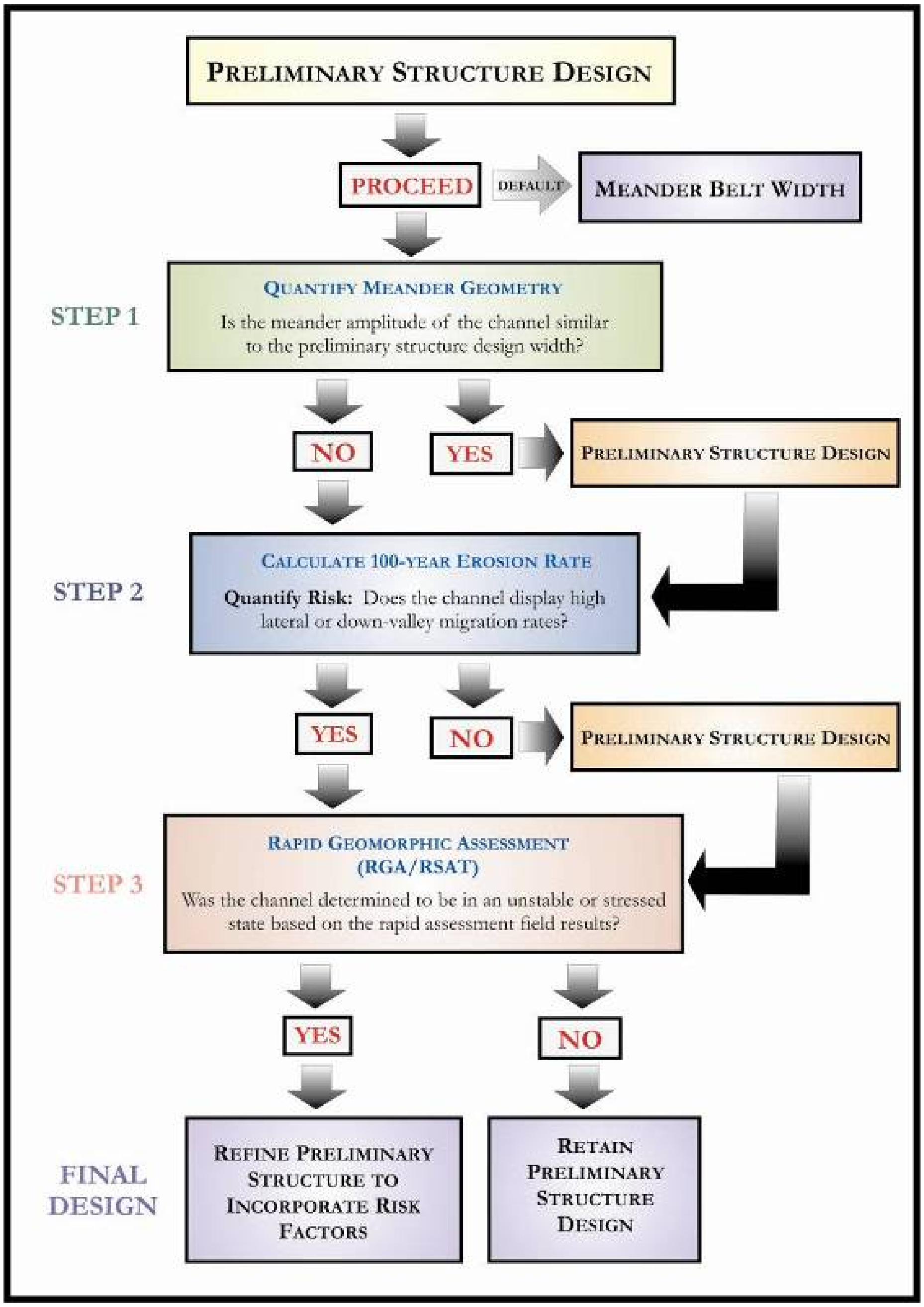


FIGURE 4 Geomorphic Risk Assessment Protocol for Span Recommendations (PARISH 2006)

Other criteria assessed when evaluating the span of a crossing include channel size and valley setting:

- **Channel size:** the potential for lateral channel movement and erosion for the watercourses within the study area generally increases with channel size. Erosive forces in larger watercourses often exceed the resistive forces of vegetation, resulting in increased channel erosion and migration. In contrast, headwater streams typically exhibit low rates of erosion and migration due to the stabilizing properties of vegetation. Both watercourses within the Part A Study Corridor are headwater tributaries. Channel sizes in these reaches are small (bankfull width of 2 m or less) or poorly defined.

- **Valley setting:** watercourses with wide, flat floodplains and low valley setting tend to migrate laterally across the floodplain over time. Watercourses that are confined in narrow, well-drained valleys are less likely to erode laterally but are susceptible to downcutting and channel widening. In the immediate vicinity of the crossings in the study area, the watercourses are unconfined in their valley settings.

Where a new crossing is proposed or an existing crossing is being replaced, a collective evaluation of all these factors is used to direct the development of new structural design parameters (span, length, and skew) that are appropriate from a fluvial geomorphic perspective.

In accordance with Toronto and Region Conservation Authority's *Crossing Guideline for Valley Stream Corridors* (TRCA 2015) it is preferable, where possible, to replace existing structures as opposed to extending a structure when a roadway is widened. The full replacement of a crossing structure is particularly preferred if the extension of an existing crossing results in negative impacts to natural hazards or natural heritage features and at a minimum, there should be no increase in flood risk or erosion. The full replacement of a crossing structure can also allow for opportunities to optimize terrestrial and aquatic habitat and wildlife connectivity. The TRCA (2015) Crossing Guidelines state:

> *Crossings should be located away from geomorphically active and unstable areas and be designed to span the zone of potential future channel migration, as defined by the meander belt or 100-year erosion limit, to reduce risks from channel migration over time. However, it is recognized in some instances this may not be practical, particularly for modifications to existing crossings or for new crossings of small, stable watercourses.*

Based on a review of watercourse crossings within the study area, the majority of the existing structures will require replacement as a result of proposed road widening/construction works. Rapid assessments helped characterize existing channel conditions at each crossing location and revealed whether the current structures are undersized or failing, resulting in instability. Ultimately, crossing recommendations resulted in a crossing span large enough to accommodate the upstream maximum meander amplitude. Alternatively, a crossing span recommendation of three times the average bankfull width of the channel was recommended for locations where meandering was not present upstream of the crossing. These span recommendations represent improvement over existing crossing infrastructure. Crossing span recommendations do not span the MBW, as this was deemed not practical, and the risk to infrastructure associated with lateral migration is minimal. Additionally, the streams are within the headwaters of the watercourse with a relatively inactive planform and poorly defined channel morphology, further suggesting a crossing spanning the MBW is not necessary.

A summary of reviewed risk parameters and the resulting structure size recommendations are provided in Table 6 in Section 7.1. Reaches within the vicinity of the crossing were used to size each culvert rather than those at a distance.

7.1 Part A Study Corridor Crossing Span Recommendations

A summary of geomorphic recommendations for crossing structures within the Part 'A' Study Corridor is provided in Table 6.

7.1.1 Crossing G (Reach R-4)

Currently, there is no road crossing at this location, and the channel consists of a moderately sinuous planform with poorly defined banks flowing between farm fields. Currently, Wood has proposed that the intersection of two new arterial roads (Arterial A2 and East-West Arterial Road) will cross over this reach of Rainbow Creek. Within the vicinity of the crossing, there is a large meander with an amplitude of 16 m; therefore, a crossing span that accommodates the potential migration at the measured amplitude is recommended. The proposed preferred crossing design (by Wood) consists of a 25 m wide, single-span bridge allowing for channel adjustment and wildlife passage. A span of 25 m is considered appropriate from a fluvial geomorphic perspective and is beyond our recommendation of a 16 m span. For further details regarding the justification for the 25 m bridge span, the reader is referred to the *Part A: Stormwater Drainage Assessment – Arterial Roads within Highway 427 Industrial Secondary Plan Area (Area 47)* (Wood 2020). During road construction, it is expected that the channel will have to be realigned to pass through the axis of the intersection, and natural channel design principles should be employed to increase bed and bank stability at the crossing location. Channel substrate through the crossing should be composed of a gradation of native material and hydraulically sized pea gravels or river stone. In addition, local erosion protection on the banks immediately upstream and downstream of the bridge should be considered. Bank treatments consisting of hydraulically sized, vegetated stone will protect banks by resisting shear forces.

As the span of 25 m has been predetermined by Wood, one alignment option using the preferred bridge span is discussed below (Figure 5):

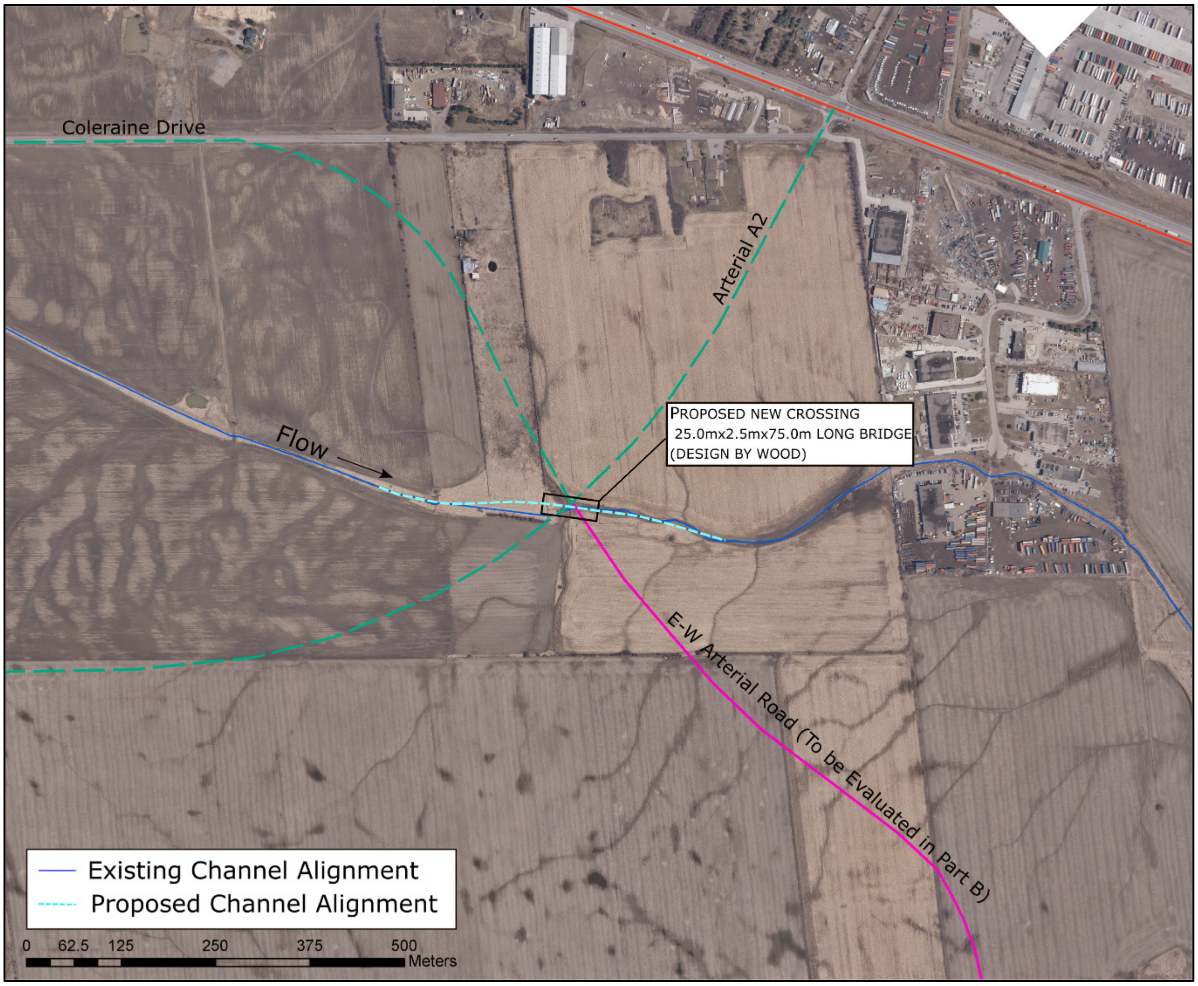


FIGURE 5 Rainbow Creek Crossing Arterial A2 Alignment Option

Arterial A2 road currently does not exist and the intersection of Coleraine Drive and Arterial A2 will be newly constructed over the watercourse. As the watercourse crossing will contain the intersection of two roads, it is recommended that the bridge be constructed perpendicular to the north-south axis of the intersection. The proposed alignment in Figure 5 would shift the existing channel slightly north to allow the channel to pass straight through the center of the proposed culvert, reducing the erosion risk within the vicinity of the bridge.

It is acknowledged that the MESP Addendum (Savanta 2018) recommended realignment of Rainbow Creek as part of the overall Rainbow Creek restoration corridor downstream of the crossing where the creek currently flows through an industrial property. Matrix is supportive of this approach; however, it was not illustrated in Figure 5 as our channel realignment is solely within the vicinity of the proposed bridge.

7.1.2 Crossing I (Reach R -6)

During the field assessment, it was noted that the existing 3.0 m span concrete box culvert is undersized, and erosion is occurring against the road embankment upstream of the crossing. Due to the degrading nature of the culvert, it is recommended during road improvements that the culvert be replaced and more appropriately sized to accommodate channel processes. Based on an average bankfull width of 1.5 m, a crossing span with a minimum opening of 4.5 m, or three times the bankfull width, is recommended. A crossing span comparable to the upstream meander amplitude (10 m) was deemed not necessary as the channel is straight within the vicinity of the road crossing and there was no evidence of lateral migration to suggest this meander will migrate towards the crossing and place infrastructure at risk. Upstream of the crossing, the channel banks are less defined, and the channel is dry most of the year. Overall, the planform of the stream appears rather inactive and often gets infilled with vegetation upstream of the crossing as it is within the headwaters of the system. The proposed preferred crossing design (by Wood) consists of a 17 m wide, single-span bridge allowing for channel adjustment and wildlife passage. A span of 17 m is considered appropriate from a fluvial geomorphic perspective and is beyond our recommendation of a 4.5 m span. For further details regarding the justification for the 17 m bridge span, the reader is referred to the *Part A: Stormwater Drainage Assessment – Arterial Roads within Highway 427 Industrial Secondary Plan Area (Area 47)* (Wood 2020).

This work will require channel alignment to ensure the channel crosses through the structure at an improved skew, where the crossing is perpendicular to the centreline axis of the channel immediately upstream. It is anticipated the replacement of the current box culvert and installation at an improved skew will help prevent future erosion along the road embankment upstream. Additionally, all three options presented below will improve the downstream erosion and backwater occurring from the existing undersized culvert and drainage ditches.

Three alignment options using the preferred bridge span are discussed in the following subsections (Figures 6a to 6c).

7.1.2.1 Alignment Option 1

This alignment would extend the Rainbow Creek channel length north of Coleraine Drive to allow for the channel to pass through the center of the proposed crossing, while avoiding the residential property southeast of the crossing. With this option, it is proposed that the crossing structure be constructed at a 45° skew to the road, allowing for smooth tie-in points both upstream and downstream of the crossing. From a channel stability perspective, this would be the preferred option, although it is acknowledged that it may be more challenging from a construction and design perspective.

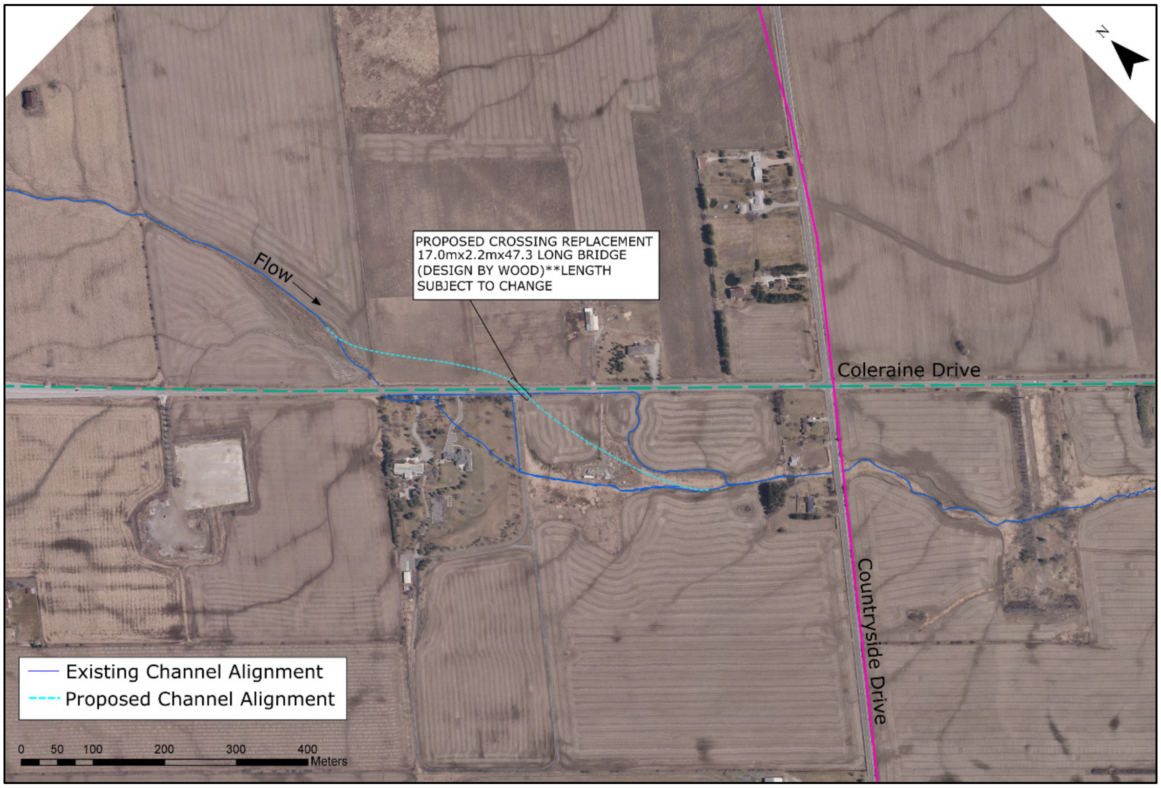


FIGURE 6a Rainbow Creek Crossing Coleraine Drive – Alignment Option 1

7.1.2.2 Alignment Option 2

This alignment would extend the Rainbow Creek channel length north of Coleraine Drive more so than Option 1 to allow for the channel to pass through the center of the proposed crossing perpendicular to the road. Downstream of the crossing, the channel ties in at a sharper angle and would require some bank protection along the east side of the driveway, sized appropriately to withstand in-channel velocities. Compared to the other options (Options 1 and 3), Option 2 provides a balance in length of channel realignment, while minimizing the disturbance to property downstream through realignment along the driveway. This option also allows the channel to pass through at an improved skew perpendicular to the road, reducing potential erosion upstream of the crossing and allows for the elimination of two drainage ditches to the west.

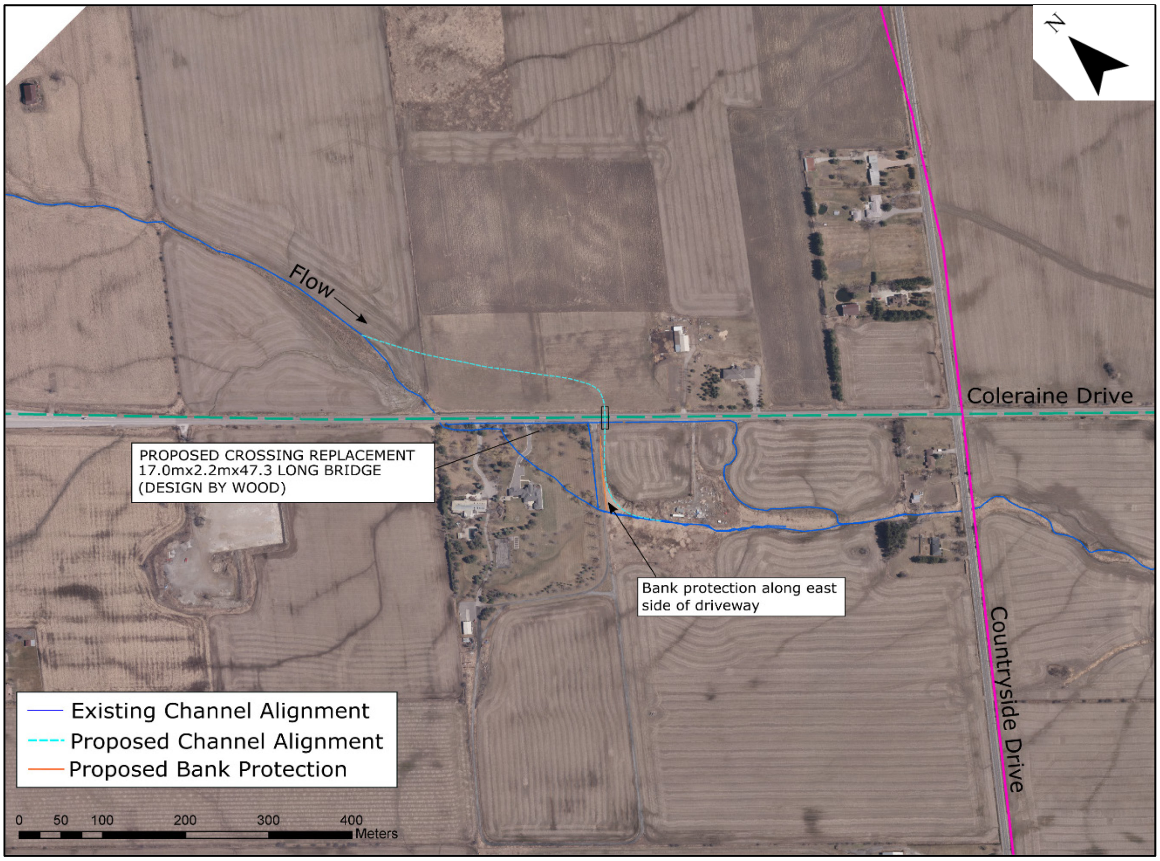


FIGURE 6b Rainbow Creek Crossing Coleraine Drive – Alignment Option 2

7.1.2.3 Alignment Option 3

This alignment would extend the Rainbow Creek channel length north of Coleraine Drive the most of the three options, allowing the channel to pass through the center of the proposed crossing perpendicular to the road. Downstream of the crossing, the channel-ties in smoothly to the existing channel. Option 3 presents the longest length of channel realignment upstream of the proposed crossing; however, this option could potentially eliminate the secondary flow path to the east of the crossing. This option is very similar to the channel realignment proposed in the MESP addendum (Savanta 2018); however, the upstream alignment has been slightly adjusted to allow for a smoother channel trajectory.

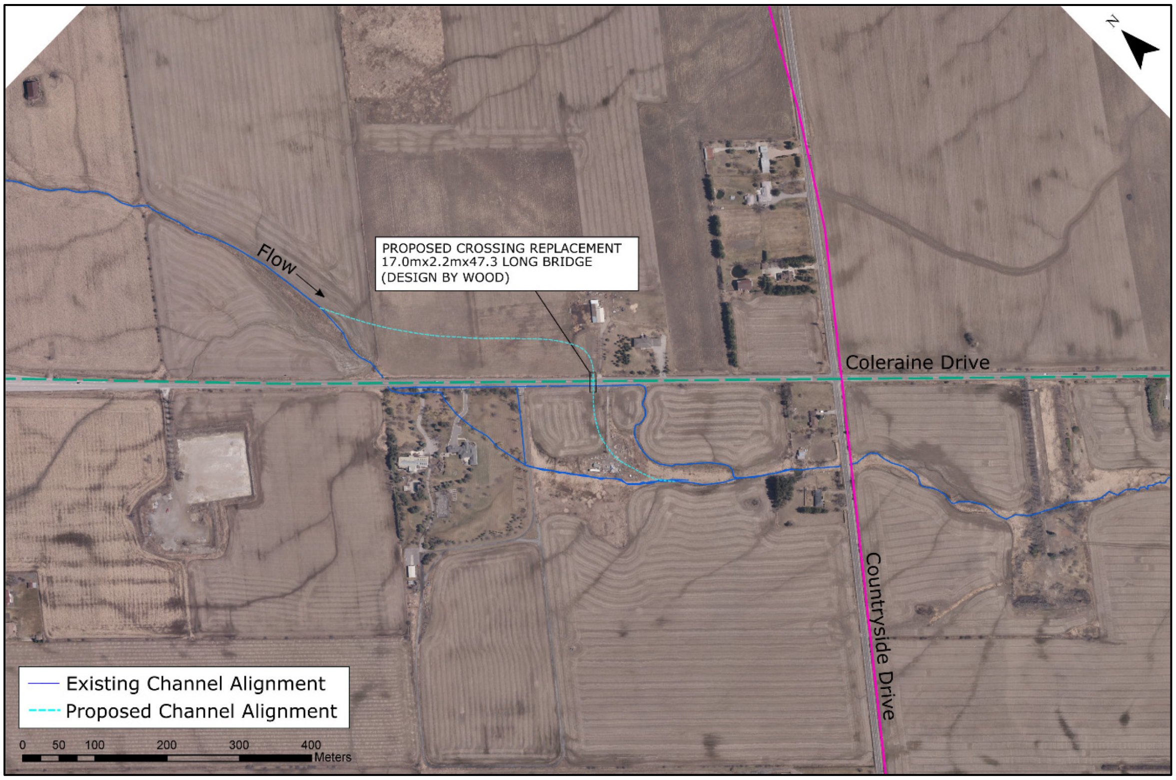


FIGURE 6c Rainbow Creek Crossing Coleraine Drive – Alignment Option 3

TABLE 6 Summary of Available Risk Assessment Parameters - Recommended Structure Size Part 'A' Study Corridor

Reach	Crossing ID	Bankfull Width (m; at crossing	Upstream Meander Amplitude (m)	RGA Score	Final MBW (m)	100-year Erosion Rate (m)	Valley Setting	Existing Structure				Minimum Recommended Structure Size Based on Fluvial Geomorphic Conditions				Preferred Structure Size Recommended by Wood
								Type	Width (m)	Skew	Condition (Pooling/ Erosion)	Type	Opening Width (m)	Criteria used for Span Recommendation	Skew	
R-4	G	1.2	16	0.13	40	-*	Unconfined	N/A				Single span bridge	16	Upstream meander amplitude	Perpendicular to road or realign through centre of bridge	25 m
R-6	I	1.5	10	0.13	22	-*	Unconfined	Concrete box	3.0	45°	Pooling downstream	Open bottom concrete box	4.5	3x average bankfull width	Perpendicular to road	17 m

RGA - Rapid Geomorphic Assessment
MBW - meander belt width
N/A - not applicable
*Channel historically straightened; no erosion rate could be measured.

7.2 Preliminary Channel Enhancement Opportunities

The preliminary crossing span recommendations and realignment options outlined above provide overall improvement to channel form, function, and stability by accommodating the bankfull channel and, where necessary, the maximum existing meander amplitude. Where larger crossing structures are anticipated (i.e., bridges), wildlife benches should be constructed through the structures to facilitate passage and allow for sufficient light penetration to ensure vegetation establishment inside the structure. Where light penetration is insufficient, additional stability provided to the bank from deep-rooted vegetation must be substituted. This will primarily consist of appropriately sized substrate that resists erosion over the range of flows that the channel will be anticipated to convey. Bed and bank restoration options may also be required at the upstream and downstream tie-in points with the existing watercourse. These treatments will ensure that the watercourse does not outflank or undermine the culvert at these locations. Bed and bank treatments will be further refined and sized during the detailed design stage to ensure long-term channel health and stability.

8 SUMMARY OF RECOMMENDATIONS

A fluvial geomorphic investigation has been completed to characterize existing conditions of the watercourses within the Part A Study Corridor with respect to channel form, function, and stability and to understand their interactions with road crossings. The assessment involved:

- a desktop and historical assessment (delineation of reaches, assess lateral migration potential of channel)
- a field investigation to characterize channel geometry and document existing fluvial geomorphic conditions and channel stability within the vicinity of the road crossings
- a MBW analysis
- a risk-based assessment of watercourse crossings

Watercourse crossings in the study area predominantly consist of channels that have been highly impacted by agricultural practices. Both watercourses upstream of the crossings have been historically straightened, making it difficult to quantify rates of lateral channel migration. RGAs reveal both watercourses are Stable/In Regime, making them unlikely to rapidly adjust.

The reassessed MBWs in the current report are considered to be more practical "engineering" erosion hazard limits, but do not necessarily supersede the Aquafor Beech (2016) values which are considered to be the long-term "geomorphic" MBWs. The MBWs presented for this report are specifically to assist in the evaluation of erosion risks to future road crossings and to inform the crossing recommendations in Section 7. The reassessed MBWs in this report are not to be used for any other purpose.

Crossing (size, type, skew, etc.) and conceptual recommendations for channel realignment have been provided for two crossing locations and these upgrades aim to improve geomorphic form and stability long term. Recommendations are based on reach characteristics and have been updated/reviewed based on the current road alignment and crossing structures(provided by Wood). Based on review of the risk factors and minimum recommended crossing structure sizes, both watercourse crossings require channel realignment as a result of the road widening/construction works. From a fluvial geomorphic perspective, it is recommended that new crossing structures accommodate a minimum span of three times the bankfull width of the channel or the maximum existing meander amplitude as indicated in this report. Based on Wood's crossing structure recommendations outlined in *Part A: Stormwater Drainage Assessment – Arterial Roads within Highway 427 Industrial Secondary Plan Area (Area 47)* (Wood 2020), the crossing spans exceed those recommended from the fluvial geomorphic study. The crossing recommendations will reasonably minimize the risk to due to natural erosion hazards within the watercourse corridors, but all recommended structures will still be within the recommended meander belt widths. At new bridge crossings, it is recommended that the structure be placed at an optimal skew perpendicular (90 degrees) to the meander axis to ensure long term channel and bank stability and the channel will have to be realigned to pass through the axis of the intersection. At all crossing locations, natural channel design principles will need to be implemented when considering upstream and downstream tie-in points as well as bed and bank treatments.

9 REFERENCES

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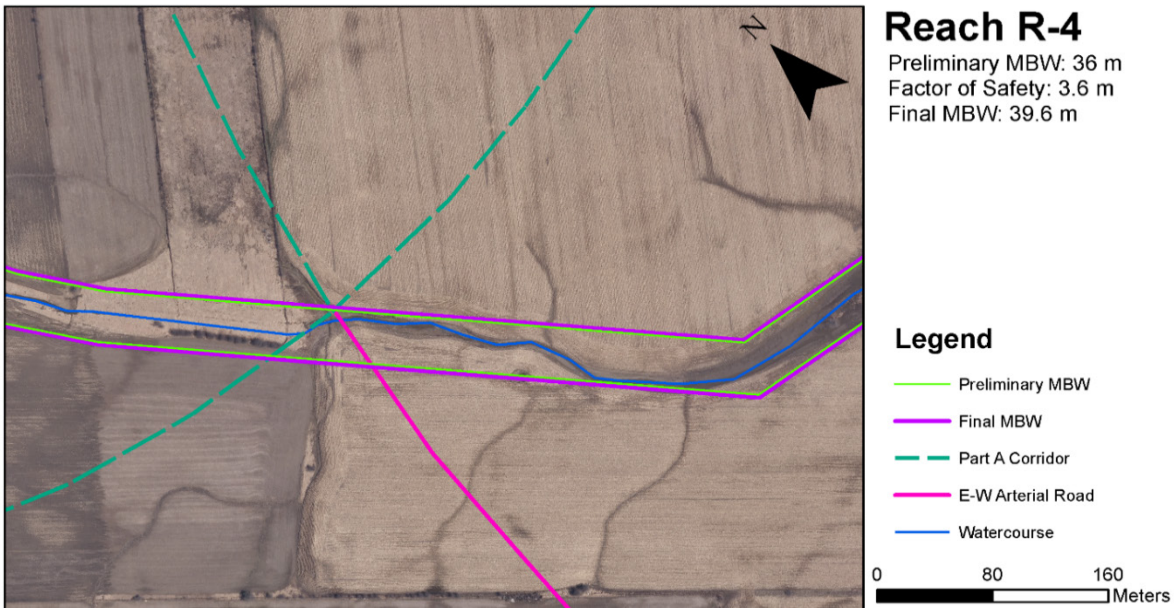
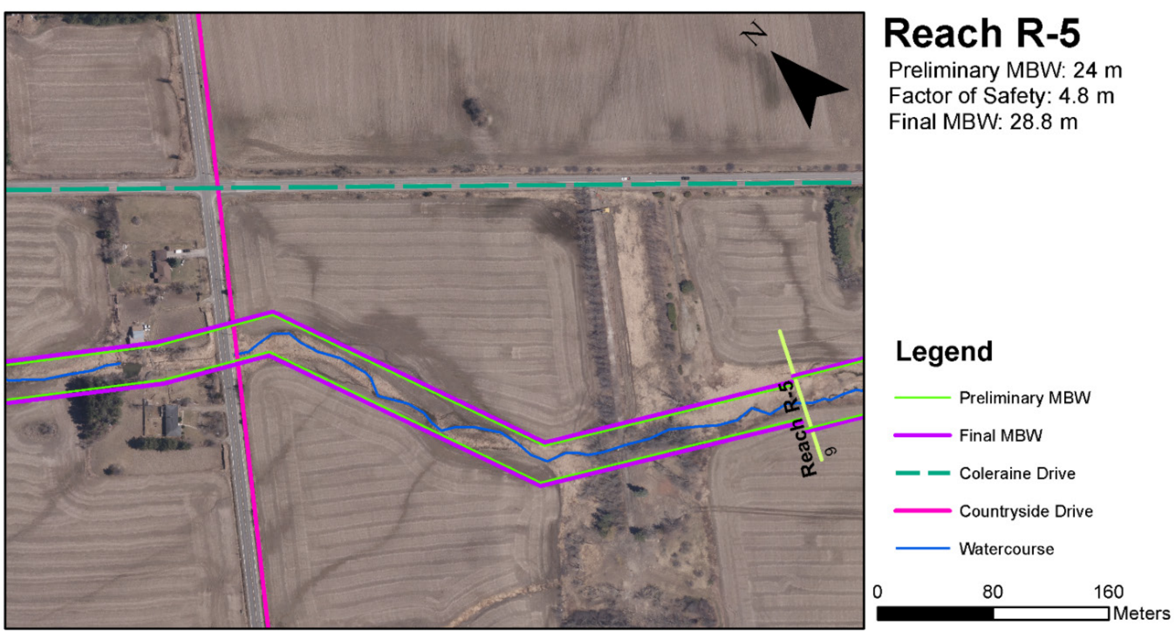
APPENDIX A
Meander Belt Mapping – Part A Study Corridor

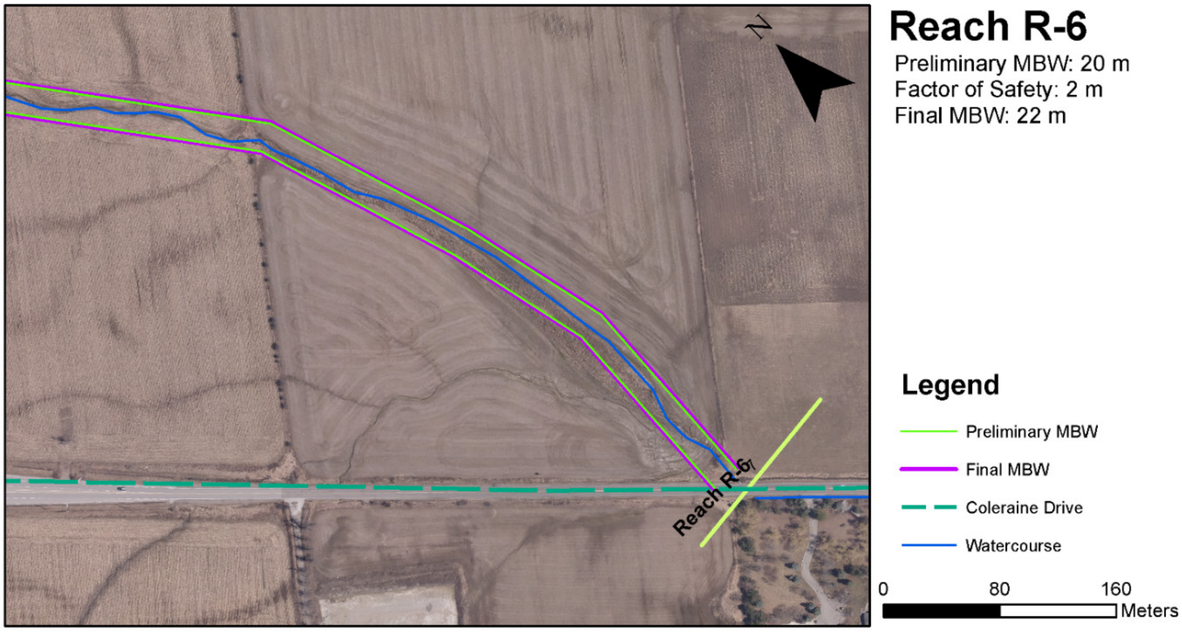
APPENDIX A

MEANDER BELT MAPPING – PART A STUDY CORRIDOR



**Alignment of E-W Arterial Road subject to change as per preliminary preferred design




Reach R-6
Preliminary MBW: 20 m
Factor of Safety: 2 m
Final MBW: 22 m
N
Reach R-6
Legend
Preliminary MBW
Final MBW
Coleraine Drive
Watercourse
0
80
160
Meters

APPENDIX B
Site Photographs

Matrix Solutions Inc.
June 30, 2016

1. Reach R-4: topographic low within agricultural field appears seasonally ploughed by remains void of crops; distinct thalweg alternated between edges of the feature.

Matrix Solutions Inc.
June 30, 2016

2. Reach R-4: downstream extent of the reach approaching industrial land use area.

Matrix Solutions Inc.
August 14, 2020

3. Reach R-5: online pond upstream from Countryside Drive; a low berm controls downstream flow.

Matrix Solutions Inc.
August 14, 2020

4. Reach R-5: planform view upstream of Countryside Drive crossing; channel is narrow and floodplain is well vegetated with long grasses and cattails.

Matrix Solutions Inc.
August 14, 2016

5. Reach R-5: looking downstream from Countryside Drive; channel flows between farm fields and is sinuous; overall channel banks and floodplain are well vegetated; standing water present at field visit.

Matrix Solutions Inc.
June 30, 2016

6. Reach R-6: looking downstream from Mayfield Road; feature is defined through topographic low in agricultural field; long grasses abundant along channel banks and bed.

Matrix Solutions Inc.
June 30, 2016

7. Reach R-6: feature crosses through hedge row between agricultural fields.

Matrix Solutions Inc.
June 30, 2016

8. Reach R-6: feature enters zone of cattails and long grasses; multiple potential flow paths have developed.

Matrix Solutions Inc.
June 30, 2016

9. Reach R-6: view downstream toward Coleraine Road crossing; channel banks poorly defined.

Matrix Solutions Inc.
August 14, 2020

10. Reach R-6: Colerain Drive culvert; extensive sedimentation and culvert backwatering along south side of Coleraine Drive.