# APPENDIX

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# FLUVIAL GEOMORPHOLOGY

# ENVIRONMENTAL ASSESSMENT STUDY OF ARTERIAL ROADS WITHIN HIGHWAY 427 INDUSTRIAL SECONDARY PLAN AREA (AREA 47) - PART B

CITY OF BRAMPTON

FLUVIAL GEOMORPHIC COMPONENT

Prepared for:
**WOOD ENVIRONMENT & INFRASTRUCTURE SOLUTIONS**

Prepared by:
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Prepared for Wood Environment & Infrastructure Solutions, November 2022


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# 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 B Study Corridor, and fluvial geomorphic concepts for the five 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 is to outline the fluvial geomorphic findings related to the Part B Study Corridor.

The proposed works to the Part B Study Corridor will modify and/or create six watercourse crossings of Rainbow Creek, Clarkway, and The Gore Road tributaries (Figure 1) and involve the realignment of a ditch along Clarkway Drive (Reach C-5B). 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 B Study Corridor. A report summarizing fluvial geomorphic findings for the Part A Study Corridor was issued in May 2021 (Matrix 2021).

## 1.1 Aims and Objectives

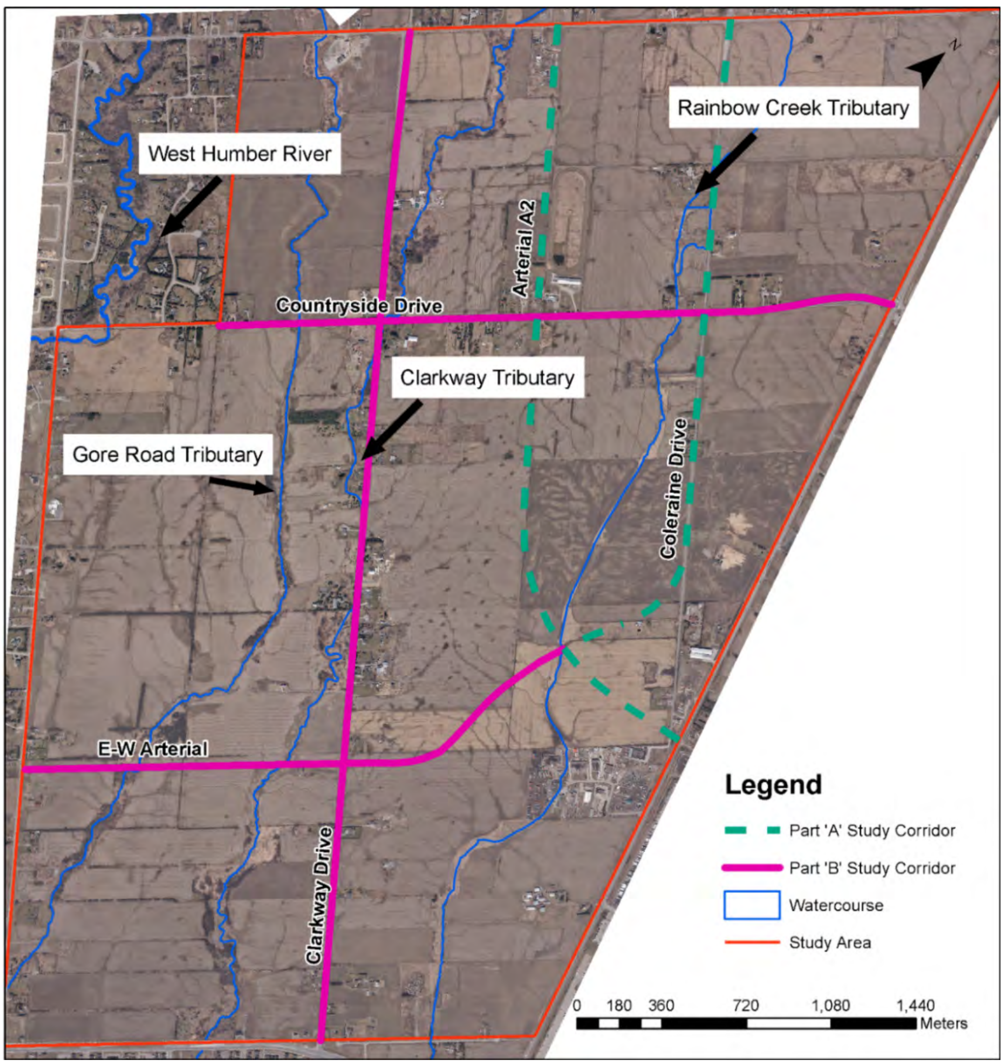
Watercourse crossings are typically evaluated through a risk-based approach, which collectively reviews geomorphic processes and stability within the vicinity of each crossing and identifies risks associated with the placement, sizing, and structure type at each location. In order to evaluate each of the six 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 (MESP; 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 MESP (Aquafor Beech 2016), the *Peel-Highway 427 Extension Area Transportation Master Plan* (Region of Peel 2009), and various other environmental studies.

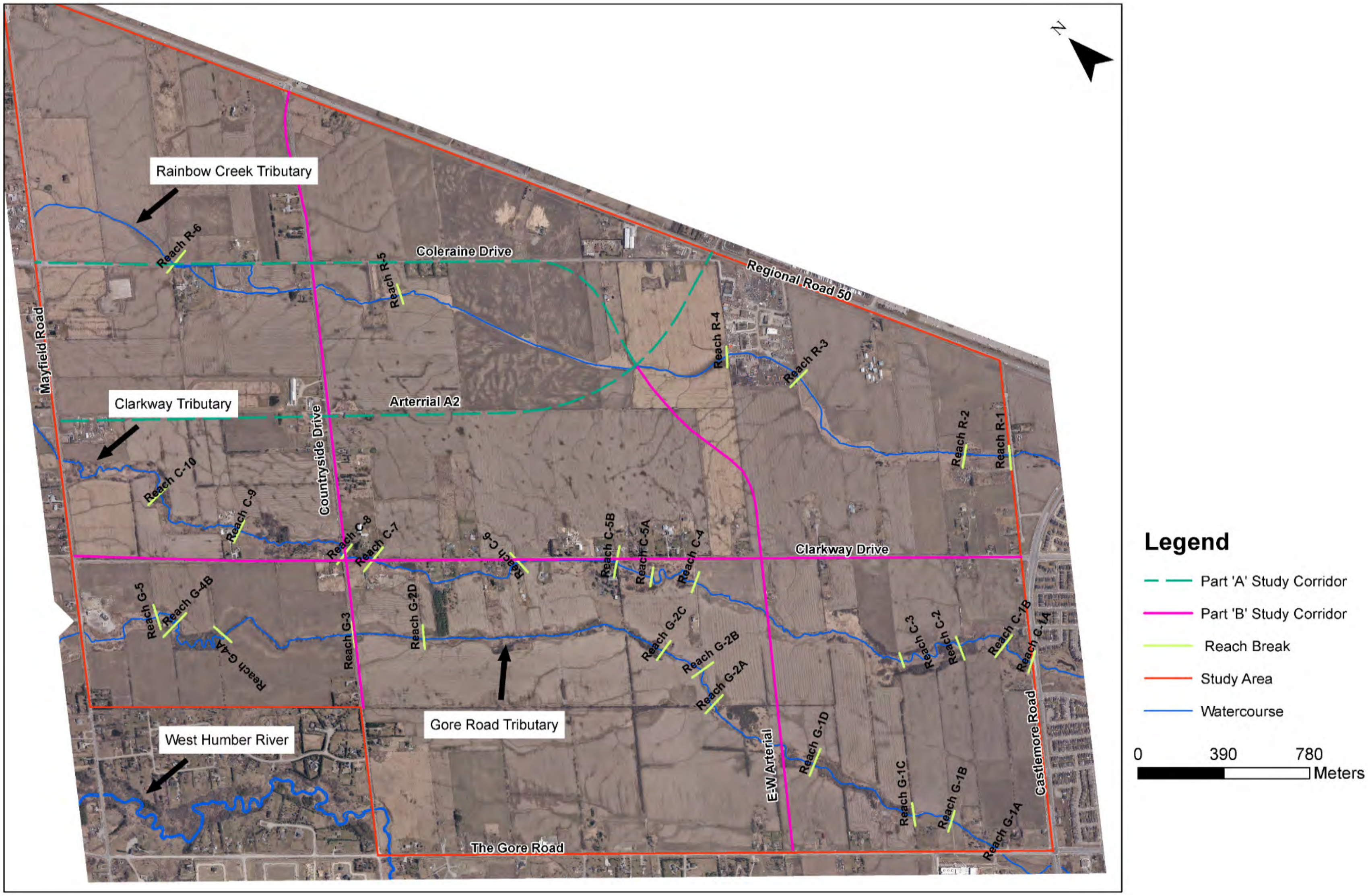
The MESP, completed by Aquafor Beech (2016), includes characterization of existing conditions within the Area 47 study area specific to watercourses, hydrology, hazard lands, and natural heritage. The report contains a fluvial geomorphic study of all watercourses within the study area and outlines watercourse 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 B Study Corridor.

# 3 DESKTOP ASSESSMENT

## 3.1 Reach Delineation

Reaches are lengths of channel (typically 200 m to 2 km in length for streams and rivers in southern Ontario) 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 with respect to 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.




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

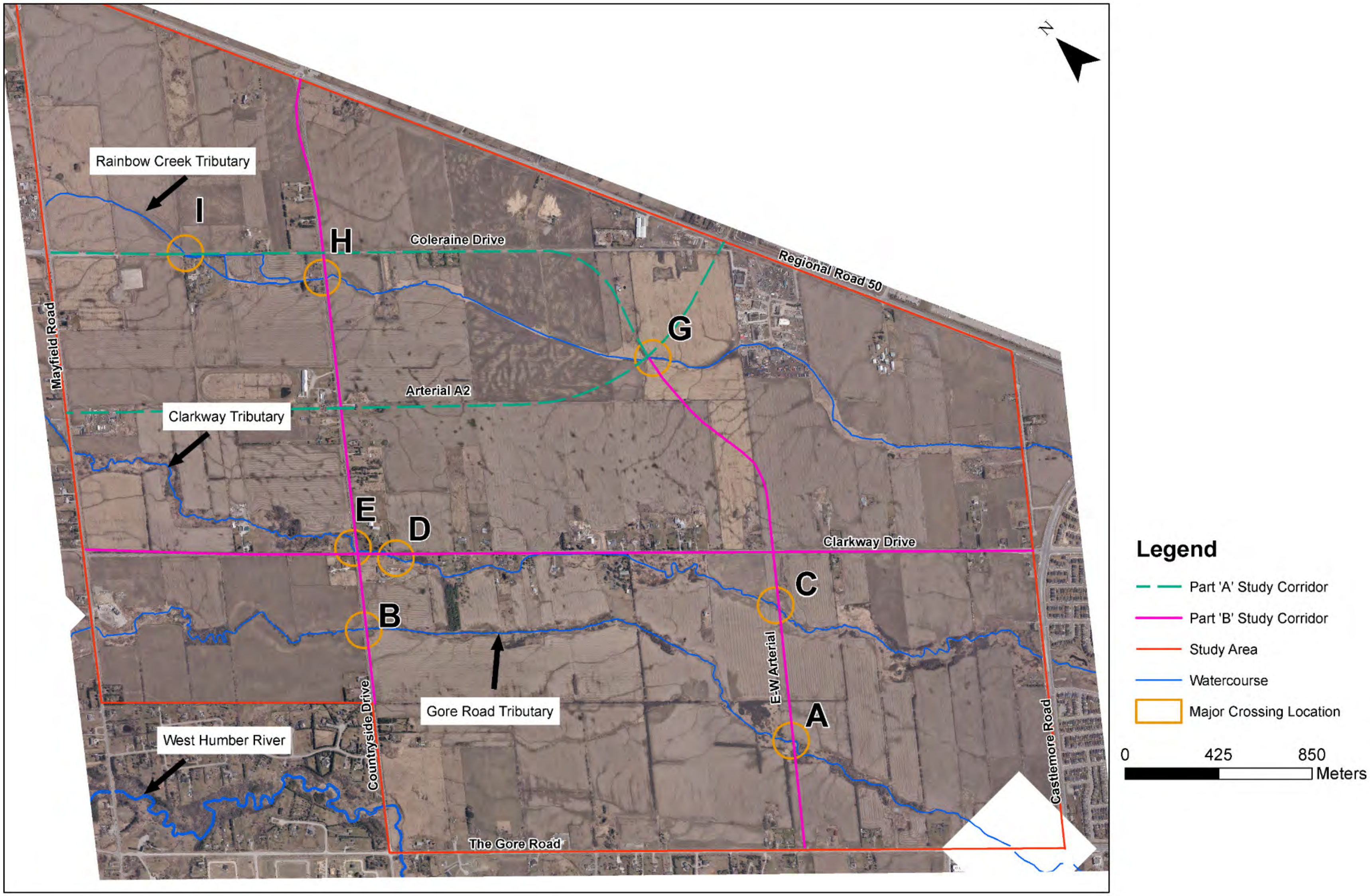
**FIGURE 2 Area 47 Watercourse Reach Breaks**

## 3.1 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. Six watercourse crossing locations were identified in the Part B Study Corridor (Table 1). Several other crossing locations were identified and correspond to headwater drainage features (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 B Study Corridor**

| Watercourse | Reach Name | Crossing ID | Crossing Location | |
|---|---|---|---|---|
| | | | Easting | Northing |
| The Gore Road Tributary | G-1D | A | 604872 | 4850823 |
| | G-2D | B | 603852 | 4852561 |
| | G-3 | B | 603852 | 4852561 |
| Clarkway Tributary | C-3 | C | 605249 | 4851291 |
| | C-6 | D and E | 604161 | 4852734 |
| | C-7 | | 604117 | 4852790 |
| | C-8 | | 604076 | 4852840 |
| Rainbow Tributary | R-5 | H | 604849 | 4853817 |




**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 B 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 B 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 completely. 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 The Gore Road Tributary

#### *5.2.1.1 Reach G-1D*

This reach is characterized by extensive backwatering and ponding, within a broad floodplain corridor with scattered trees. It is approximately 560 m long following a sinuous planform, with a riparian corridor averaging 80 m wide. Riparian vegetation is comprised of long grasses, shrubs, and sporadic deciduous trees. Shading over the channel provided by tree cover is estimated at 50%, and long grasses often overhang the banks. The channel appears to have undergone historical straightening and effects of level channel crossings are still visible (i.e., rutted and uneven bank profiles, higher accumulation of unconsolidated fines along bed). At the time of field investigation, the reach was primarily dry with water in pools and backwatering from a beaver dam. Channel morphology is characterized by ill-defined riffle features consisting of pebbles and gravels with some cobble substrates. Bankfull widths range from 2.8 to 3.2 m wide, with average bankfull depths of 0.3 m at riffles and 0.75 m in pools. Wetted depths range from 0.2 to 0.5 m. Banks are fairly stable, with infrequent signs of slumping or fracture lines; however, undercutting of banks is common along the outside of meander bends and exposed tree roots and woody debris are often observed. Evidence of high flow is observed at 0.9 m above the channel bed.

Through this reach is a proposed crossing of the east-west Arterial Road. Having once been historically straightened to accommodate agricultural activities, this reach is beginning to regain a sinuous planform; however, rates of channel migration could not be accurately quantified based on the highly impacted nature of the channel. Based on the RSAT score of 25, the channel is in moderate condition in terms of overall health and function; limiting factors to the health of the reach are observed with regards to instream habitat and water quality. The reach is also characterized as transitional or stressed based on an RGA score of 0.25. Dominant geomorphic processes observed are widening and aggradation.

#### *5.2.1.2 Reach G-2D*

Downstream from Countryside Drive, bankfull widths range between 1.8 and 3.0 m, with an average bankfull depth of 0.5 m. The reach is approximately 325 m long, with an average riparian corridor 20 m wide. Banks along the reach are relatively stable with slumping and undercutting observed where adjacent to debris jams. No bars were observed; however, one occurrence of a detached slump bank creating a secondary channel was noted. The few trees present within the corridor are set back from the bank; therefore, there are no instances of exposed tree roots. Overhanging long grasses and cattails growing along the banks provide potential refuge for aquatic species within the reach. Riffle features composed of gravels and cobbles are slightly embedded with silts and sands. Pool beds typically contain 1 to 2 cm of unconsolidated sediment. Wetted width throughout the reach is 1.0 to 2.0 m, with noticeable pinch points restricting downstream flow. On average, wetted depth is 0.05 m at riffles and 0.12 m at pools. The maximum pool depth was observed downstream of an online pond outlet with a depth of 0.25 m.

At the upstream extent of this reach is the existing culvert crossing on Countryside Drive. This reach has been historically straightened for agricultural purposes and remains straight with very little evidence of meander development; therefore, an annual migration rate could not be calculated. The reach is considered to be in moderate overall health with an RSAT score of 26. Limiting factors affecting the health and function of the reach include water quality, riparian conditions, and biological indicators. The overall fluvial form and function of the reach is dominated by channel widening processes. The reach is considered to be transitional or stressed, with an RGA score of 0.28.

#### *5.2.1.3 Reach G-3*

Upstream from Countryside Drive, Reach G-3 extends for approximately 750 m following a slightly sinuous pattern. Compared to the downstream reach, Reach G-3 has a slightly larger bankfull cross-section of 3.5 m wide and 0.75 m deep. A pinch-point immediately downstream from the Countryside Drive crossing backwaters flow for approximately 50 m upstream, causing accumulation of organic material and unconsolidated silt and sand. The riparian corridor is 20 to 25 m wide and entrenched 2 to 3 m below the surrounding agricultural fields. Mature deciduous trees provide approximately 75% shading over the reach with localized gaps. Slumping and detached banks are common, and poorly formed point bars are observed along the inside meander bends. Riffle features are comprised of gravels and cobbles embedded in fine silt and sand, while pools typically have a thin layer of unconsolidated silt and sand along the bed.

The downstream extent of this reach is located at another existing culvert crossing at Countryside Drive. This reach is in moderate health with an RSAT score of 27, with limiting factors such as water quality, riparian conditions, and instream habitat. The reach contains an RGA score of 0.27, indicating that it is transitional or stresses. The dominant mode of geomorphic adjustment affecting fluvial form and function is aggradation.

### 5.2.2 Clarkway Tributary Reaches

#### *5.2.2.1 Reach C-3*

Reach C-3 follows a sinuous planform through a 20 m wide riparian corridor composed of long grasses, shrubs, and scattered trees. Surrounding land use is dominated by agricultural fields. One level farm crossing is present approximately mid-way through the reach. The channel is moderately entrenched, with bank heights 1.0 to 1.2 m high, while on average bankfull depth is 0.7 m. Bankfull widths ranged between 2.2 and 3.0 m, with narrower sections frequently undercut by as much as 0.5 m. Slumping and detached banks are common throughout the reach and are likely attributed to the overall lack of mature riparian vegetation that would provide bank stabilization through a stable rooting matrix. At the time of the site visit, water was contained only within pools, with wetted depth ranging from 0.23 to 0.42 m. Riffles were primarily comprised of cobble material and minor depositional sand.

A road crossing of the east-west Arterial Road is proposed along this reach. Similar to most reaches within the study area, Reach C-3 has undergone historical straightening but has begun to re-establish a sinuous planform. Based on the RSAT score of 32, this reach is in moderate condition in terms of overall stream health and function, where the limiting factor is water quality. The reach is also characterized as transitional or stressed based on an RGA score of 0.22, where the dominant geomorphic process observed is aggradation.

#### 5.2.2.2 Reach C-5B

Reach C-5B serves as a roadside ditch south of Clarkway Drive between Countryside Drive and the proposed east-west Arterial Road. Erosion is actively occurring along the road embankment and the channel will likely have to be realigned as a result of the proposed road widening. It was difficult to determine “bankfull” dimensions as the channel is very entrenched. Approximate channel dimensions were 3 m in width and 1.5 m depth. Active erosion is occurring in the banks as both banks are near vertical and contain exposed parent material. Gabion baskets have been placed on the left bank to prevent erosion and bank slumping but are in poor condition and failing as a result of undercutting.

#### 5.2.2.3 Reach C-6

Reach C-6 extends upstream from Reach C-5B and is approximately 700 m long, following a sinuous planform that flows through rural-residential properties. Four private laneway crossings are observed along the reach and erosion along the bridge footings is common. The channel flows through a well-established riparian corridor approximately 20 to 24 m in width. The channel is entrenched into the floodplain by 1 to 2 m. Tree cover over the watercourse extends over approximately 50% of the reach. Woody debris jams are common within the tributary resulting in local scour and erosion of the bed and banks. Undercut banks and exposed tree roots are commonly observed throughout the reach. At the time of the field investigation, the channel was primarily dry with minimal water observed in pools. The maximum wetted pool depth observed was 0.25 m. Bankfull widths ranged from 3.2 to 4.0 m, while bankfull depth ranged from 0.5 to 0.65 m.

The upstream extent of this reach is located at the existing crossing on Clarkway Drive, 137 m south of Countryside Drive. Based on an RSAT score of 30, the stream is in moderate condition in terms of overall stream health and function, limited by factors such as the lack of biological indicators and water quality. The stream is also characterized as transitional or stressed based on an RGA score of 0.24, where the dominant geomorphic processes observed are widening and aggradation.

#### 5.2.2.4 Reach C-7

Similar to Reach C-5B, Reach C-7 flows adjacent to Clarkway Drive within the roadside ditch. The reach is approximately 140 m and has been modified to flow in the ditch based on positioning of the upstream and downstream road crossings (Countryside Drive and Clarkway Drive). Frequent signs of bank slumping and fracture lines along the top of bank are common, and recent bank stabilization measures in the form of an armourstone retaining wall have been put in place along the right bank (west bank) adjacent to Clarkway Drive. The channel planform is straight and the proximity to the road ranges from 10 m to as close as 4 m along the armourstone retaining wall. Riparian vegetation varies and is comprised of grasses along the upstream extent and forest cover along the downstream extent, where exposed and elevated tree roots are observed. Bankfull widths range from 2.5 to 3.0 m throughout the reach, and bankfull depths range from 0.6 to 0.7 m. Banks are near vertical, and the channel is entrenched by approximately

1.0 m. Riffle substrate is comprised of gravel and cobble with some sand, artificial rip-rap, and boulder bank protection is also present near the downstream crossing.

An RSAT score of 27 was calculated for this reach, indicating stream health is moderate. Limiting factors affecting the condition of the channel are scour, instream habitat, and lack of biological indicators. The dominant process affecting fluvial form is channel widening. An RGA score of 0.28 indicates that the channel is in a transitional or stressed state.

#### *5.2.2.5 Reach C-8*

Clarkway Tributary Reach C-8 extends upstream from Countryside Drive for approximately 580 m and follows a sinuous planform. A reach break was placed at Countryside Drive due to change in surrounding land use from rural-residential to rural-industrial. At this location, several channel modifications including a private crossing structure have resulted in ponding and backwatering along the channel. The reach flows through a broad (>30 m) riparian corridor that consists of altering wooded and meadow sections. Riparian cover provides approximately 40% to 50% shading over the channel. Channel banks are generally stable throughout the reach; however, undercutting of outer meander banks and exposed tree roots was observed. Average bankfull widths were 2.5 m at riffles and 4.0 m at pools. Bankfull depth ranged from 0.75 to 1.0 m. The downstream extent of the reach flows parallel to Countryside Drive for approximately 75 m, and the road embankment is protected by riprap and gabion baskets. At the road crossing, extensive erosion and outflanking of the structure is occurring.

The reach is considered to be in moderate stream health with an RSAT score of 28. Limiting factors affecting the health and function of the reach include water quality and lack of biological indicators. The RGA revealed fluvial form and function are dominated by channel degradation and widening processes, and the stream is transitional or stressed, with an RGA score of 0.35.

### 5.2.3 Rainbow Tributary Reaches

#### *5.2.3.1 Reach R-5*

Reach R-5 follows a sinuous planform through a riparian corridor averaging 20 m in width. At the upstream reach extent at Coleraine Drive, the reach has undergone a partial realignment. This reach previously flowed through a rural-residential property. The current alignment splits flow along both the east and west sides of Coleraine Drive. Along the west side of Coleraine Drive, the feature flows within the roadside ditch for approximately 180 m and then follows a private lane way 100 m to the west before reconnecting with the original planform. Along the east side of Coleraine Drive, the channel flows within the roadside ditch for 360 m before crossing through an 850 mm corrugated steel pipe (CSP) culvert with riprap scour protection at the inlet and outlet. The channel rejoins the original planform 125 m to the west. The CSP culvert outlet is also perched by 0.28 m. Approaching the Countryside Drive culvert crossing, the feature has a bankfull width of 1.0 m and a bankfull depth of 0.3 m. Bed substrate is comprised of silty sand with few cobbles and gravels and riffle-pool morphology was not observed. Long grasses dominate bank vegetation. An online pond is located approximately 50 m upstream from Countryside Drive; however, downstream the channel was dry at the time of field investigation.

The existing health and function of the reach is moderate, with an RSAT score of 28. Limiting factors affecting the condition of the channel are riparian conditions, instream habitat, and lack of biological indicators. The dominant process affecting fluvial form is channel widening and an RGA score of 0.25 indicates that the channel is in a transitional or stressed state.

### 5.2.4 Rapid Assessment Summary - Part B Study Corridor

Tables 2, 3, and 4 summarize the results of the rapid assessments for the Part B Study Corridor 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) |
|---|---|---|---|---|---|---|---|
| G-1D | 2.8 to 3.2 | 0.3 to 0.75 | 2.0<br>Moderately Entrenched | Low | 1.16<br>Sinuous | 0.5 | 50 to 80 |
| G-2D | 1.8 to 3.0 | 0.5 | 1.3<br>Entrenched | Low | 1.07<br>Straight | 0.35 | 80 |
| G-3 | 3.5 | 0.75 | 1.4<br>Entrenched | Low | 1.04<br>Straight | 0.75 | 60 to 70 |
| C-3 | 2.2 to 3.0 | 0.7 | 1.3<br>Entrenched | Low - Moderate | 1.1<br>Sinuous | 1.1 | 80 |
| C-6 | 3.2 to 4.0 | 0.5 to 0.65 | 1.25<br>Entrenched | Low | 1.1<br>Sinuous | 1.0 | 70 to 80 |
| C-7 | 2.5 to 3.0 | 0.6 to 0.7 | 1.3<br>Entrenched | Low | <1.0<br>Straight | 1.0 | 80 |
| C-8 | 2.5 to 4.0 | 0.75 to 1.0 | 2.5<br>Slightly Entrenched | Low | 1.12<br>Sinuous | 0.5 | 60 to70 |
| R-5 | 1.0 | 0.3 | n/a<br>Not Entrenched | Low | <1.0<br>Straight | 0.3 | 20 to 30 |

*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 | | |
| G-1D | A | 0.33 | 0.15 | 0.38 | 0.14 | 0.25 | Transitional/Stressed |
| G-2D | B | 0.33 | 0.28 | 0.5 | 0 | 0.28 | Transitional/Stressed |
| G-3 | B | 0.44 | 0.14 | 0.5 | 0 | 0.27 | Transitional/Stressed |
| C-3 | C | 0.33 | 0.29 | 0.13 | 0.14 | 0.22 | Transitional/Stressed |
| C-6 | D | 0.33 | 0.14 | 0.5 | 0 | 0.24 | Transitional/Stressed |
| C-7 | D and E | 0.22 | 0.29 | 0.63 | 0 | 0.28 | Transitional/Stressed |
| C-8 | E | 0.33 | 0.43 | 0.5 | 0.14 | 0.35 | Transitional/Stressed |
| R-5 | H | 0.33 | 0.14 | 0.38 | 0.14 | 0.25 | Transitional/Stressed |

**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** | - |
| G-1D | A | 6 | 4 | 3 | 3 | 5 | 4 | 25 | Moderate |
| G-2D | B | 5 | 5 | 5 | 4 | 3 | 4 | 26 | Moderate |
| G-3 | B | 6 | 4 | 4 | 4 | 5 | 4 | 27 | Moderate |
| C-3 | C | 6 | 5 | 5 | 5 | 6 | 5 | 32 | Moderate |
| C-6 | D | 6 | 5 | 6 | 4 | 5 | 4 | 30 | Moderate |
| C-7 | D and E | 5 | 4 | 4 | 4 | 6 | 4 | 27 | Moderate |
| C-8 | E | 5 | 5 | 5 | 4 | 5 | 4 | 28 | Moderate |
| R-5 | H | 6 | 5 | 4 | 4 | 3 | 3 | 25 | Moderate |

# 6 MEANDER BELT WIDTH ASSESSMENT

When channel 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. It is delineated using georeferenced historical aerial images and for each reach, channel centrelines are drawn from the imagery in GIS. For this assessment, 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. Several of the reaches within the Part B study corridor have been historically impacted by agricultural and/or channel straightening, therefore migration rates could not be determined for all but one reach. Typically, where the 100-year migration rate can not be accurately quantified, 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. Channel migration rates could not be measured for several of the reaches 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 B 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 2016MESP MBW (m) |
| G-1D | A | 44 | 20% | 8.8 | **53** | 65 |
| G-2D | B | 16 | 10% | 1.6 | **18** | 60 |
| G-3 | B | 40 | 0.1 m/year | 20 | **60** | 57 |
| C-3 | C | 30 | 20% | 6 | **36** | 69 |
| C5B | - | 21 | 10% | 2.1 | **23** | 46 |
| C-6 | D | 40 | 20% | 8.0 | **48** | 67 |
| C-7 | D and E | 20 | 10% | 2.0 | **22** | 72 |
| C-8 | E | 24 | 20% | 4.8 | **29** | 65 |
| R-5* | H | 24 | 20% | 4.8 | **29** | 58 |

MBW - meander belt width
MESP - Master Environmental Service Plan
*Planform trajectory could not be completely field verified.
**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 the final selected crossing size may be governed by hydraulics. The determination of preliminary fluvial geomorphic crossing span recommendations follows 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. Within the current study area, it is not practical to span the MBW as the watercourses are located with the more upstream reaches of the watershed and are not as susceptible to lateral migration given their smaller channel dimensions and lower flows/velocities.

- **Meander geometry**: the meander amplitude and wavelength are important parameters to ensure that channel processes and functions can be maintained within the crossing. The local meander geometry can also be used as an acceptable criterion for structure sizing . This criterion represents a low-risk approach for crossing design and is promoted as a reasonable and 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.

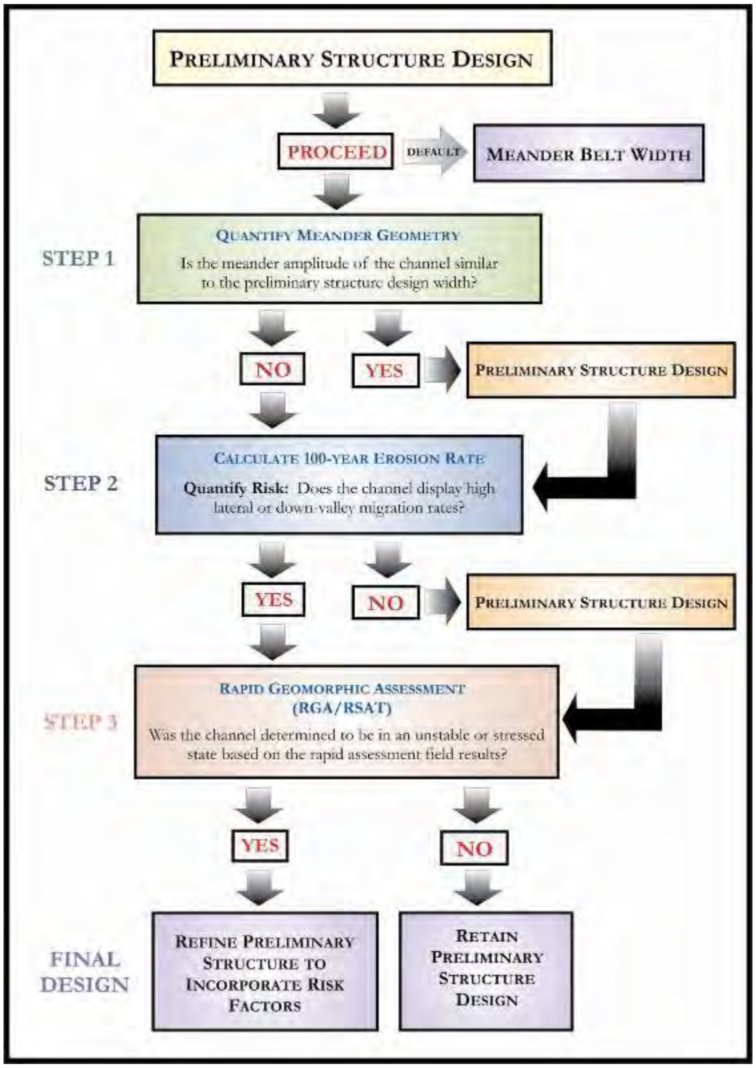



**FIGURE 4 Geomorphic Risk Assessment Protocol for Span Recommendations (PARISH 2006)**

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. Watercourses within the Part B Study Corridor are headwater tributaries or low order streams. Channel sizes in these reaches contain relatively small bankfull dimensions (bankfull width of 4 m or less) and have been impacted or historically straightened due to agricultural practices.

- **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 with minimal evidence of lateral migration.

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 does not reduce or remove natural flooding and erosion hazards or if it negatively impacts natural heritage features. At a minimum, there should be no increase in flood risk or erosion hazards. 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, all of the existing structures will require replacement or the design of a new structure as a result of proposed road widening and new road 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 provide crossing spans large enough to accommodate the upstream maximum meander amplitude. Alternatively, a crossing span recommendation of three times the average bankfull width may be feasible in some cases where there are other design constraints; however, the associated erosion risks of a smaller crossing span typically need to be mitigated with erosion protection measures. In either case, 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 low due to the relative sizes and drainage areas of the channels. Specifically, the streams are within the headwaters of the watercourse or are low order streams with a relatively inactive planform and limited lateral migration, further supporting that spanning the MBW is not necessary at these locations.

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 B Study Corridor Crossing Span Recommendations

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

### 7.1.1 Crossing A (Reach G-1D)

Currently, there is no road crossing at this location and the channel consists of a sinuous planform with extensive ponding upstream of the proposed crossing and an average bankfull channel width of 3 m. The current road design proposes an east-west Arterial Road that will cross perpendicular to the watercourse, The Gore Road Tributary (City of Brampton 2019a, 2019b, 2019c). Within the vicinity of the crossing, there is a large meander with an amplitude of 28 m; therefore, a crossing span of 28 m to accommodate the potential migration at the measured amplitude is recommended. The proposed crossing structure should be perpendicular to the watercourse centerline and should consist of a single-span bridge allowing for natural channel adjustments and wildlife passage. Two alignment options using the preferred crossing span from a geomorphic perspective are presented in the following subsections (Figures 5a and 5b).

Two other crossing span options are presented in Table 6 and include a no-risk option (54 m), where the crossing spans the MBW, or a medium-risk option (9 m), where the crossing spans three times the bankfull width of the channel. From a geomorphic perspective, the low-risk option of the crossing spanning the maximum meander amplitude (28 m) is the preferred option to ensure infrastructure is not at risk as a result of future channel adjustments.

#### *7.1.1.1 Alignment Option 1*

This alignment option most closely resembles that of the current channel planform and involves channel realignment on the downstream end to accommodate the construction of the proposed east-west Arterial Road. During road construction, the upstream end of the channel will require only minor realignment to pass through the axis of the road. Upstream, there is also the option to remove the beaver dam that is backwatering the channel and narrow or re-grade the channel to a more uniform width of 3 m as observed in the undisturbed areas of the channel. To accommodate the proposed road right-of-way of 36 m, the downstream end of the channel will require more substantive realignment in which the current channel alignment will need to be shifted further east (southeast). Erosion protection along the south road embankment will be required to protect the road from future channel migration processes. Options for the bank treatment could include a retaining wall or a riprap bank treatment consisting of hydraulically sized stone that will protect the bank by resisting shear forces.

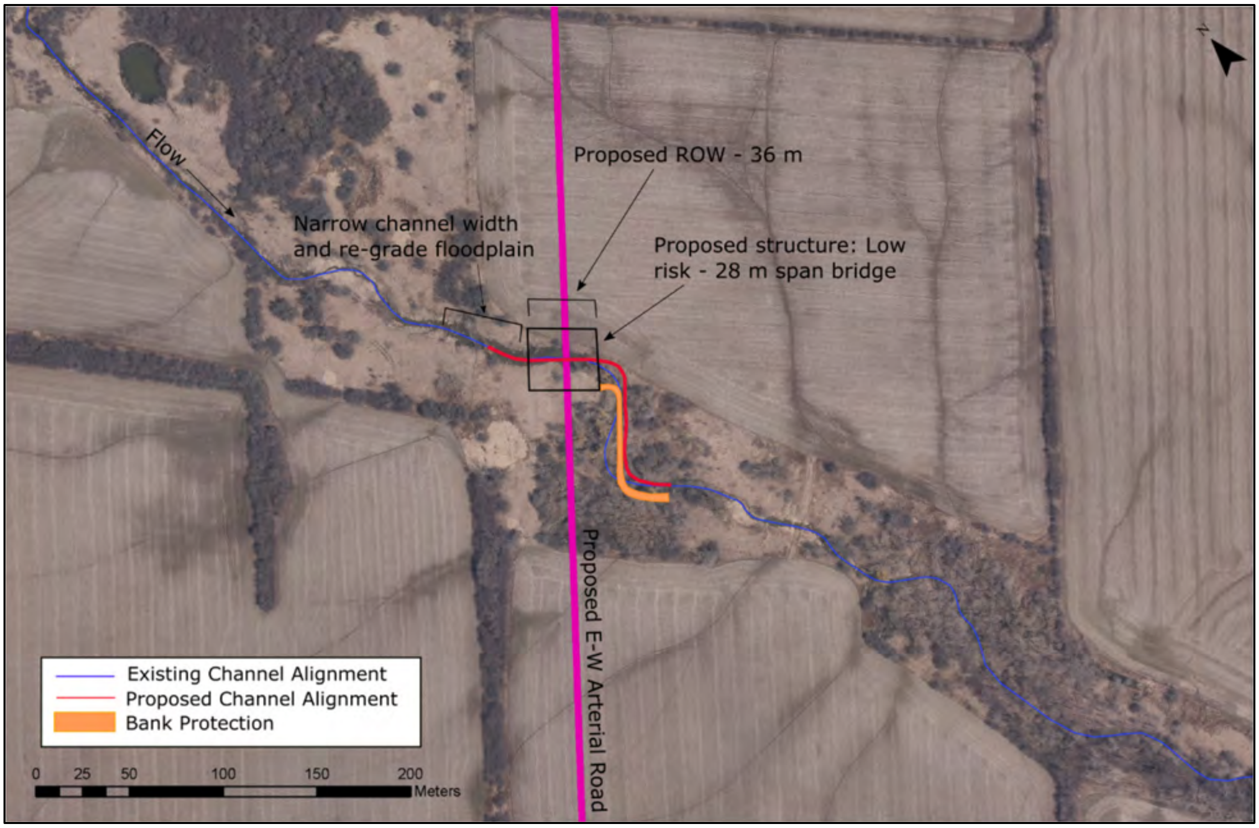



**FIGURE 5a Gore Road Tributary Crossing Proposed East-West Arterial Road (Crossing A) - Alignment Option 1**

### *7.1.1.2 Alignment Option 2*

This alignment option results in a greater length of channel realignment and increased ground disturbance; however, represents a lower risk of bank/road embankment erosion and does not require the design of robust erosion protection. During road construction, the upstream end of the channel will require only minor realignment to pass through the axis of the road. Upstream, there is also the option to remove the beaver dam that is backwatering the channel and narrow or re-grade the channel to a more uniform width of 3 m as observed in the undisturbed areas of the channel. To accommodate the proposed road right-of-way of 36 m, the downstream end of the channel will require more substantive realignment in which the current channel alignment will need to be shifted further east (southeast) than Alignment Option 1. This alignment option creates a smoother tie-in to the channel downstream and eliminates the large meander adjacent to the proposed road, reducing the risk of channel erosion and risk to infrastructure.

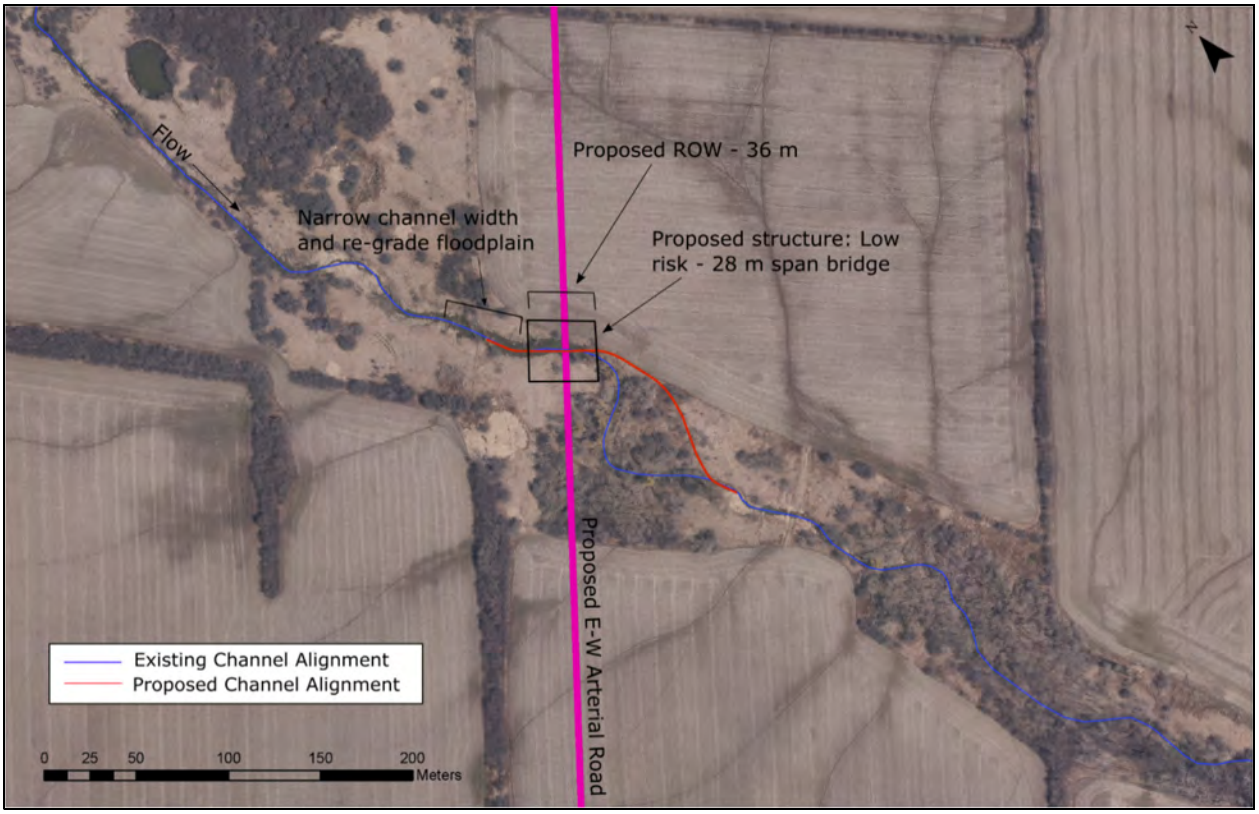



**FIGURE 5b Gore Road Tributary Crossing Proposed East West Arterial Road (Crossing A) - Alignment Option 2**

### 7.1.2 Crossing B (Reach G-2D and G-3)

The existing crossing structure in between these reaches consists of a 5.5 m span concrete box culvert. This width is wider than the reach-averaged bankfull width of 3.5 m; however, backwatering at peak flow events caused by a pinch-point downstream extends approximately 50 m upstream of the crossing, likely a result of an undersized crossing structure. It is recommended that the structure be replaced to accommodate a wider channel equivalent to the upstream meander amplitude, resulting in a minimal crossing span of 28 m. This span is sufficient to support the long-term form and function of the channel and should be set at an optimal skew perpendicular (90°) to the meander axis. During road construction, the channel will only require minor realignment to pass through the center of the crossing structure. The pond on the south side of the road will likely be impacted and require removal/relocation as a result of the road works.

Two other crossing span options are presented in Table 6 and include a no risk option (60 m) where the crossing spans the MBW or a medium risk option (10 m) where the crossing spans three times the bankfull width of the channel. From a geomorphic perspective, the low-risk option of the crossing spanning the maximum meander amplitude (28 m) is the preferred option to ensure infrastructure is not at risk as a result of future channel adjustments and will accommodate flows at higher return periods.

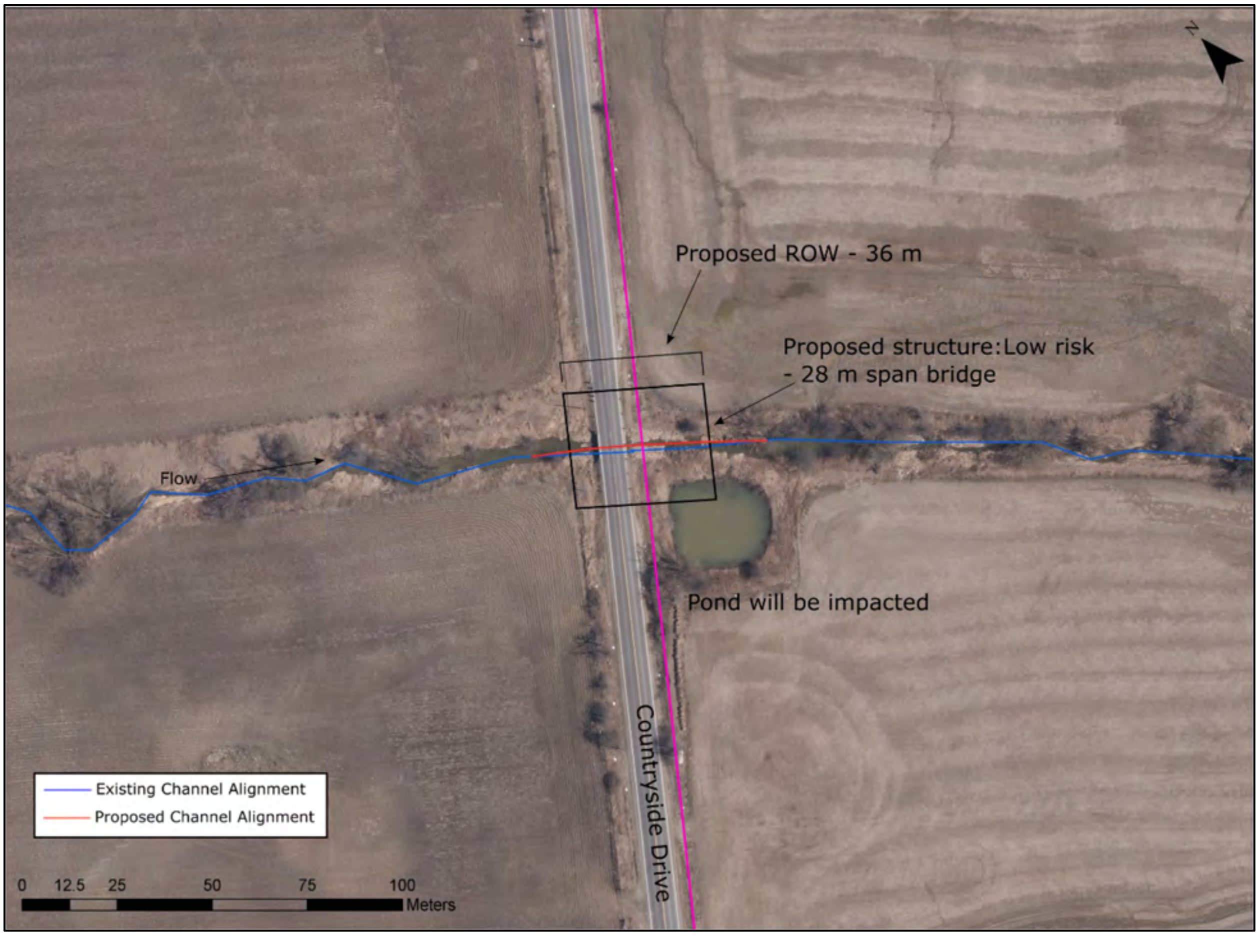



**FIGURE 6 Gore Road Tributary Crossing Countryside Drive (Crossing B) - Alignment Option**

### 7.1.3 Crossing C (Reach C-3)

Currently, there is no road crossing at this location and the channel consists of a sinuous planform with local bank erosion observed due to the lack of mature, well-rooted vegetation to stabilize the banks. The channel contains an average bankfull channel width of 2.6 m. The current road design proposes an east-west Arterial Road that will cross the watercourse at a skew (~45°). Although the watercourse does not contain large meander amplitudes upstream, the channel is regaining sinuosity since being historically straightened and the crossing structure should accommodate the meander amplitude of 16 m measured downstream. Therefore, a minimum crossing span of 16 m is recommended, and the crossing structure should consist of a single span bridge or concrete arch culvert allowing for minor channel adjustment and wildlife passage. Two alignment options using the preferred crossing span from a geomorphic perspective are presented in the following subsections (Figures 7a and 7b).

Two other crossing span options are presented in Table 6 and include a no risk option (36 m) where the crossing spans the MBW or a medium risk option (9 m) where the crossing spans three times the bankfull width of the channel. From a geomorphic perspective, the low-risk option of the crossing spanning the maximum meaner amplitude (16-m) is the preferred option to ensure infrastructure is not at risk as a result of channel adjustment.

#### *7.1.3.1 Alignment Option 1*

This alignment option most closely resembles the current channel planform and involves minimal channel realignment upstream and downstream of the proposed road crossing to accommodate the right-of-way of 36 m. Through the crossing structure, the channel will require realignment to pass through the center of the structure. With this option, it is proposed that the crossing structure be constructed at a skew to the road (approximately 45°), allowing for smooth tie-in points upstream and downstream of the crossing. From a channel stability perspective, this is the preferred option, although it is acknowledged that it would result in the design and construction of a longer crossing structure (length of approximately 75 m).


**FIGURE 7a Clarkway Tributary Crossing Proposed East-West Arterial Road (Crossing C) - Alignment Option 1**

#### *7.1.3.2 Alignment Option 2*

This alignment option results in a greater length of channel realignment and increased ground disturbance; however, allows for the design of the crossing structure to be perpendicular to the road. During road construction, the upstream and downstream ends of the channel will require realignment to pass through the axis of the structure. A significant portion of the previous channel will have to be backfilled and regraded. Erosion protection along outer banks of the designed meanders both north and south of the road will be required to protect the road from future channel migration processes. Bank protection could include the design of a vegetated stone treatment, hydraulically sized to withstand in-channel velocities and shear stress. It is also noted that other design considerations and options would be feasible, in which the crossing structure presented below may be shifted east or west along the road with minor alterations to the proposed channel alignment to better accommodate the road construction works.

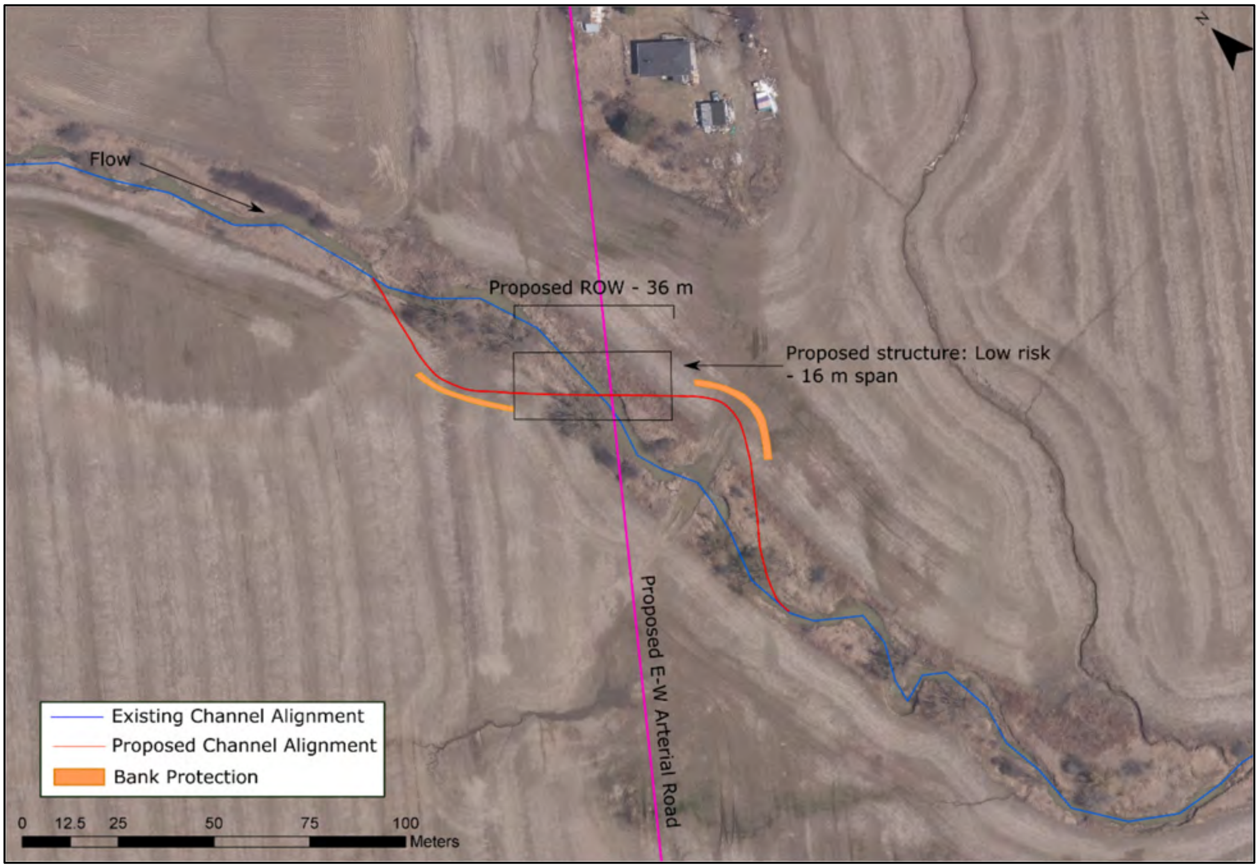



**FIGURE 7b Clarkway Tributary Crossing Proposed East-West Arterial Road (Crossing C) - Alignment Option 2**

### 7.1.4 Crossings D and E (Reaches C-6, C-7, and C-8)

The existing structures at the Clarkway Drive (Crossing D) and Countryside Drive crossing (Crossing E) are concrete box culverts with spans of 6.5 and 5.75 m, respectively. Upstream of Countryside Drive, bank erosion and bank slumping are prevalent, and the existing concrete box culvert has been outflanked. Additionally, a knickpoint has formed, creating a scour pool adjacent to Countryside Drive, indicating the current crossing is undersized. Between Countryside and Clarkway Drive, the channel flows parallel to the road via a roadside ditch with active erosion observed along the right bank (closest to the road). A stone retaining wall was previously constructed to mitigate bank erosion; however, erosion and bank undercutting are still prevalent. On average, the bankfull channel width is approximately 3.5 m.

It is recommended that both crossing structures be replaced to accommodate the upstream meander amplitude. This results in a minimum crossing span of 18 m and will improve geomorphic function of the watercourse and help to convey flow appropriately through the crossing. During road construction, the channel will have to be realigned to pass through the axis of the intersection and natural channel design principles should be employed to ensure bed and bank stability at the crossing location. Two alignment options using the preferred crossing span from a geomorphic perspective are presented in the following subsections (Figures 8a and 8b).

Two other crossing span options are presented in Table 6 and include a no-risk option (48 m) where the crossing spans the MBW or a medium risk option (10 m) where the crossing spans three times the bankfull width of the channel. From a geomorphic perspective, the low-risk option of the crossing spanning the maximum meaner amplitude (18 m) is the preferred option to ensure infrastructure is not at risk as a result of channel adjustment; however, the medium risk option with a crossing span of 10 m has been illustrated on Alignment Option 1 if there are design constraints that do not allow for a larger sized culvert to be constructed.

#### *7.1.4.1 Alignment Option 1*

This alignment option most closely resembles the current channel planform and involves minor channel realignment upstream of Countryside Drive, with more substantive channel realignment between Countryside and Clarkway Drive and downstream of Clarkway Drive. These works provide an opportunity to realign the channel such that a more sinuous planform can be achieved and bank erosion along the road embankment can be minimized. For the purpose of this conceptual alignment, it has been assumed that Countryside Drive will be widened eastward to minimize channel realignment on the west side, and that Clarkway Drive will be primarily widened to the south to avoid disturbing the residential property/driveway to the north.

Immediately upstream of the Countryside Drive crossing, the channel will be realigned to pass through the center of the proposed crossing structure, reducing the potential for the channel to migrate toward the road. Erosion protection will be required on two banks with sharper bends in the channel as illustrated in Figure 8a. This option could include the design of a vegetated stone treatment, hydraulically sized to withstand in-channel velocities and shear stress. From a geomorphic perspective, the preferred crossing structure at both crossings is the low-risk option with a span of 18 m to accommodate the largest meander amplitude upstream. However, from a design perspective, if this is not achievable, the medium risk option with a crossing span of 10 m (or equal to three times the bankfull width of the channel) is also suitable, but erosion protection may need to be more robust (e.g., larger stone sizes).

Between Countryside Drive and Clarkway Drive, the channel will require realignment away from the road and slight sinuosity along with hardened bank treatments may be designed to ensure the new road is not at risk due to erosion. Erosion protection along the west side of a residential driveway will also be required to ensure the channel does not migrate towards the driveway. Downstream of Clarkway Drive, to accommodate the proposed right-of-way of 36 m, the channel will require realignment to the southwest to tie into the existing creek corridor. Erosion protection on the right bank immediately downstream of the crossing will be required to ensure channel banks remain stable.

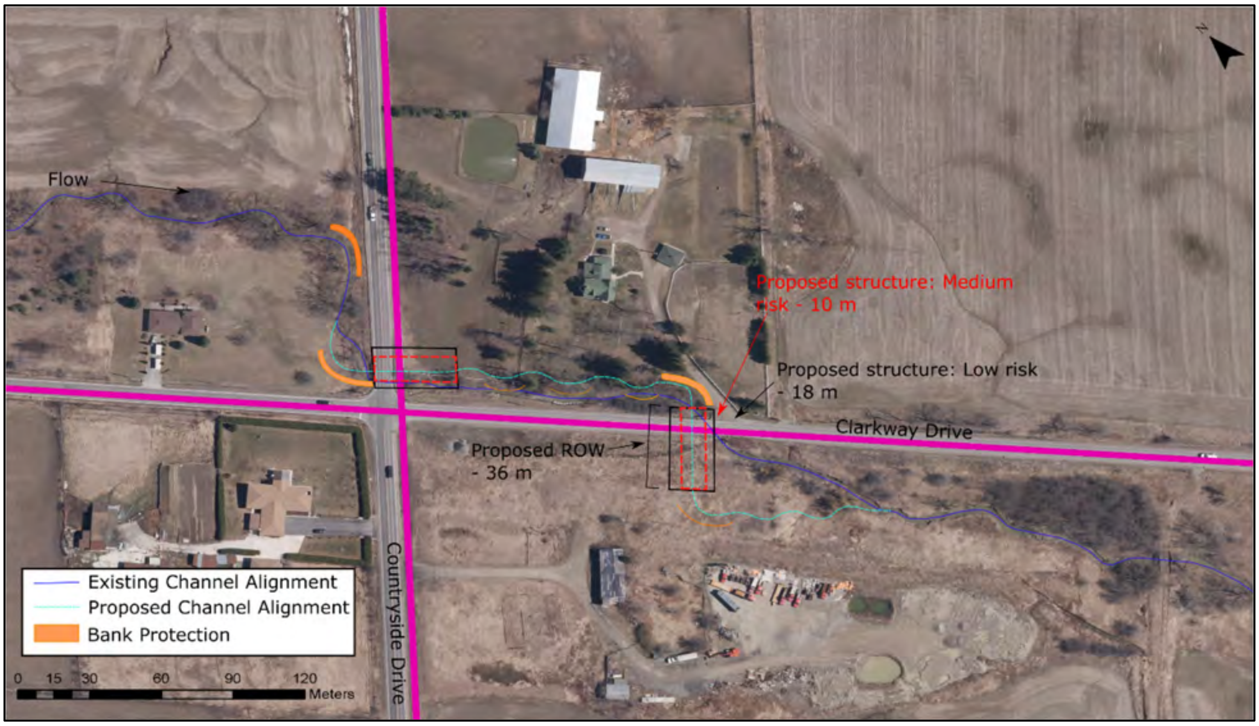



**FIGURE 8a Clarkway Tributary Crossing Countryside Drive and Clarkway Drive (Crossings D and E) - Alignment Option 1**

### *7.1.4.2 Alignment Option 2*

The second alignment option would require the channel to be entirely re-routed to the south side of Clarkway Drive, allowing the channel to pass through the center of the intersection. This option results in the removal of the existing Clarkway Drive culvert and instead consists of a longer bridge structure under the intersection. Optimally, the bridge should be skewed at an angle of 45°; however, this angle may be adjusted to balance the preferred channel realignments upstream and downstream. Overall, this option allows for a lesser amount of channel realignment (by channel length) and minimizes impacts to the residential property on the north side of Clarkway Drive. Immediately upstream and downstream of the crossing, erosion protection will be required to stabilize the right bank and will help limit lateral channel migration. Although this option only requires the design and construction of a single crossing structure, it will require a much longer bridge length (approximately 75 m) which may or may not be feasible from a road design perspective. Downstream of the road crossing, the channel planform will be designed with slight channel sinuosity to promote natural channel processes and habitat improvements.

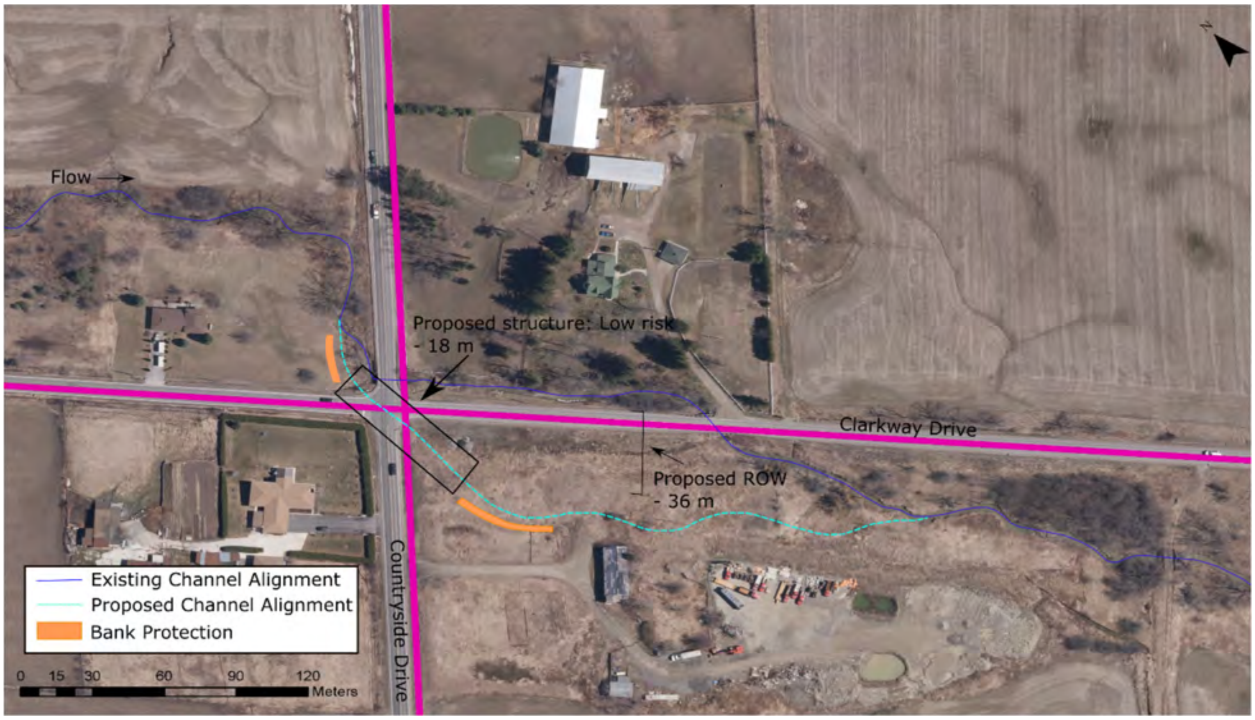



**FIGURE 8b Clarkway Tributary Crossing Countryside Drive and Clarkway Drive (Crossings D and E) - Alignment Option 2**

### 7.1.5 Crossing H (Reach R-5)

The existing crossing structure at Countryside Drive consists of a 3.0 m span concrete box. The channel is very narrow in this location with an average bankfull width of 1 m. This reach has been historically impacted by agricultural practices and has been historically straightened. Within the vicinity of the crossing, the largest meander amplitude is 12 m; therefore, a crossing span of 12 m is recommended as the channel attempts to regain sinuosity. The proposed crossing design should consist of a single span bridge or arch culvert, allowing for channel adjustment and wildlife passage. During road construction, the channel will have to be realigned to pass through the axis of the intersection and natural channel design principles should be employed to ensure bed and bank stability at the crossing location. For the purpose of this conceptual alignment, it has been assumed that Countryside Drive will be widened eastward to avoid disturbing the residential property/driveway to the west.

#### *7.1.5.1 Alignment Option 1*

This alignment option most closely resembles the current channel planform and involves minimal channel realignment upstream and minor realignment downstream. To keep channel realignment minimal, it is proposed the crossing structure be constructed with a slight skew (~15°). To accommodate the proposed right-of-way of 36 m, the channel will be shifted slightly south on downstream end to allow the channel to pass through the center of the crossing structure. Downstream of the crossing the channel will be realigned to the east to tie into the existing planform with minimal ground disturbance.

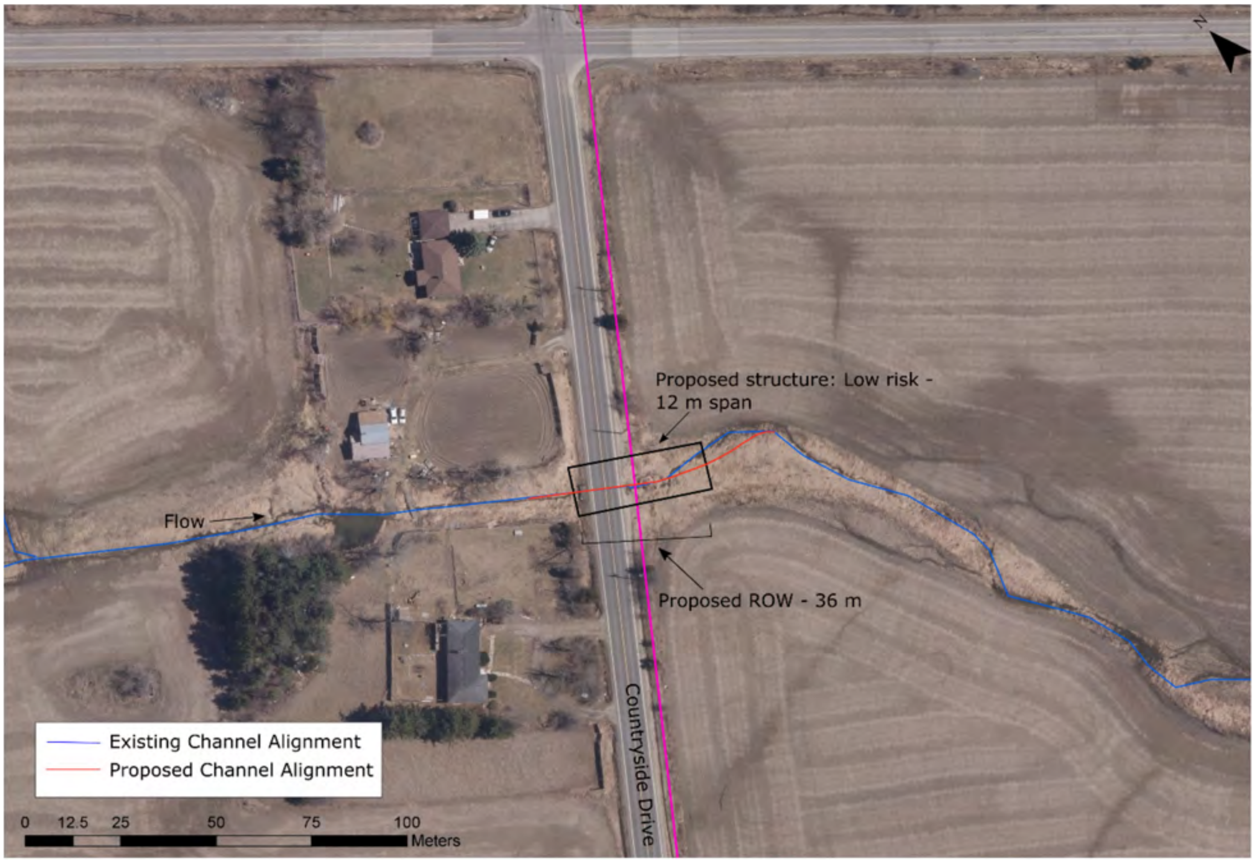



**FIGURE 9a Rainbow Creek Tributary Crossing Countryside Drive (Crossing H) - Alignment Option 1**

### *7.1.5.2 Alignment Option 2*

This alignment option results in a greater length of channel realignment and increased ground disturbance; however, allows the channel to be designed with slight sinuosity and a smoother downstream tie-in to the existing planform. Similar to Alignment Option 1, channel realignment upstream of Countryside Drive will be minimal.

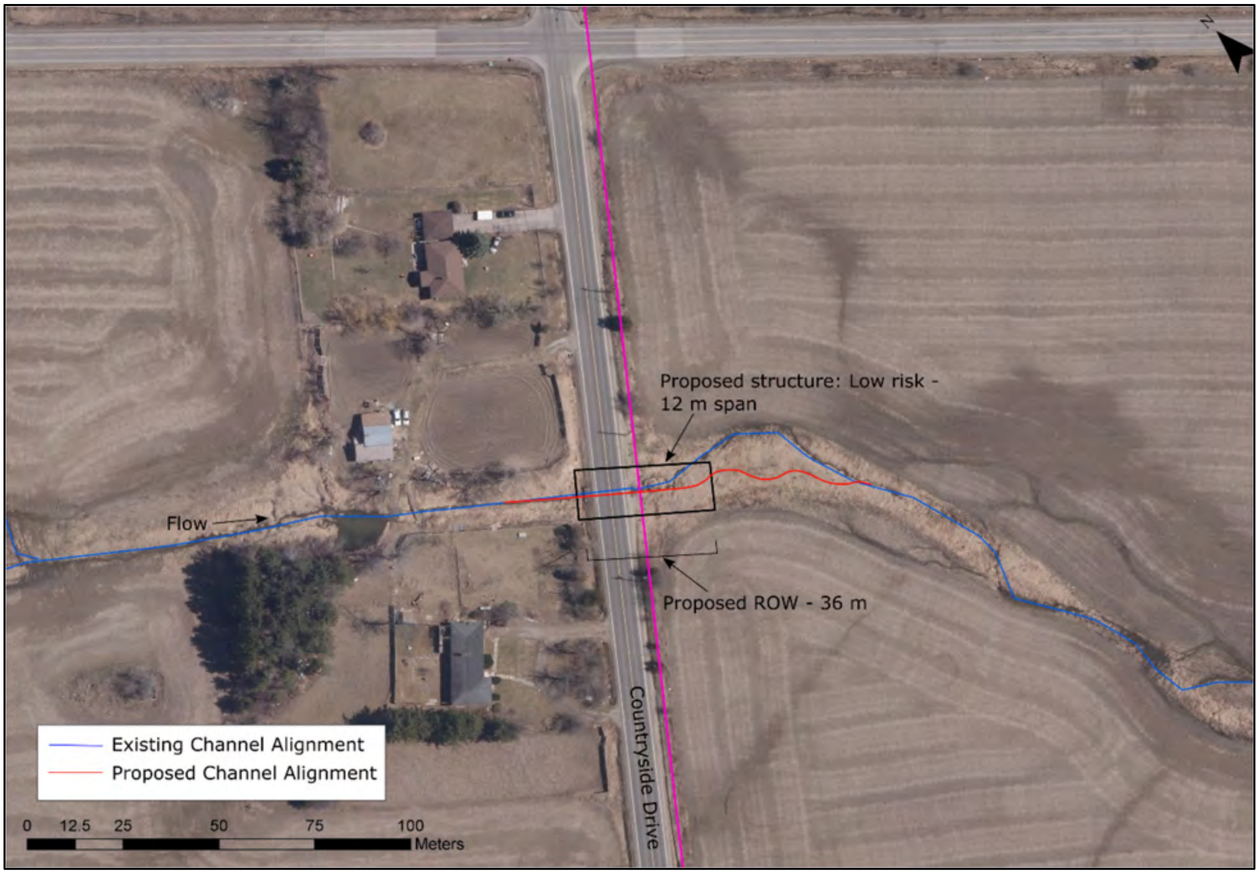



**FIGURE 9b Rainbow Creek Tributary Crossing Countryside Drive (Crossing H) - Alignment Option 2**

**TABLE 6 Summary of Available Risk Assessment Parameters - Recommended Structure Size Part B 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 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | Span (m) | | | |
| | | | | | | | | Type | Width (m) | Skew | Condition (Pooling/ Erosion) | Type | Medium Risk (Minimum 3x Bankfull Channel) | Low Risk (Upstream Meander Amplitude) | No Risk (Final Meander Belt) | Skew |
| G-1D | A | 3.0 | 28 | 0.25 | 53 | -* | Partially confined | N/A | | | | Open foot culvert/ bridge | 9.0 | 28 | 54 | Realign through centre of bridge/culvert |
| G-2D | B | 2.4 | N/A | 0.28 | 18 | -* | Unconfined | Concrete box | 5.5 | 90° | Minor erosion downstream | Open foot culvert/ bridge | 10 | 28 | 60 | Maintain skew |
| G-3 | B | 3.5 | N/A | 0.27 | 60 | 10 | Confined | Concrete box | 5.5 | 90° | Ponding upstream | | | | | |
| C-3 | C | 3.0 | 16 | 0.22 | 36 | - | Confined | N/A | | | | Open foot culvert/ bridge | 9.0 | 16 | 36 | Realign through centre of bridge/culvert |
| C-6 | D | 3.6 | 18 | 0.24 | 48 | -* | Confined | Concrete box | 6.5 | 45° | Scour downstream of crossing | Open foot culvert/ bridge | 10 | 18 | 48** | Maintain or increase |
| C-7 | D | 3.3 | N/A | N/A | 22 | -* | Confined by road | Bridge | 6.5 | 45° | Erosion along road embankment | | | | | |
| C-8 | E | 3.5 | 18 | 0.35 | 29 | -* | Confined | Concrete box with wingwalls | 5.75 | 90° | Erosion and scour upstream | Open foot culvert/ bridge | 10 | 18 | 48 | Maintain skew |
| R-5 | H | 1.0 | 12 | 0.25 | 29 | -* | Unconfined | Concrete box | 3.0 | 90° | Good condition | Open foot culvert/ bridge | 3.0 | 12 | 30 | Maintain skew or increase |

RGA - Rapid Geomorphic Assessment
MBW - meander belt width
*Channel historically straightened; no erosion rate could be measured.
**No risk option/MBW increased here from results to remain consistent with upstream crossing (not feasible to have a large change in crossing sizes where they are within such close proximity)

## 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, in most cases, the maximum existing meander amplitude near the crossings. 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 and are illustrated in the conceptual design figures if required. These treatments will ensure that the watercourse does not outflank or undermine the culvert or road embankment at these locations. Bed and bank treatments will need to be further refined and sized during the detailed design stage to ensure long-term channel health and stability.

Although not a watercourse crossing, Reach C-5B currently flows parallel to Clarkway Drive on the south side as a roadside ditch. To accommodate the proposed right-of-way of 36 m, this ditch will need to be shifted south outside the right-of-way, with the addition of bank treatments or a retaining wall along the left bank to protect the road.

# 8 SUMMARY OF RECOMMENDATIONS

A fluvial geomorphic investigation has been completed to characterize existing conditions of the watercourses within the Part B 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 approach for watercourse crossing recommendations

Watercourse crossings in the study area predominantly consist of channels that have been highly impacted by agricultural land use practices. Several watercourses upstream of their respective crossings have been historically straightened or impacted, making it difficult to quantify rates of lateral channel migration. RGAs reveal the watercourses are transitional/stressed, primarily due to channel widening or aggradation. It is anticipated that the replacement and redesign of new crossing structures will locally reduce channel instability by conveying higher flows through wider culverts and/or will stabilize these watercourse crossings with implementation of natural channel design methods.

**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 five crossing locations and these upgrades aim to improve geomorphic form and stability long term. Recommendations are based on reach characteristics and have been designed based on the right-of-way dimensions provided by Wood. Based on review of the risk factors and minimum recommended crossing structure sizes, all watercourses require channel realignment as a result of the road widening/construction works, although some more substantive than others. From a fluvial geomorphic perspective, it is recommended that new crossing structures accommodate a minimum span of the largest meander amplitude within the vicinity of the crossing. If this is not achievable from a design perspective, the medium risk span of three times the bankfull width of the channel may be considered, but the design of more robust bed and bank stabilization measures may be required. The crossing recommendations outlined in the current report 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 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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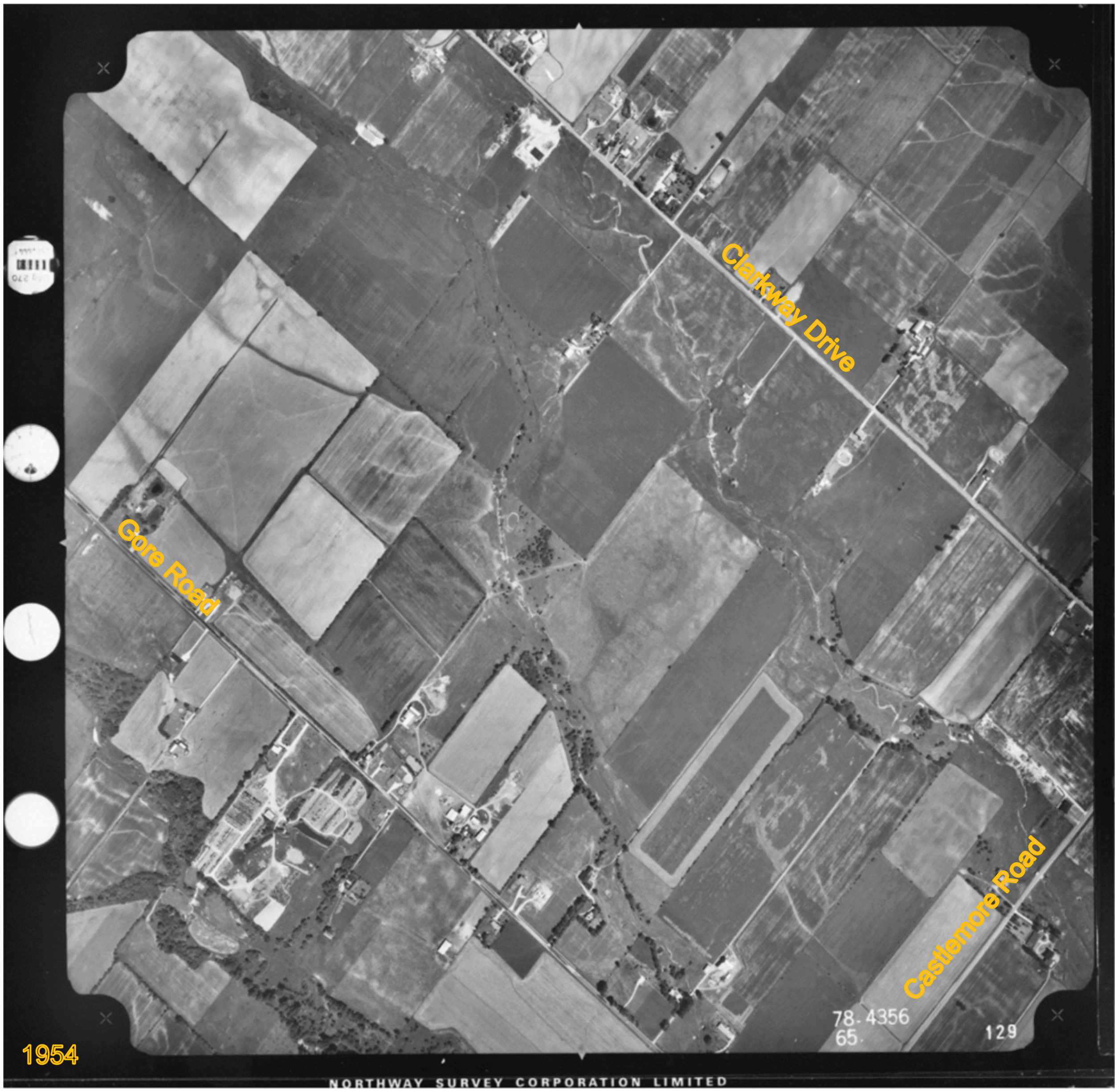
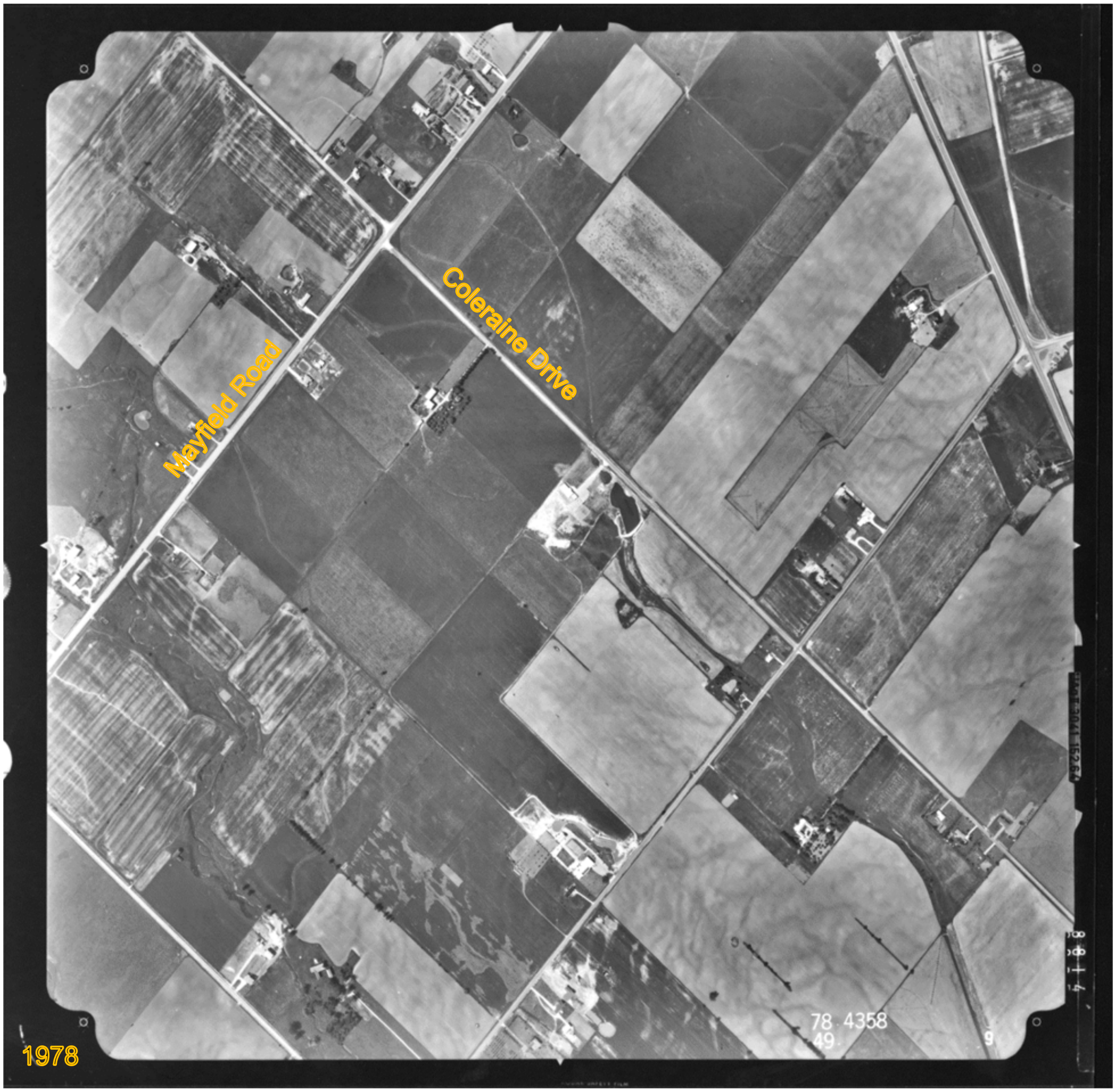
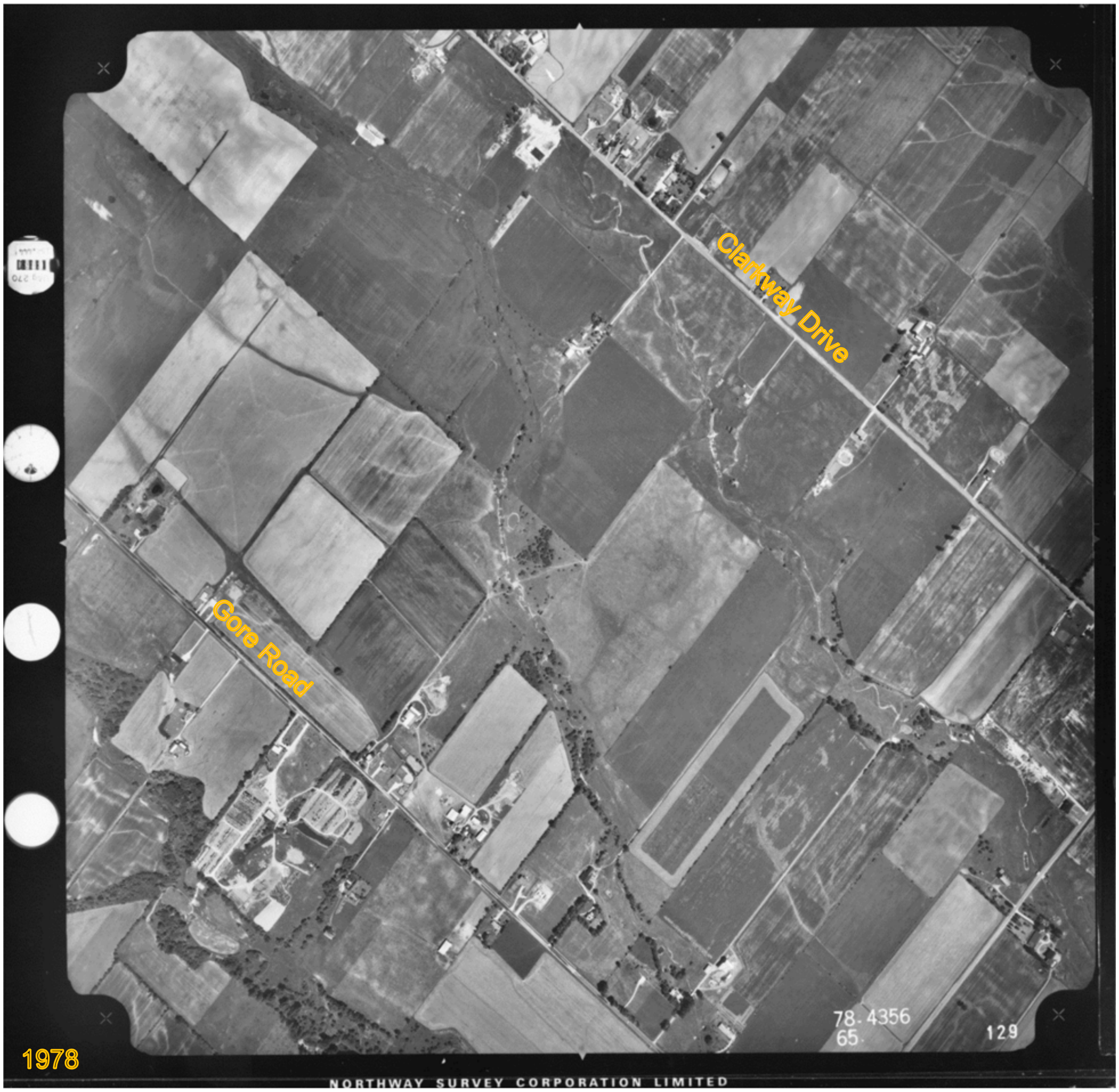
# APPENDIX A
# Historical Images

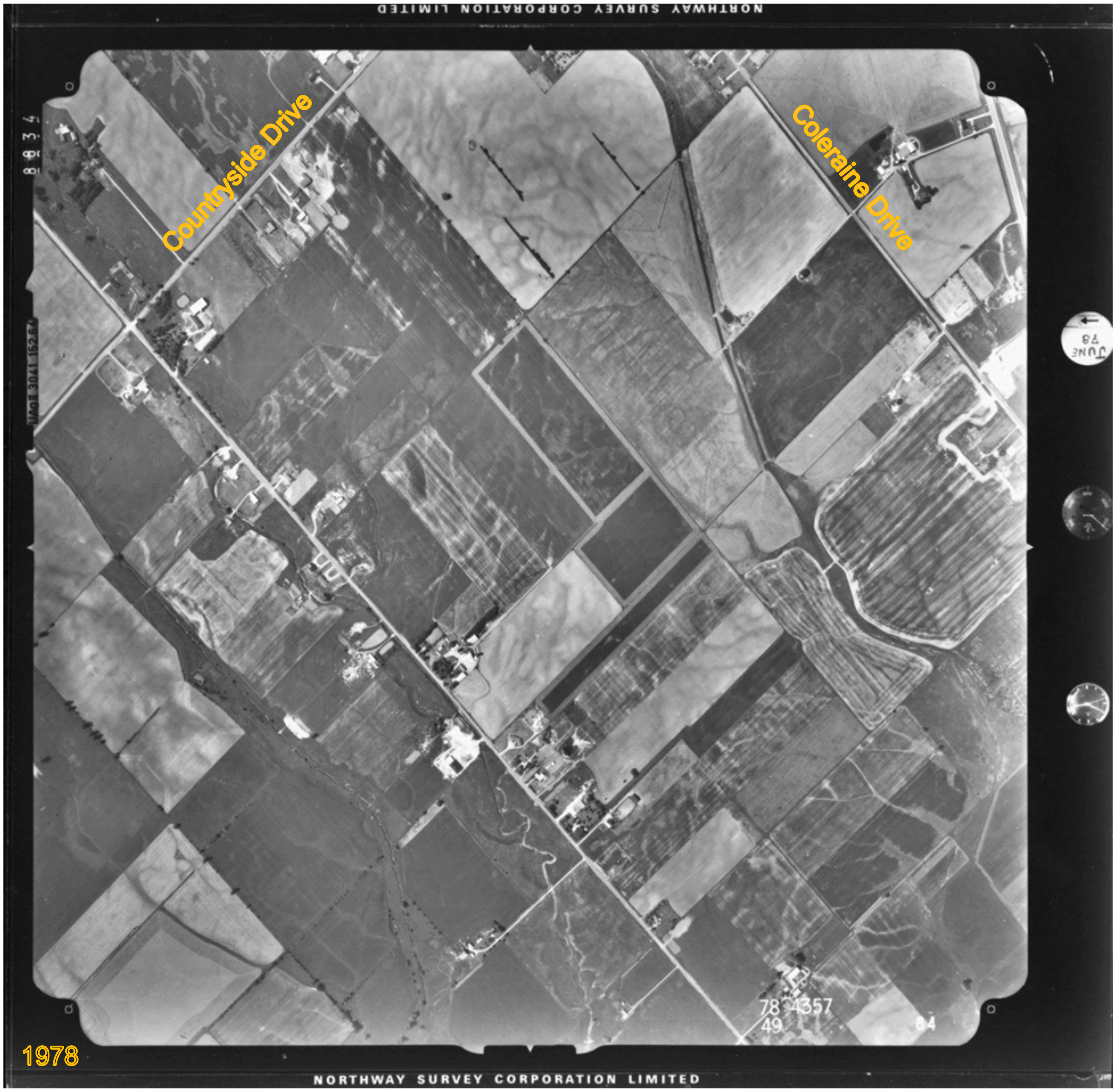
# APPENDIX A

# HISTORICAL IMAGES




Coleraine Drive
Mayfield Road
1978
78 4358
49

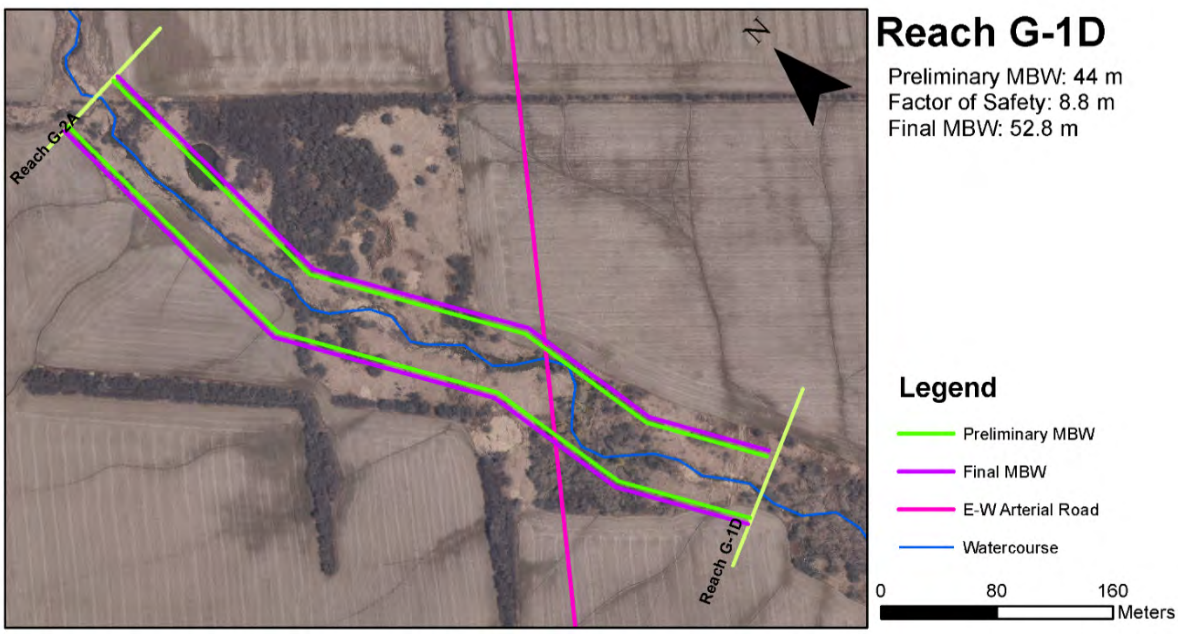

Clarkway Drive
Gore Road
1978
78-4356
65
129
NORTHWAY SURVEY CORPORATION LIMITED

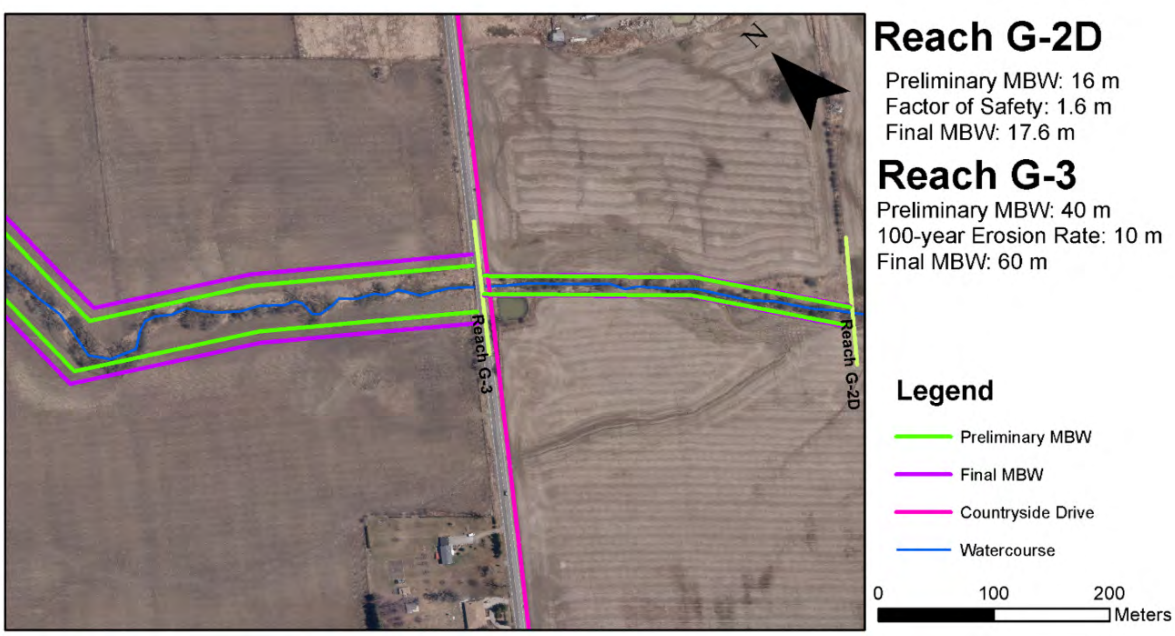

NORTHWAY SURVEY CORPORATION LIMITED
Countryside Drive
Coleraine Drive
1978
78 4357
49
NORTHWAY SURVEY CORPORATION LIMITED

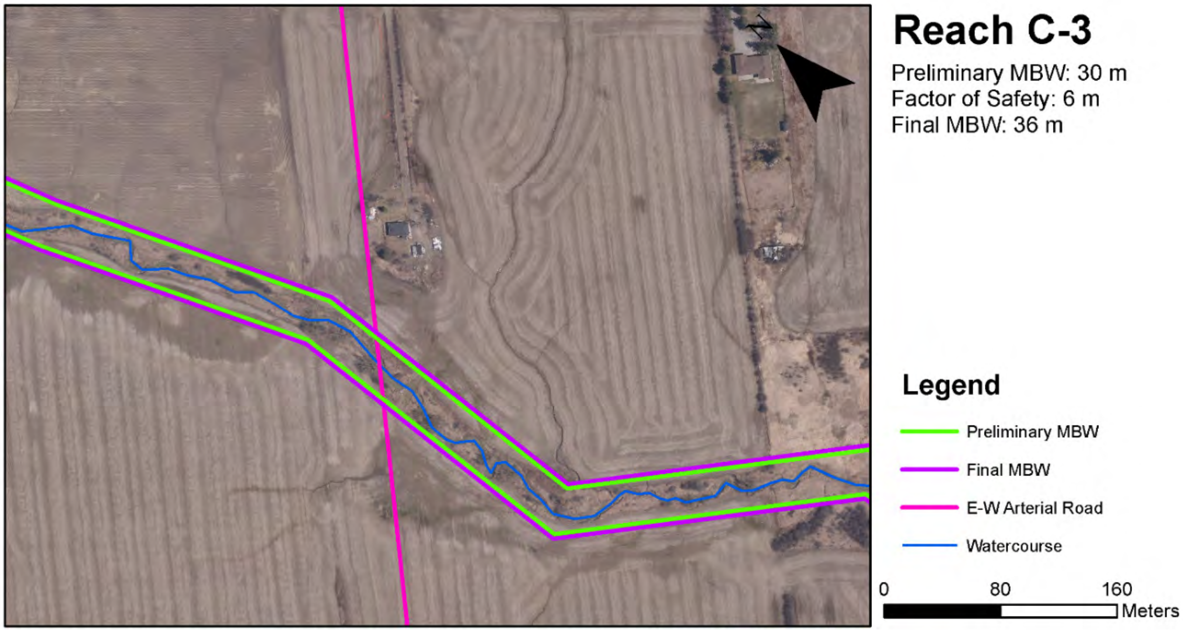
# APPENDIX B
# Meander Belt Mapping

# APPENDIX B

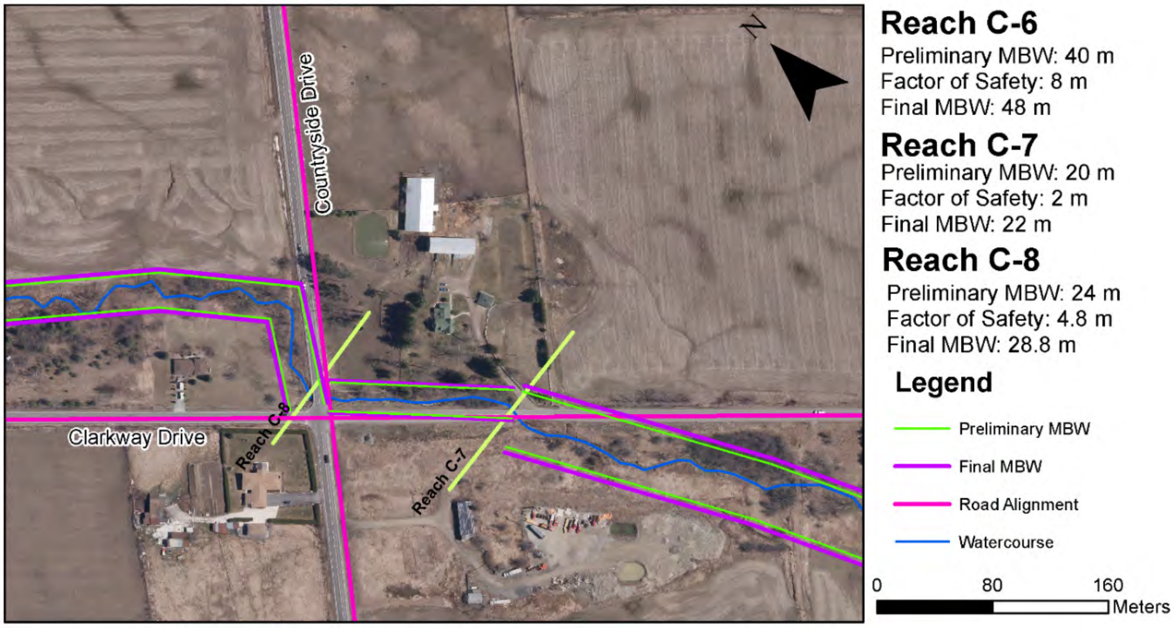
# MEANDER BELT MAPPING




Reach C-3
Preliminary MBW: 30 m
Factor of Safety: 6 m
Final MBW: 36 m
Legend
Preliminary MBW
Final MBW
E-W Arterial Road
Watercourse
0
80
160
Meters


Reach C-5B
Preliminary MBW: 21 m
Factor of Safety: 2.1 m
Final MBW: 23.1 m
Reach C-6
Reach C-5B
Legend
Preliminary MBW
Final MBW
Clarkway Drive
Watercourse
0
80
160
Meters


Countryside Drive
Clarkway Drive
Reach C-8
Reach C-7
N
Reach C-6
Preliminary MBW: 40 m
Factor of Safety: 8 m
Final MBW: 48 m
Reach C-7
Preliminary MBW: 20 m
Factor of Safety: 2 m
Final MBW: 22 m
Reach C-8
Preliminary MBW: 24 m
Factor of Safety: 4.8 m
Final MBW: 28.8 m
Legend
Preliminary MBW
Final MBW
Road Alignment
Watercourse
0 80 160
Meters


N
Reach R-5
Reach R-5
Preliminary MBW: 24 m
Factor of Safety: 4.8 m
Final MBW: 28.8 m
Legend
Preliminary MBW
Final MBW
Coleraine Drive
Countryside Drive
Watercourse
0 80 160
Meters

# APPENDIX C
# Site Photographs

*Matrix Solutions Inc.*
*June 29, 2016*

1. Reach G-1D: evidence of high flow above bed

*Matrix Solutions Inc.*
*June 29, 2016*

2. Reach G-1D: typical pool cross-section with overhanging vegetation

*Matrix Solutions Inc.*
*June 29, 2016*

3. Reach G-1D: woody debris jam and high-water marks

*Matrix Solutions Inc.*
*June 29, 2016*

4. Reach G-1D: pool cross-section with high-water marks

*Matrix Solutions Inc.*
*June 29, 2016*

5. Reach G-1D: extensive ponding upstream from beaver dam

*Matrix Solutions Inc.*
*June 29, 2016*

6. Reach G-2D: narrow channel cross-section downstream from crossing

*Matrix Solutions Inc.*
*June 29, 2016*

7. Reach G-2D: offline pond downstream from Countryside Drive crossing; channel is entrenched below floodplain and surrounding agricultural fields

*Matrix Solutions Inc.*
*June 29, 2016*

8. Reach G-3: upstream from Countryside Drive crossing; channel is entrenched; ponding is occurring upstream and widens flow pathway but creates shallower channel; vegetation dominated along the bed

*Matrix Solutions Inc.*
*June 29, 2016*

9. Reach G-3: stagnant water due to ponding upstream from Countryside Drive crossing

*Matrix Solutions Inc.*
*June 29, 2016*

10. Reach C-3: we;;-defined channel planform with cobble and gravel bed material and overhanging vegetation

*Matrix Solutions Inc.*
*June 29, 2016*

11. Reach C-3: undercutting and detached channel banks are common throughout the reach

*Matrix Solutions Inc.*
*June 29, 2016*

12. Reach C-3: multiple detached banks along outside meander belt

*Matrix Solutions Inc.*
*June 29, 2016*

13. Reach C-3: typical riffle cross-section

*Matrix Solutions Inc.*
*June 29, 2016*

14. Reach C-3: typical pool cross-section

*Matrix Solutions Inc.*
*June 29, 2016*

15. Reach C-3: looking upstream along channel from floodplain vantage point; wide riparian corridor and channel entrenchment apparent

*Matrix Solutions Inc.*
*June 29, 2016*

16. Reach C-5B: first private laneway crossing at upstream extent of reach

*Matrix Solutions Inc.*
*June 29, 2016*

17. Reach C-5B: sharp meander bend at upstream extent of reach; extensive erosion of outer bank; bank height >2 m

*Matrix Solutions Inc.*
*June 29, 2016*

18. Reach C-5B: cattails frequently grow along shallow riffle cross-sections throughout reach

*Matrix Solutions Inc.*
*June 29, 2016*

19. Reach C-5B: local erosion and undercutting of bank adjacent to road

*Matrix Solutions Inc.*
*June 29, 2016*

20. Reach C-5B: gabion baskets protect road embankment at the downstream extent of the reach; the gabion baskets are in poor condition with undercutting and failure of netting

*Matrix Solutions Inc.*
*July 28, 2016*

21. Reach C-6: view of reach from Clarkway Drive crossing; bank erosion and undercutting are visible on the outside meander bend

*Matrix Solutions Inc.*
*July 28, 2016*

22. Reach C-6: boulder bank protection along outside meander bend; erosion and undercutting still occuring

*Matrix Solutions Inc.*
*July 28, 2016*

23. Reach C-6: typical pool cross-section with gravel point bar development

*Matrix Solutions Inc.*
*July 28, 2016*

24. Reach C-6: wood debris common within channel and on banks

*Matrix Solutions Inc.*
*July 28, 2016*

25. Reach C-6: typical riffle cross-section with dry channel bed; long grasses and cattails grow along banks

*Matrix Solutions Inc.*
*July 28, 2016*

26. Reach C-6: exposed and elevated tree roots along outside meander bend toward downstream extent of the reach

*Matrix Solutions Inc.*
*July 28, 2016*

27. Reach C-6: stone retaining wall with re-bar reinforcements along bank toward downstream reach break

*Matrix Solutions Inc.*
*July 28, 2016*

28. Reach C-7: looking downstream along channel; bank erosion along south bank is common throughout the reach

*Matrix Solutions Inc.*
*July 28, 2016*

29. Reach C-7: woody debris has caused constriction of flow and local increase in erosion

*Matrix Solutions Inc.*
*July 28, 2016*

30. Reach C-7: vegetated coir-mat bank protection along south bank

*Matrix Solutions Inc.*
*July 28, 2016*

31. Reach C-7: ponding upstream from armourstone bank protection

*Matrix Solutions Inc.*
*July 28, 2016*

32. Reach C-7: exposed and undercut tree roots are evidence of channel widening

*Matrix Solutions Inc.*
*July 28, 2016*

33. Reach C-7: crossing at Clarkway Drive; south bank protected by boulder placement

*Matrix Solutions Inc.*
*July 28, 2016*

34. Reach C-8: bank undercutting along typical pool cross-section

*Matrix Solutions Inc.*
*July 28, 2016*

35. Reach C-8: riprap stone protection along Countryside Drive embankment and outside meander bend

*Matrix Solutions Inc.*
*July 28, 2016*

36. Reach C-8: knick-point and scour pool formation adjacent to Countryside Drive

*Matrix Solutions Inc.*
*July 28, 2016*

37. Reach C-8: vertical eroding bank and detached bank along outside meander bend; gravel point bar formation along inside meander bend

*Matrix Solutions Inc.*
*July 28, 2016*

38. Reach C-8: detached bank constricts pathway approaching Countryside Drive crossing

*Matrix Solutions Inc.*
*July 28, 2016*

39. Reach C-8: view of Countryside Drive crossing from Clarkway Drive; approach angle of channel causes erosion and scour

40. 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.*
*August 14, 2016*

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

*Matrix Solutions Inc.*
*August 14, 2016*

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

*Matrix Solutions Inc.*
*August 14, 2016*

43. 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