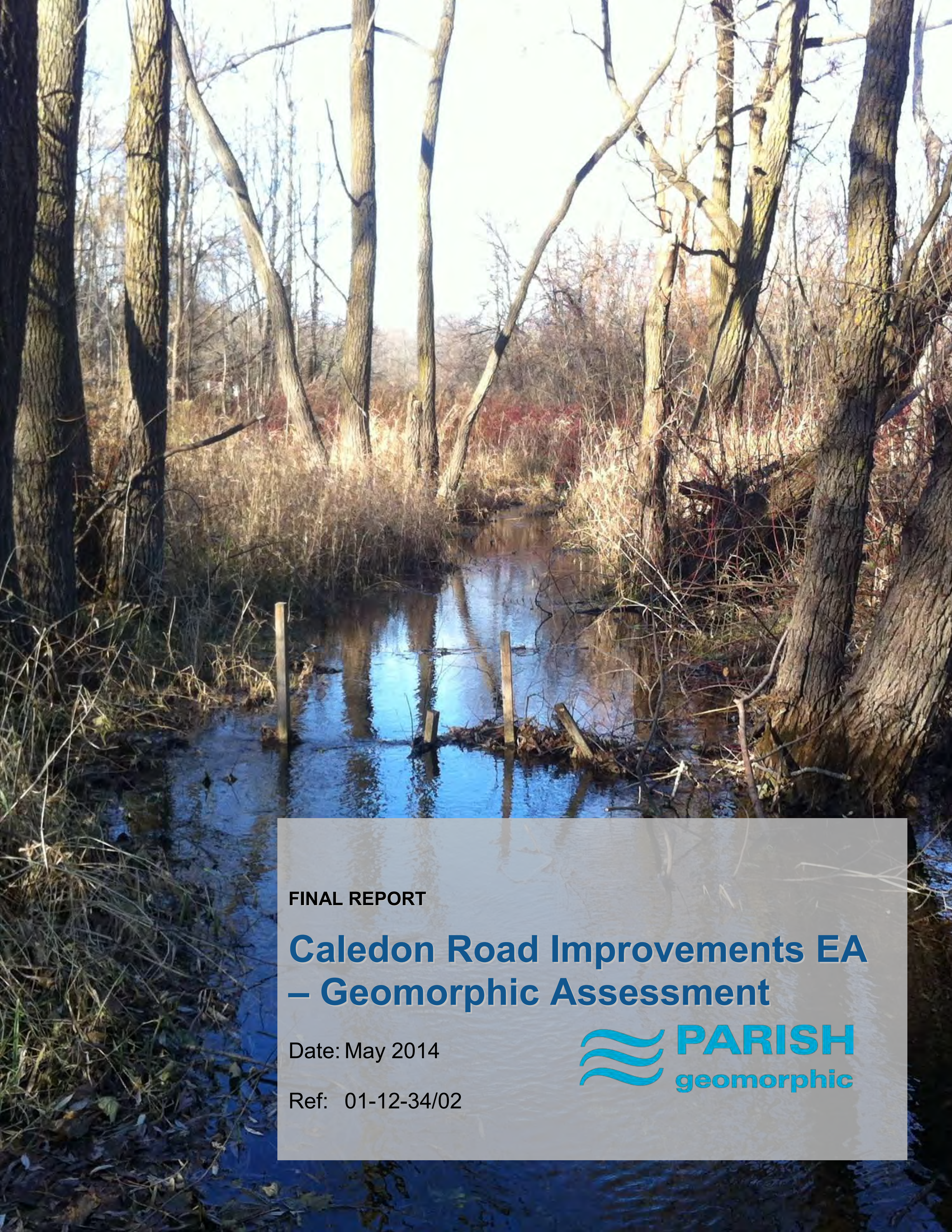
Appendix S
Geomorphic Assessment



FINAL REPORT

Caledon Road Improvements EA – Geomorphic Assessment

Date: May 2014

Ref: 01-12-34/02

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Document Title:	Caledon Road Improvements EA – Geomorphic Assessment
Status:	Final Report
Version:	02
Date:	May 2014
Project name:	Caledon Road Improvements EA
Project number:	01-12-34
Client:	HDR Inc.
Reference:	01-12-34/02

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Date of approval:	May 16, 2014

Contents

1. Introduction

The Region of Peel has initiated a Class Environmental Assessment in regards to proposed improvements to regional roads within the Belfountain area, within the Town of Caledon.

The regional roads include:

- Winston Churchill Boulevard from Bush Street to Old Base Line
- Mississauga Road from Bush Street to Old Base Line
- Bush Street from Winston Churchill Boulevard to Mississauga Road
- Old Base Line from Winston Churchill Boulevard to Mississauga Road

In support of the EA Study for these road works, a geomorphic assessment of associated watercourse crossings was undertaken. A total of 11 watercourse crossings were investigated within the study corridor and include a low-order tributaries of the West Credit River and main branch of the Credit River.

PARISH Geomorphic Ltd. has been retained by HDR Inc. to provide geomorphic support regarding the watercourse crossings. This report includes a desktop review of the subject crossings and a field investigation of the current crossing conditions. In order to determine whether a proposed crossing structure is suitable from a geomorphic perspective, watercourse crossings are typically evaluated according to a risk-based approach. This approach collectively reviews geomorphic conditions within vicinity of a crossing and identifies risks associated with the selected placement, sizing, and structure type.

In order to achieve this, the following tasks were undertaken:

- Collect and review any pertinent background information, such as topographic mapping, historic aerial photographs, and any previous reports that would pertain to the channel/road crossing.
- Use available mapping to confirm channel reach boundaries.
- Where possible, complete channel migration analyses in order to determine 25-year erosion rates.
- Delineate the meander belt on a reach basis in the vicinity of the subject development using available mapping and air photos.

- Complete field reconnaissance to confirm existing geomorphic conditions, document any evidence of active erosion, and confirm appropriateness of the desktop results.
- Assess risk of proposed crossings related to channel migration, flooding, and other factors.

Study Area

The 11 crossings assessed include the most significant or permanent watercourses that traverse the subject regional roads, and/or those that were identified as requiring assessment by Credit Valley Conservation (CVC). Additional minor culverts were identified; however these crossings were associated with insignificant drainage features. The existing structures that accommodate the Credit River system tributaries include: culverts 44 and 48 along Mississauga Road; culverts 14 and 10 along Bush Street; culverts WCB-06, WCB-09, WCB-14 and WCB-16 on Winston Churchill Boulevard; and culverts OBL-2, OBL-04, and OBL-08 along Old Base Line Road. Land use surrounding all of the subject watercourses is predominantly agricultural/scrub meadow. The culvert locations are displayed in **Figure 1.1**.

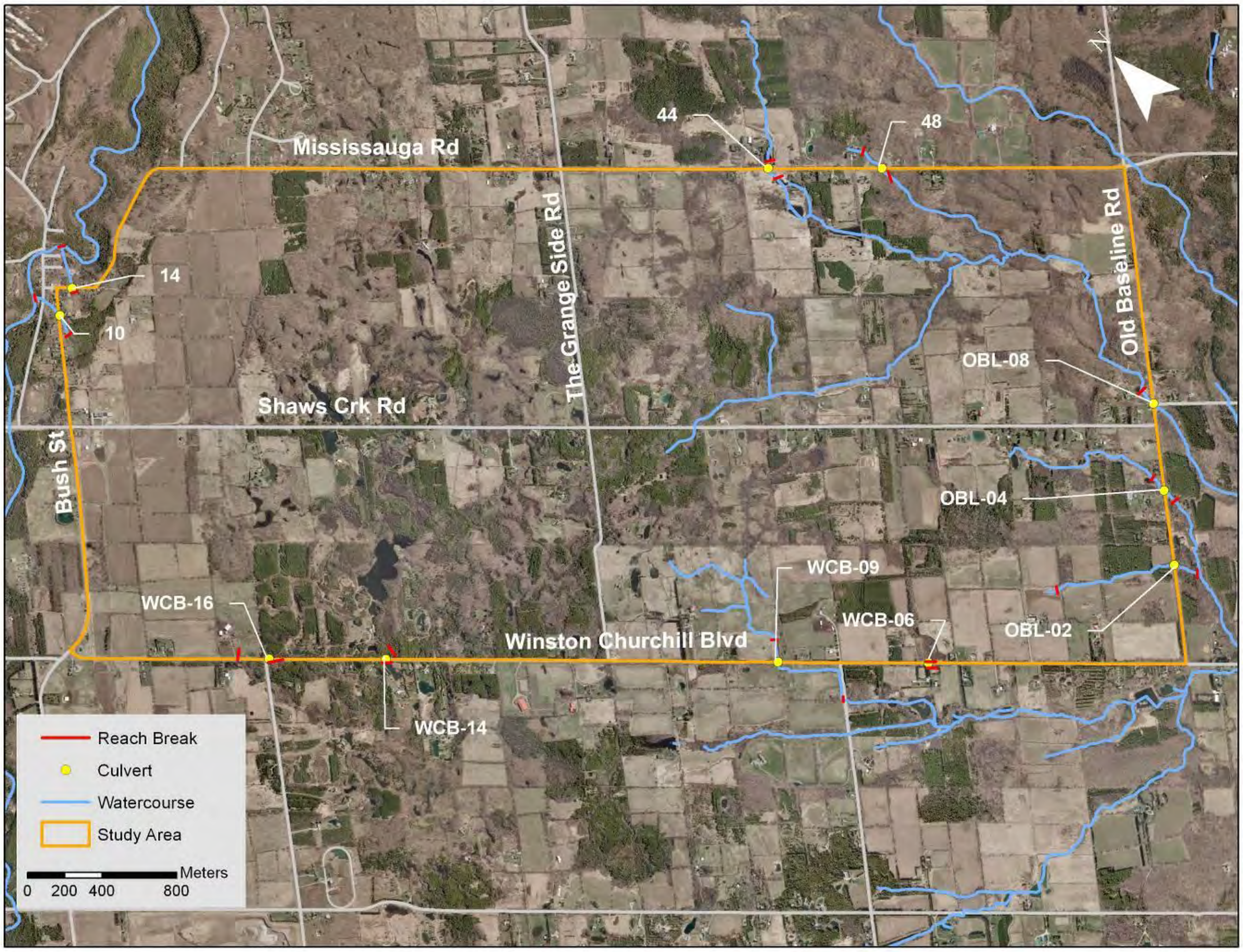

Figure 1.1: Study area and location of watercourse crossings.

2. Background Review

A background review was undertaken to gather information regarding the Credit River system tributaries within the study area. Reviewed data included previous reports and mapping resources, including information concerning physiography and surficial geology. A general understanding of the underlying geology provides insight into channel form. Geology influences channel geometry, rates of migration, and defines the quantity and type of channel sediments.

The watercourse crossings fall within one of three physiographic regions, while the relevant surficial geology includes three material types. The physiographic regions identified include the Guelph Drumlin Field (culvert 10), Horseshoe Moraine (culverts 44, 48, OBL-02, OBL-04, OBL-08, and WCB-09), and Niagara Escarpment (culvert 14). Both the Guelph Drumlin Field and Horseshoe moraine generally consist of mostly sandy silt till, while the Niagara Escarpment is characterized by very steep sloping terrain due to the presence of an erosion resistant outcrop of dolomite (Chapman & Putnam, 1984). Surficial geology at the crossings includes gravel, diamicton, and bedrock material, which is displayed in **Figure 2.1** along with the culvert locations (Ontario Geological Survey).

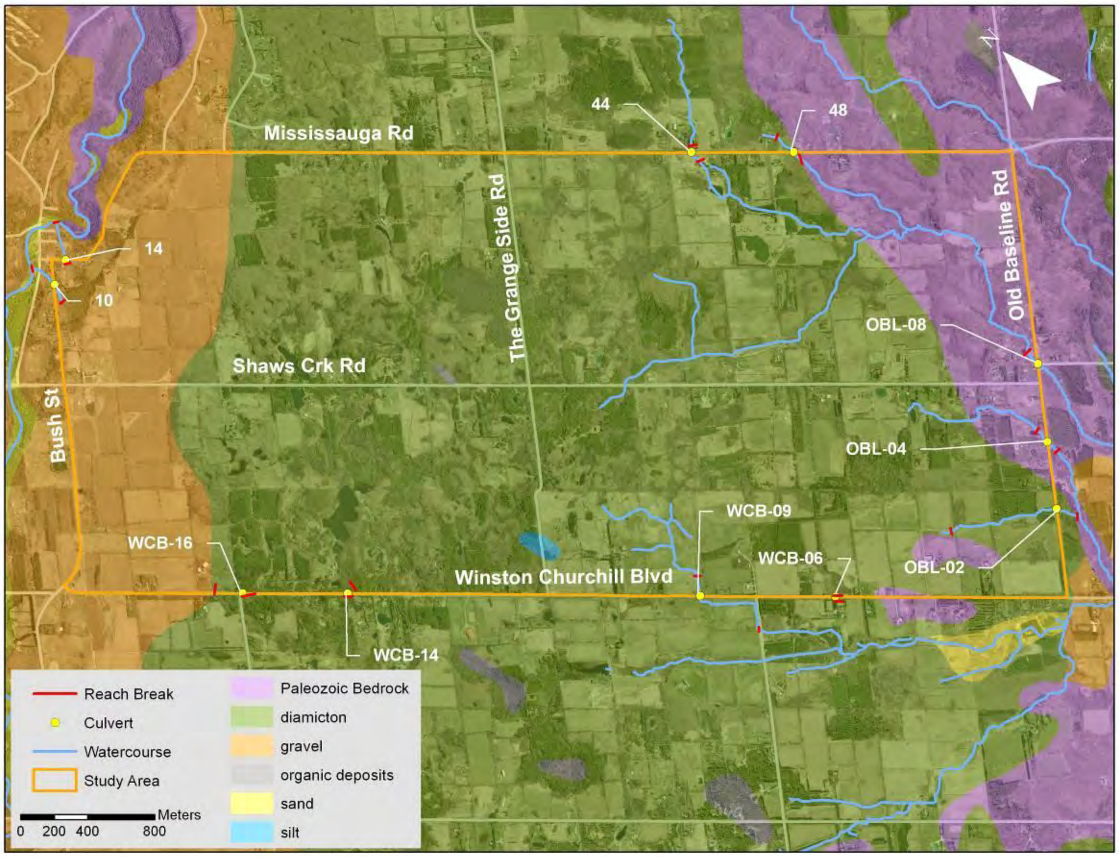

Figure 2.1: Surficial geology regions within the study area (Ontario Geological Survey)

3. Reach Delineation

The characteristics of the flow or channel materials can change along a creek or stream. In order to account for these changes, channels are separated into reaches – normally several hundred meters to several kilometers in length. A reach displays similarity with respect to its physical characteristics, such as channel form, function, and valley setting. Delineation of a reach considers sinuosity, gradient, hydrology, local geology, degree of valley confinement, and vegetative control using methods outlined in PARISH Geomorphic Ltd. (2002).

A study reach was delineated for each of the eight crossings. These reaches were primarily delimited according to geologic and hydrologic controls, such as tributary or pond confluences and wetland areas. Reaches are typically verified or refined following a field reconnaissance, which will be carried out when property access is granted. The provisional reach breaks are displayed below in **Figure 3.1,** which correspond to each of the subject regional roads.

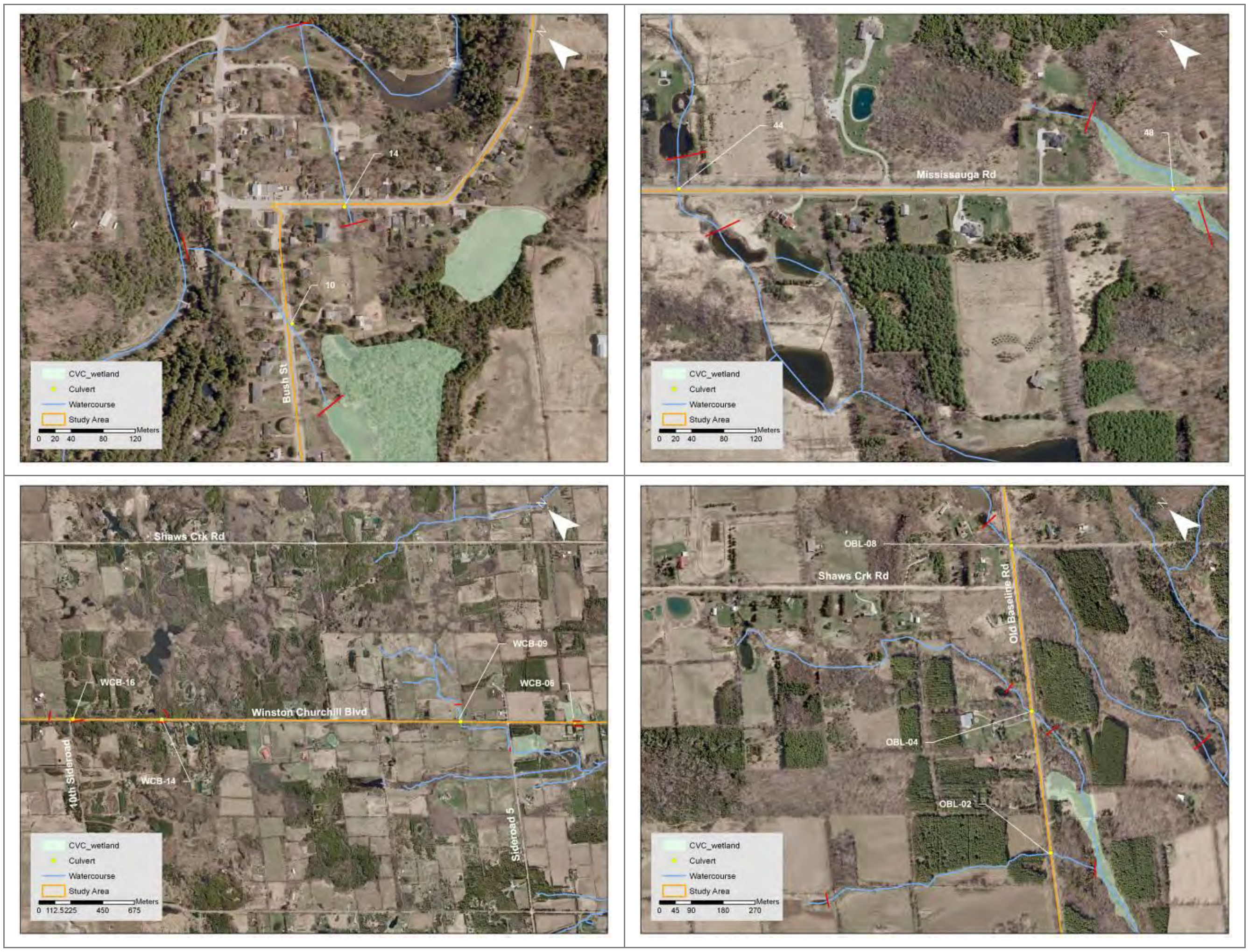

Figure 3.1: Reach delineation for culverts along each of the regional roads within the study area.

4. Historical Assessment

4.1 Migration Rate Analysis

River and stream systems are dynamic landscape features. Over time, their configuration and position within the floodplain changes as a result of meander evolution, development and migration processes. These lateral and down-valley planform adjustments are typically quantified over a 100-year period by means of a migration rate analysis. These 100-year erosion rates are determined by measuring the distance from known control points to a governing meander bend over the available historical record.

Due to issues with channel scale and degree of riparian cover, the calculation of accurate migration rates is not always feasible. In such cases, historic planform overlays can provide further understanding of the degree of relative planform adjustment as well as disparity between analyzed images. In this study area, it was apparent that many of the watercourses have undergone channelization due to the surrounding agricultural land uses. Further, the size of these low-order streams and obstruction from woodlots made channel identification difficult. Therefore, a migration rate analysis could not be completed.

5. Field Reconnaissance

5.1 Existing Conditions

In order to confirm existing geomorphic conditions, document any evidence of active erosion, and enable verification of meander belt width delineation, a field investigation of the delineated reaches will be carried out. This typically involves an evaluation of each reach by applying rapid geomorphic assessments, which are explained at the end of this section. To date, only data concerning the existing culvert structures could be investigated due to property access issues. Measurements upstream and downstream of the crossing structures were compared to the opening widths, which provide a provisional indication of whether the existing structures are adequate form a geomorphic perspective. **Figure 5.1** displays the subject crossings with an inset photograph of each structure, while **Table 5.1** summarizes the existing water crossing conditions.

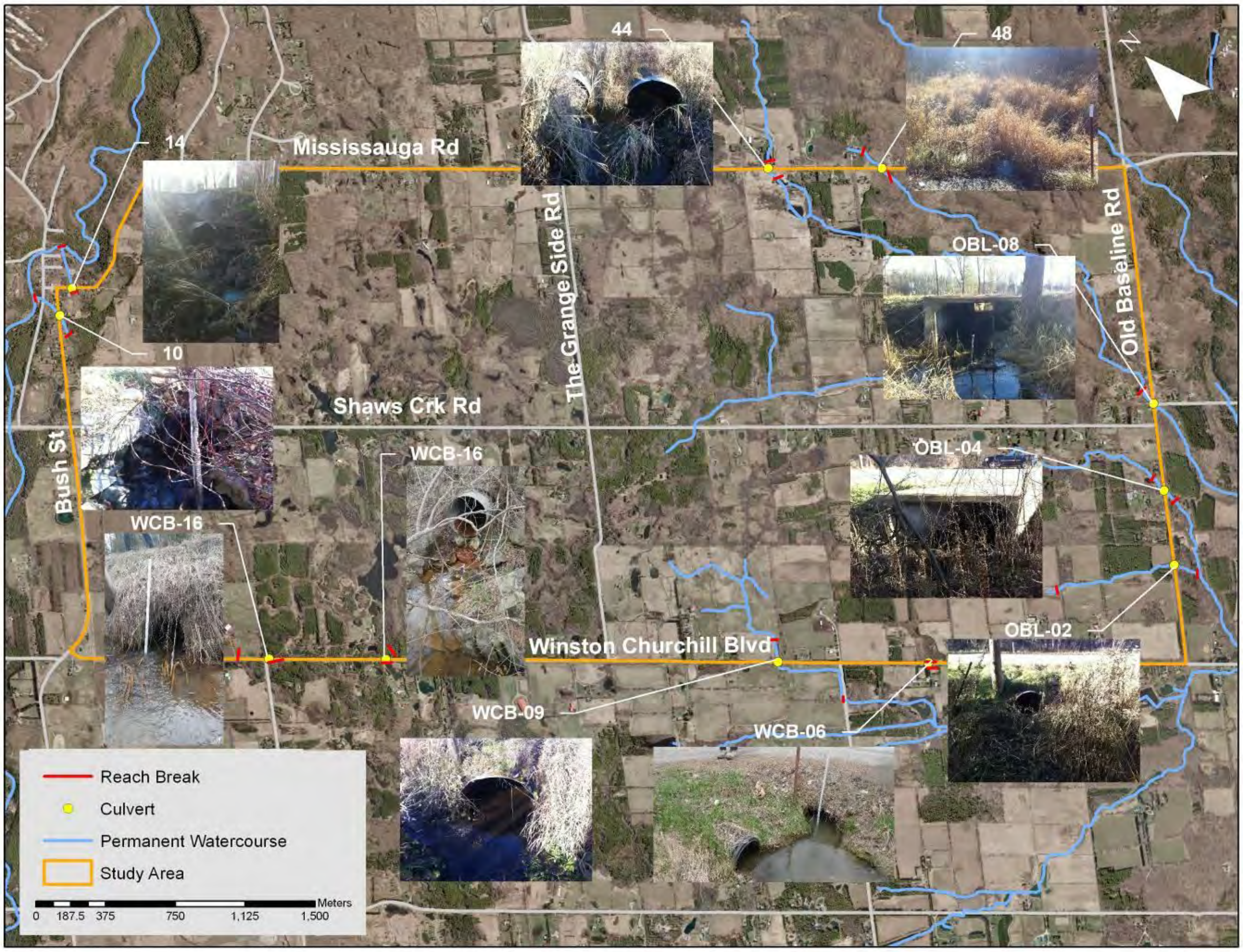

Figure 5.1: Culvert structures photographed at each crossing location.

Table 5.1: Summary of provisional crossing assessment

Crossing	Structure		Bankfull Dimensions (m)		Relative Crossing Size			Gradient	Valley Setting	Flow Restriction
	Type	Opening Width (m)	Width	Depth	Channel Width < Opening	Channel Width = Opening	Channel Width > Opening			
OBL-02	CSP	0.6	~1.25	~0.23			√	low	Partially confined	Woody debris
OBL-04	Concrete Box	3.25	~3.5	~0.3			√	low	Partially confined	Woody debris
OBL-08	Concrete Box	4.5	~4.5	~0.5		√		low	Partially confined	vegetation
44	Double CSP	0.75	~2.0	~0.6			√	low	unconfined	vegetation
48	CSP	0.5	n/a	n/a				low	unconfined	vegetation
10	Plastic Pipe	0.45	~2.75	~0.3			√	moderate	unconfined	Concrete debris
14	CSP	0.6	~1.1	~0.3			√	high	unconfined	none
WCB-06	CSP	0.6	~0.8	~0.36			√	low	unconfined	vegetation
WCB-09	CSP	1.34	~1.9	~0.35			√	high	Partially confined	vegetation
WCB-14	CSP	0.45	~0.63	~0.12			√	low	Partially confined	none
WCB-16	CSP	0.9	~0.76	~0.41		√		high	Partially Confined	Bank failure

Rapid Geomorphic Assessment

The Rapid Geomorphic Assessment (RGA) was designed by the Ontario Ministry of Environment (1999) to assess reaches in rural and urban channels. This qualitative technique documents indicators of channel instability. Observations are quantified using an index that identifies channel sensitivity based on the presence or absence of evidence of aggradation, degradation, channel widening, and planimetric adjustment. Examples of these include the presence of bar forms, exposed infrastructure, head cutting due to knick point migration, fallen or leaning trees and exposed tree roots, channel scour along the bank toe, transition of the channel from single thread to multiple thread, and cut-off channels. Overall, the index produces values that indicate whether the channel is stable/in regime (score ≤0.20), stressed/transitional (score 0.21-0.40), or adjusting (score ≥0.40) (**Table 5.2**).

Table 5.2: RGA Classification

Factor Value	*Classification*	*Interpretation*
≤0.20	In Regime or Stable (Least Sensitive)	The channel morphology is within a range of variance for streams of similar hydrographic characteristics – evidence of instability is isolated or associated with normal river meander propagation processes
0.21-0.40	Transitional or Stressed (Moderately Sensitive)	Channel morphology is within the range of variance for streams of similar hydrographic characteristics but the evidence of instability is frequent
≥0.41	In Adjustment (Most Sensitive)	Channel morphology is not within the range of variance and evidence of instability is wide spread

Rapid Stream Assessment Technique

The Rapid Stream Assessment Technique (RSAT) was developed by John Galli at the Metropolitan Washington Council of Governments (Galli, 1996). The RSAT 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, in-stream habitat, water quality, riparian conditions, and biological indicators.

Once a condition has been assigned a score, these scores are totaled to produce an overall rating that is based on a 50 point scoring system, divided into three classes: low (<20), moderate (20-35), and high (>35).

While the RSAT does score streams from a more biological and water quality perspective than the RGA, this information is also of relevance within a geomorphic context. This is based on the fundamental notion that, in general, the types of physical features that generate good fish habitat tend to represent good geomorphology as well (i.e., fish prefer a variety of physical conditions – pools provide resting areas while riffles provide feeding areas and contribute oxygen to the water – good riparian conditions provide shade and food – woody debris and overhanging banks provide shade). Additionally, the RSAT approach includes semi-quantitative measures of bankfull dimensions, type of substrate, vegetative cover, and channel disturbance.

5.2 Rapid Assessment Results

Rapid assessments were completed for each reach (crossing) within the limits of permissions by property owners. In some cases where the channel was undefined, like those streams draining wetland/marsh features, the rapid assessments could not be completed. Despite this setback, notes and site photos document the setting at each site and can assist in recommending updates to each crossing.

OBL-02

Upstream of the crossing, a pond had developed amongst some deciduous trees presumably due to recent melt. The channel remained undefined for approximately 100m upstream where a width of 1.5m and depth of 0.25m were measurable. On the downstream side, the channel grade steepened upon exiting the culvert into a single thread channel flowing over carbonate cobbles and boulders, forming a series of steps, characteristic of many streams on the Niagara Escarpment. Approximately 200m downstream the channel became multi-threaded through a cedar swamp. The substrate was comprised of silt, pebbles, and gravel, with cobbles occurring throughout. The stream was found to be in a transitional state with an RGA score of 0.26, with evidence of all forms of adjustment occurring. Aggradation was found upstream, and degradation, widening, and planform adjustment downstream of the culvert. Stream health (RSAT) scores were moderate with a value of 31.

OBL-04

Within the study area, this reach is one of the more significant watercourses, with water permanently flowing, and a concrete box culvert with a span of over 3m. The channel form is relatively straight, intersecting with Olde Base Line Road at approximately a 45° angle. It flows between a grassy field and a private pond, with deciduous trees lining the banks. Major woody debris occurs throughout and the bedform is dominated by a series of pools and jams, with unconsolidated gravels, sands, and silt depositing along the bed. Bankfull widths ranged from 1.8-4m, and depths from 0.33 to 0.71m. Bank heights increased downstream towards the road, and gravelly substrate lines the bed of the channel through the concrete culvert structure. The form and function of the channel can be identified as being in a state of transition with an RGA score of 0.31 and aggradation as the primary form of adjustment. Stream heath was determined to be moderate with a score of 28.

OBL-08

This watercourse was the only other within the study area that was major enough to require a relatively large crossing span (4.5m), also a concrete box culvert structure. It flows out of an online pond at the upstream end through a riparian zone dominated by deciduous trees, with major wood debris occurring. At the time of the survey, a late spring freshet was underway, creating overbank flooding. Despite this, bankfull features were visible below the water surface and inflections within the cross-section could be felt in order to estimate the bankfull channel dimensions. Bankfull widths were in the 3m range, and depths around 0.31m. Like OBL-04, the bed was comprised of unconsolidated gravels and sands. This reach is also in a state of transition with aggradation as the primary form of adjustment with an RGA score of 0.24. Stream heath was determined to be moderate with a score of 28.

WCB-06

Rapid assessments could not be undertaken for this reach. The upstream side lacked channel definition and has been mapped by CVC as a wetland. Downstream of the culvert outlet, a small stream filled with grasses exists as a ditch for only 15-20m before it is piped through a corrugated steel pipe beneath the property to the West.

WCB-09

This reach is primarily located within the roadside ditch flowing from the East side of Winston Churchill Boulevard, to the West side in a Southerly direction. It drains agricultural land east of the road though a tributary which leads into the ditch 10m upstream of the culvert inlet. It was apparent upon multiple visits that a natural channel is forming within the roadside ditch which is steep and straight. However, within the constraints of the ditch geometry, a series of knickpoints and alternating zones of bank erosion indicate that the channel is trying to regain some length, and reduce energy (slope). Bankfull widths ranged from 2 to 2.2m, and depths from 0.3 to 0.95m, as bank heights increased downstream but widths were confined to the ditch geometry. Riffles and pools were developing with substrates comprised of medium gravel and coarse sand in the riffles, and silt and sand in the pools. A few lateral bars had also formed, also composed of medium gravel, likely from road fill. Overall, the bed was relatively soft and unconsolidated. At the downstream end of the reach along Sideroad 5, the channel widens and shallows as confinement is reduced where the channel width is 3.35m with a depth of 0.57m. The culvert beneath Winston Churchill runs perpendicular with respect to the flow direction of the ditch, creating some sharp bends at either end. This reach was found to be in a state of transition with an RGA score of 0.30, and degradation as the primary form of adjustment. The stream was found to be moderately healthy with an RSAT score of 25.

WCB-14

Rapid assessments could not be undertaken for this reach. The upstream side was not flowing during the survey and was poorly defined, and downstream was backwatered with its base level being controlled by an online pond. Although the channel was poorly defined upstream, a width and depth could be estimated 5m upstream of the inlet with a width of

0.63m and a depth of 0.12m. Erosion was evident at the downstream side as the culvert was perched above the water surface by almost 0.5m, and the channel became much wider and deeper: 1.9m and 0.35m, respectively. Rip rap was utilized to stabilize this undercut. There is a notable difference in elevation between the inlet and outlet which likely increases the stream power and velocity under high flow conditions, creating the wider and deeper channel geometry downstream.

WCB-16

Similar to WCB-09, this reach is primarily located within the roadside ditch, with the culvert perpendicular to the prevailing flow. However, it is draining a smaller area, and initiates in a cedar swamp immediately upstream of the road, resulting in a smaller, more stable channel form. A small, deep channel exists for 2.5m upstream of the culvert, with a steep gradient and two steps and pools as it enters the culvert. The bank along the inlet has failed creating a small deposit, interrupting flow. At the outlet, the channel takes a sharp turn to the north through the drainage ditch, and a lateral bar has developed consisting of pebbles and fine to medium gravels. The channel is only confined along the left bank by the road, and the right there is connection of higher flows to a small marshy area and an online pond further downstream. At the downstream end of the reach (20m down from the outlet) there is a Bell phone utility box with a cobble step 0.3m high in the channel which would likely prevent fish migration upstream. This reach is relatively stable, and in regime, with evidence of aggradation mostly occurring due to the soft, unconsolidated bed. However, the score of 0.2 suggests that this reach may become more unstable and reach a state of transition. The RSAT score was moderate but rather low with a score of 21.

Culvert 10

Property access was not gained for this crossing, and rapid assessments were limited to what could be seen within and from the right of way, and in this case, could not be completed. Upstream of the road the watercourse is connected to a landscaped pond and flows into a plastic pipe underneath Bush Street. At the outlet and downstream, cobbles and boulders line the bed and banks, and the channel width is approximately 1.5m up to 2.75m, with a depth of approximately 0.25m.

Culvert 14

Like Culvert 10, property access was not gained for this crossing, and rapid assessments were limited to what could be seen within and from the right of way. This reach was inspected in August of 2013 when the bed was dry. Some geomorphic indicators could be identified and were applied as best as possible within the limits of the right of way to complete the RGA. The lack of flow did not present opportunity to perform the rapid stream assessment technique. Bankfull widths were estimated at 0.45 and 0.75m, up to 1.1m, with corresponding depths ranging from 0.2 to 0.3m, between the upstream and downstream portions of the reach. Upstream the channel is steep and artificially lined with coarse gravels and cobbles. Downstream, the channel resembles that downstream of Culvert 10, being steep and consisting of cobbles, gravels and boulders. Tree roots were exposed and bank heights increased downstream, indicative of some channel degradation. However, this reach was found to be in regime (stable) with a low RGA score of 0.10. The RSAT could not be completed as it was a dry channel with limited access.

Culvert 44

At this stream crossing, Mississauga Road runs overtop of a twin culvert (CSP) where a stream drains a pond 20m upstream and outlets to a marshy area characterized by cattails, eventually connecting with another online pond 40m downstream of the outlet. Upstream, the channel is slightly sinuous with a width of 3.2m, with a depth around 0.37m and is well connected to the floodplain. This steepens within the right of way upon approach to the inlet of the culvert(s). Downstream of the road, the channel widens into a marshy area and backwatering occurs into the culvert outlet. Channel substrates are coarse gravels and cobbles upstream, with finer gravels and sands downstream. Wood debris is present throughout, and a fence crosses the channel at the property line upstream. Than channel was found to be relatively stable (in regime), with a score of 0.19, which is close to entering a state of transition. Its primary form of adjustment is in the planform as it becomes a multi thread channel downstream through the wetter area. The stream health is moderate with an RSAT score of 32.

Culvert 48

This culvert was bound by wetland marshes with an undefined main channel, with the upstream side identified as a wetland by CVC. Substrates were characteristically fine and the surrounding land was dominated by wetland grasses and deciduous trees and shrubs. Rapid assessments could not be undertaken as a result, and a define channel could only accurately be identified approximately 100m downstream of the culvert outlet.

6. Meander Belt Width Delineation

Streams and rivers are dynamic features that change their configuration and position within a floodplain by means of meander evolution, development, and migration processes. When meanders change shape and position, the associated erosion and deposition 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 intended 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 space that a meandering watercourse occupies on its floodplain, within which all associated natural channel processes occur, is commonly referred to as the meander belt.

The Belt Width Delineation Procedure is applicable to a range of systems and follows a process-based methodology for determining the meander belt width based on background information, historic data (including aerial photography), degree of valley confinement and channel planform (Parish Geomorphic Ltd., 2004).

Due to the small scale of the subject channels and high probability of alteration, the meander belt widths could not be applied according to natural planform. In these cases, meander belt widths can be determined using empirical relations based on channel parameters. The following equations (**Table 6.1**) provide an estimate of meander belt width dimensions according to bankfull width, hydraulic depth, and maximum depth. These relations are based on measurements of real watercourses, however; the transferability to watercourses that are situated within southern Ontario is limited due to differences in hydrologic regime, drainage area, and general controlling factors. Reviewed collectively, they provide a data set from which to corroborate results attained through use of the standard belt width delineation procedures. Measured dimensions were completed at the time of the rapid assessments and used as input parameters. **Table 6.1** summarizes meander belt width dimensions for all study reaches. **Table 6.2** summarizes the average meander belt width for each reach as calculated using the formulas in **Table 6.1**. It was found that Bridge and Mackay, and Collinson seemed to severely over predict the belt width and were therefore removed from the average values in **Table 6.2**

Table 6.1: Empirical formulas for estimating meander belt width dimensions.

Meander Belt Empirical Analysis	
Source	**Equation**
Williams (1986) - width (m)	$4.3W^{1.12}$
Williams (1986) – channel area (m^2)	$18Ac^{0.65}$
Ward (2002) - width (ft) - no factor of safety	$4.8W^{1.08}$
Lorenz et al. (1985) - width (m)	$7.53W^{1.01}$
*Bridge and Mackey (1993) - hydraulic depth (m)	$59.9D^{1.8}$
*Collinson (1978) - maximum depth (m)	$65.6\ D_{max}{}^{1.57}$

*removed from average MBW calculations displayed in Table 6.2

Table 6.2: Meander belt widths as calculated using empirical formulas

Culvert	Preliminary Belt Width (m)
OBL-02	11.18
OBL-04	21.32
OBL-08	18.00
WCB-06	5.38
WCB-09	14.35
WCB-14	3.46
WCB-16	6.69
Culvert #10	6.13
Culvert #14	3.90
Culvert #44	19.71
Culvert #48	n/a

7. Crossing Assessment – Data Integration

To provide insight towards structure sizing of watercourse crossings in the study area, a risk-based procedure was followed. In general, the two primary factors that must be considered from a geomorphic perspective when evaluating crossing design are the potential for (1) channel migration/erosion and (2) channel incision. These two risk factors are affected by the following structure design parameters:

1. Channel migration/erosion (lateral instability):
    a. Length
    b. Span
    c. Skew

2. Channel incision (vertical instability):
    a. Invert (footing or bed)
    b. Length

In order to evaluate these risk factors, a geomorphic risk assessment protocol has been developed to assess a crossing structure in terms of the existing local geomorphic conditions (**Figure 7.1**). This risk assessment protocol typically provides a site-specific process to evaluate and determine whether the crossing structure size is appropriate from a geomorphic perspective. The protocol is based on existing and historic conditions that are applied to provide insight as to whether the structure is likely to be at risk given the projected future climate conditions. The following factors are considered within the protocol:

a) **Channel Size**: The potential for lateral channel movement and erosion tends to increase with stream size. Headwater streams tend to exhibit low rates of lateral migration due to the stabilizing influence of vegetation on the channel bed and banks. Erosive forces in larger watercourses tend to exceed the stabilizing properties of vegetation and result in higher migration rates.

b) **Valley Setting**: Watercourses with wide, flat floodplains and with low valley and channel slopes 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 more susceptible to down-cutting and channel widening, particularly where there are changes to upstream land use. Typically the classification of the valley will fall into one of three categories: confined, partially confined, and unconfined.

c) **Meander Belt Width**: The meander belt width represents the maximum expression of the meander pattern within a channel reach. Therefore, this width/corridor covers the lateral area that the channel could potentially occupy over time. This value has been used by regulatory agencies for corridor delineation associated with natural hazards and the meander belt width is typically of a similar dimension to the regulatory floodplain. The use of the meander belt width for structure sizing has been established as a criterion by some regulatory agencies and certainly represents a very conservative approach.

d) **Meander Amplitude**: The meander amplitude and wavelength are important parameters to ensure that channel processes and functions can be maintained within the crossing. For the purposes of this protocol, the meander amplitude of the watercourse would be measured in vicinity of the crossing and used as a guide to determine the relative risk to the structure. The number of meander wavelengths to be considered is both dependent on the scale of the watercourse and the degree of valley confinement. These were measured in the field during the rapid assessments.

e) **Rapid Geomorphic Assessment (RGA) Score**: An RGA score is essentially a measure of the stability of the channel. Channels that are unstable tend to be actively adjusting and thus are sensitive to the possible effects of the proposed crossing. Accordingly, there is more risk associated with unstable channels. While the actual RGA score will be reported, there are three levels of stability: 0-0.20 is stable; 0.21-0.40 is moderately stable; >0.40 is unstable.

f) **100-year Migration Rates**: Using historical aerial photographs, migration rates may be quantified (where possible) for each crossing location. A higher migration rate indicates a more unstable system and higher geomorphic risk.

Based on existing conditions, the majority of the proposed watercourses are appropriately located in terms of orientation to the channel. Having the road perpendicular to flow is important to maintain an open channel and reduce the likelihood of migration issues. In some cases, the channel crosses the road at an angle, and existing structures have been skewed appropriately (OBL-04 and OBL-08), these may benefit from further skew or channel realignment at the opening of each crossing. For those channels that have formed within roadside drainage ditches as a result of high, regular flow conveyance, the road essentially runs parallel to flow, but the culvert perpendicular, creating 90 degree bends upstream and downstream, which will pose erosion risk as the channel naturally migrates at these bends. In these cases (e.g. WCB-09 and WCB-16), the design phase should incorporate a more appropriate skew and channel realignment to enhance the form and function of the channel and reduce risk due to erosion.

Amplitudes were not measured in the field as the majority of these reaches were relatively straight a meander amplitude could not accurately be measured. Risk associated with the migration tendencies of meander features lessens with distance. A qualitative review of conditions surrounding each existing crossing structure was provided by the rapid assessments and revealed whether the current structures may be undersized or contributing to any stability issues. Furthermore, the presence of wetlands or ponds that will likely remain as features was considered in the sizing of each crossing. An attempt was made as to not oversize the structure if a wetland was present upstream, as the structure itself would provide necessary flow restriction to allow such habitats to develop. Open bottom culverts are recommended to enhance the function of each crossing. In cases where the culvert is perched (WCB-14) an effort should be made to reconnect the invert of the culvert to the channel invert to prevent scour and further undercutting. **Table 7.1** provides a summary of the bankfull features and size of each crossing, the empirically determined meander belt width, and a crossing size recommendation.

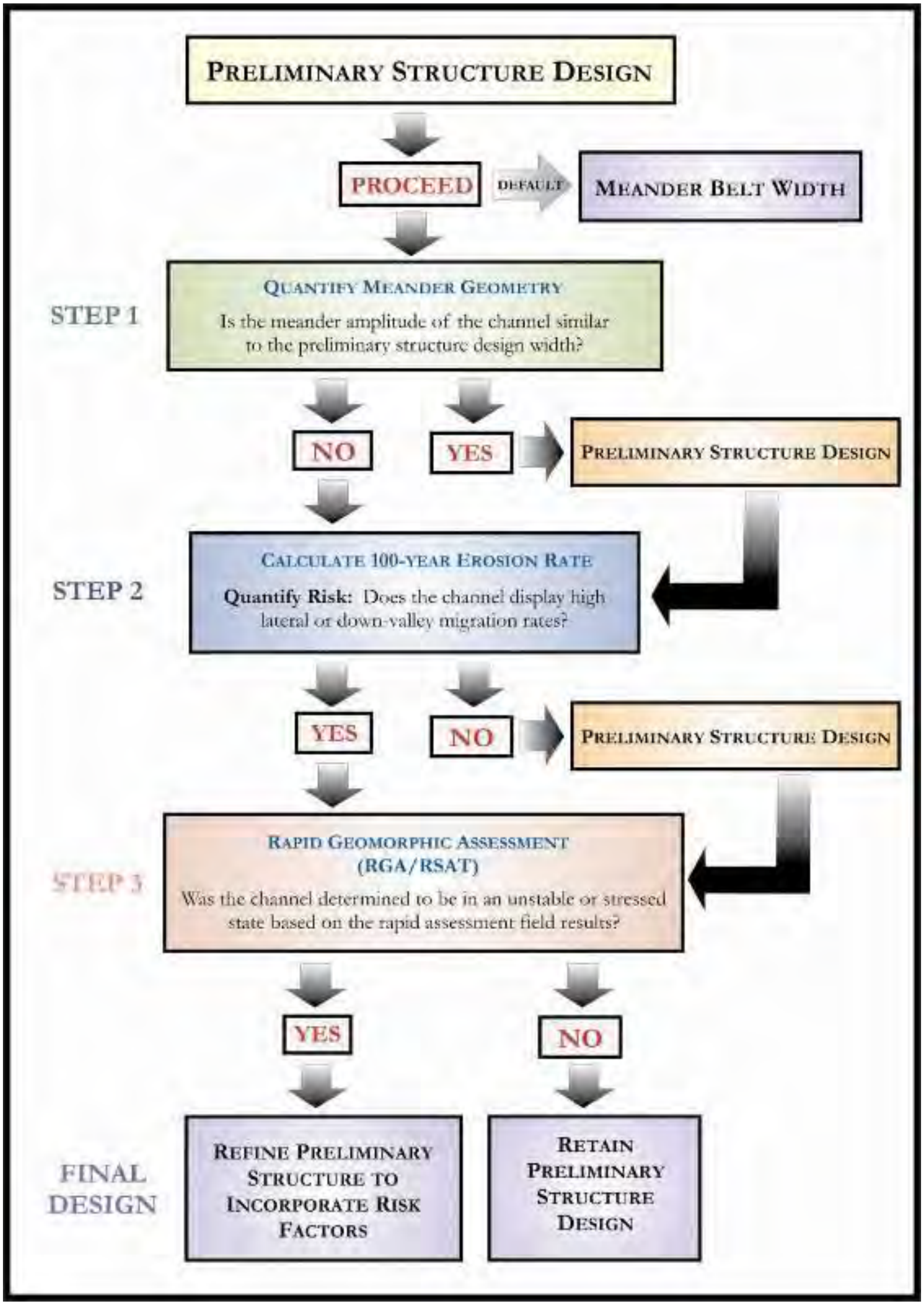

Figure 7.1: Geomorphic risk assessment protocol for span recommendations (PARISH Geomorphic Ltd, 2006).

Table 7.1: Summary of available risk assessment parameters.

Culvert	Channel Conditions / Modifications	Meander Amplitude (distance u/s or d/s) (m)	Bankfull Width (m) [at crossing]	Valley Setting	Preliminary Meander Belt Width (m)	Preliminary MBW Range (m)	RGA score	Existing Structure (mm)	Recommended Structure Size (m)
OBL-02	Farm upstream	n/a	1.80	Partially Confined	11.62	8.31 – 13.63	0.26	600	3.00
OBL-04	Offline Pond U/S	n/a	3.26	Partially Confined	22.25	16.15 – 25.37	0.31	3300 x 1200	6.00
OBL-08	Online Pond U/S	n/a	3.00	Partially Confined	19.14	14.72 – 23.68	0.24	3050 x 1400	6.00
WCB-06	Ditch, another CSP located 20m D/S of outlet	n/a	0.8	Unconfined	5.40	3.35 – 8.01	n/a	600	1.50
WCB-09	Roadside Ditch	n/a	2.16	Partially Confined	14.75	10.19 – 18.68	0.30	600	6.00
WCB-14	Pond D/S	n/a	0.63	Partially Confined	3.60	2.56 – 4.72	n/a	450	1.50
WCB-16	Roadside Ditch	n/a	1.15	Partially Confined	7.00	5.03 – 8.67	0.2	900	3.00
Culvert #10	Pond U/S, Hardening D/S	n/a	0.98	Unconfined	6.26	4.20 – 7.77	n/a	450	1.50
Culvert #14	Hardening U/S and D/S	n/a	0.60	Unconfined	3.90	2.43 – 5.65	0.1	900	1.50
Culvert #44	Pond U/S	n/a	3.20	Unconfined	20.86	15.82 – 24.38	0.19	2 x 750	6.00
Culvert #48	Wetland	n/a	n/a	Unconfined	n/a	n/a	n/a	500	Maintain Existing

8. Conclusions & Recommendations

A risk assessment was applied to 11 proposed crossings along major roads within the study area for tributaries of the Credit River. This assessment reviewed background information, which included past documents, aerial photos, and contour mapping. Study reaches were identified using desktop analyses and further assessed in the field within the limits of property access permissions. During the field investigations, indicators of active geomorphic processes were noted, channel dimensions were measured, and a stability index was provided for each study reach.

A wide array of watercourse types cross study area, ranging from a defined system with 3.2m bankfull width to intermittent drainage lines with no defined bed or banks. The majority of these streams were found to be in a transitional state, though none had severely high RGA scores to indicate that they are actively adjusting to prevailing conditions. Recommended structure types and sizes were provided for each identified watercourse crossing. These recommendations were based on a collective review of basic risk-assessment parameters that consider the site-specific geomorphic conditions (**Table 7.1**).

Upon detailed design, it is recommended that these minimum crossing spans are utilized using concrete culverts with an open-bottom, functional design. Improved culvert skew and/or channel realignment should be undertaken for those reaches in which flow is primarily restricted to the roadside drainage ditch (WCB-09 and WCB-16).

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Appendix A

Photographic Record

Crossing: 44

Photo 1: View looking downstream towards twin corrugated steel pipe culvert inlets.

Photo 2: View looking downstream of culvert outlet towards marshy area.

Crossing: 48

Photo 3: View looking downstream from culvert inlet where channel is undefined.

Photo 4: View looking upstream. Channel becomes more defined approximately 100metres downstream of culvert crossing.

Crossing: 10

Photo 5: View looking upstream of culvert crossing at online pond.

Photo 6: View looking just downstream of the online pond at culvert inlet.

Crossing: 14

Photo 7: View looking upstream of culvert crossing at dry, steep, artificial channel.

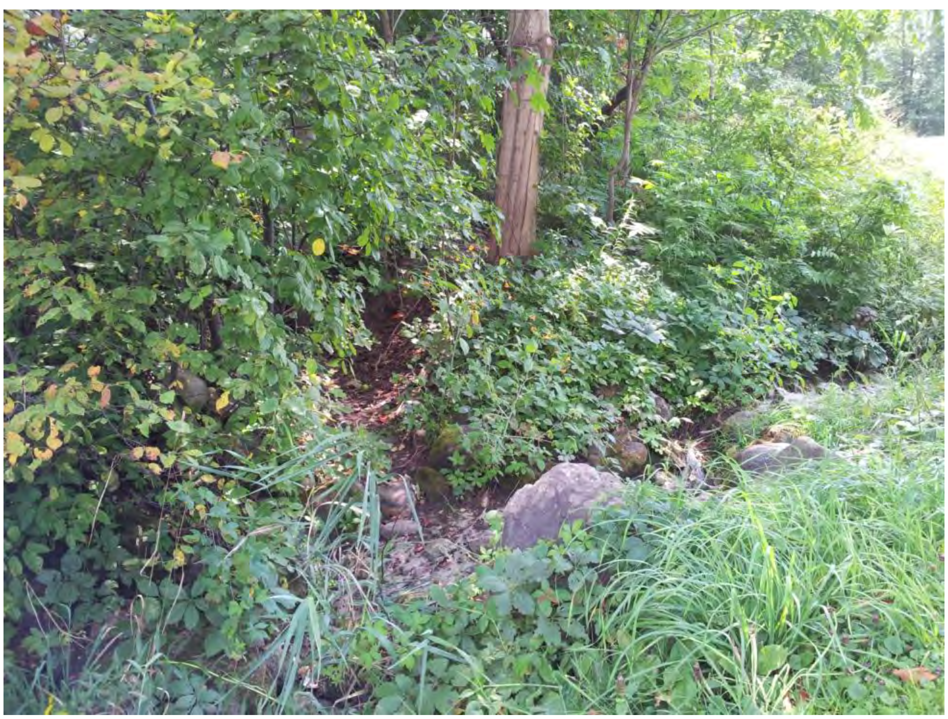

Photo 8: View looking downstream of culvert crossing at dry, steep channel.

Crossing: WCB-06

Photo 9: View looking upstream at culvert outlets.

Photo 10: View looking downstream of culvert.

Crossing: WCB-09

Photo 11: View looking downstream towards culvert inlet. Level logger is present just upstream of culvert.

Photo 12: View looking upstream towards culvert outlet.

Crossing: WCB-14

Photo 13: View looking downstream towards culvert inlet. Culvert appears to be collapsing.

Photo 14: View looking upstream towards the perched culvert outlet.

Crossing: WCB-16

Photo 15: View looking upstream towards culvert inlet which is being compromised by the failing bank.

Photo 16: View looking upstream towards culvert outlet which is being compromised due to slumping bank.

Crossing: OBL-02

Photo 17: View looking upstream towards culvert outlet.

Photo 18: View looking upstream of culvert inlet.

Crossing: OBL-04

Photo 19: View looking downstream at culvert inlet. Level logger is present just upstream of culvert.

Photo 20: View looking downstream from culvert outlet.

Crossing OBL-08

Photo 21: View looking downstream towards culvert inlet. Level logger is present just upstream of culvert.

Photo 22: View looking downstream of roadside ditch which drains into culvert inlet.