FLUVIAL GEOMORPHOLOGICAL ASSESSMENT

TESTON ROAD ENVIRONMENTAL ASSESSMENT (BETWEEN 250 METRES WEST OF PINE VALLEY DRIVE AND KLEINBURG SUMMIT WAY)
VAUGHAN, ONTARIO

Prepared for:
HDR INC.

Prepared by:
MATRIX SOLUTIONS INC.

Version 1.0
March 2022
Mississauga, Ontario

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APPENDICES

1 INTRODUCTION

The Corporation of the City of Vaughan is undertaking a Schedule C Municipal Class Environmental Assessment (EA) to identify improvements to Teston Road (RR49) from 250 m west of Pine Valley Drive to Kleinburg Summit Way in Vaughan, Ontario. HDR Inc. is the primary consultant completing engineering and environmental services for this EA and retained Matrix Solutions Inc. to assess geomorphic conditions at the watercourse crossings within the study area. The geomorphic assessment forms part of *Phase 1 - Identification of Problem and/or Opportunity Statements* of the EA process and has been updated provide a review of geomorphic impacts for the preliminary design.

The study area is located within the Humber River watershed. This watershed is under the jurisdiction of the Toronto and Region Conservation Authority (TRCA). The following watercourse crossings and features were identified to assess in the study (Figure 1):

- Tributary 1: tributary to the East Humber River, ~180 m west of Kipling Street, associated with Crossing 1 (C1)
- Tributary 2: west branch of Purpleville Creek, ~340 m east of Kipling Street, associated with Crossing 2 (C2)
- Tributary 3: tributary to Purpleville Creek, ~800 m east of Kipling Street, associated with Crossing 3 (C3)

The purpose of this geomorphic assessment is to characterize the crossings, identify erosion hazards, and provide design recommendations that will accommodate channel dynamics. Design considerations are also provided for areas in which the watercourse runs along the existing road embankment. The recommendations in this assessment will be considered to evaluate and select a preferred design alternative for the Teston Road improvements. Geomorphic recommendations and opportunities for the preferred design are included based on the preliminary design of the preferred alternative provided by HDR.

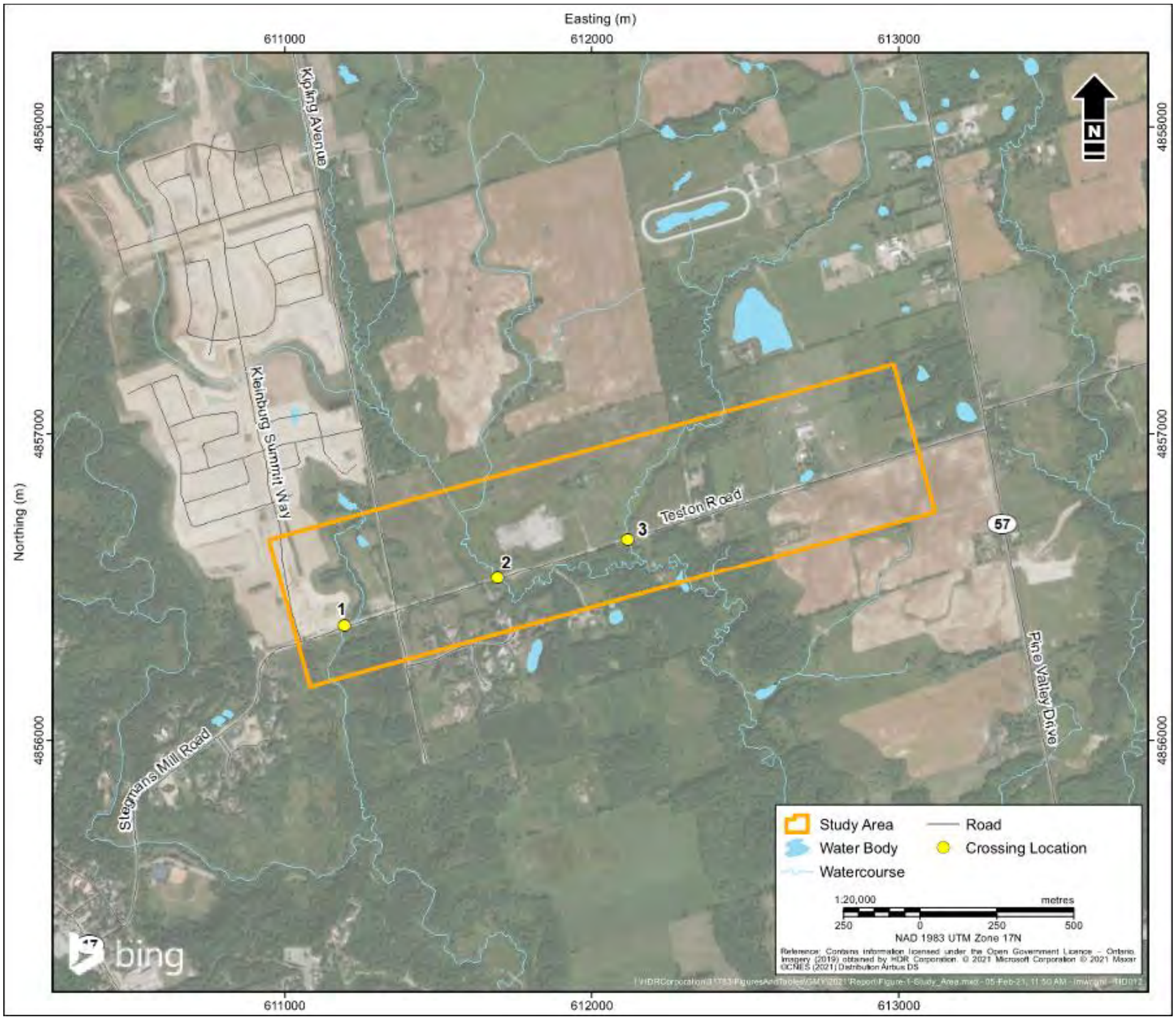


FIGURE 1 Study Area, Geomorphological Assessment

1.1 Scope

Matrix's geomorphic scope includes the following:

- characterizing watercourses in the study area at crossings and adjacent to the road
- assessing channel stability at crossings, including rapid geomorphic assessments (RGAs)
- assessing the erosion hazards at the watercourse crossings, with reference to historical aerial photographs, meander belt widths, empirical relationships, and field observations
- providing conceptual-level crossing recommendations to minimize erosion hazards and to maintain or improve geomorphic function and flow characteristics for the proposed road improvements

- provide a geomorphic review of the preliminary design and assess impacts and mitigation strategies

The following information was used to complete the scope of work:

- field reconnaissance on December 4, 2020 by Matrix
- historical aerial photography accessed from the Regional Municipality of York (York Region) and Google Earth
- detailed 2019 orthophotograph of the study area
- base mapping from Land Information Ontario
- 1 m topographic mapping
- available background reports related to the study area

2 BACKGROUND REVIEW

2.1 Study Area

The study area is located in the City of Vaughan just east of Kleinburg, Ontario, in the mid to lower portions of the East Humber Subwatershed. Approximately 18 km upstream of Lake Ontario, the Humber River splits into the West, Main, and East branches. Tributary 1 intersects the East Branch south of Teston Road. Tributaries 2 and 3 join south of Teston Road and flow into Purpleville Creek, which meets the East Branch of the Humber River south of Major Mackenzie Drive. The study area is a mixture of natural areas and low-density residential properties both north and south of Teston Road. Much of the study area is included in the Regional Greenlands System of York Region. The property northwest of Tributary 1 is in the process of being developed into a suburban residential area.

2.2 Principles of Watercourse Crossing Design

Guidance documents have been developed by local conservation authorities to promote the design of sustainable watercourse crossings. As per the TRCA *Crossing Guidelines for Valley and Stream Corridors* (TRCA 2015), TRCA's objectives for geomorphic hazards include following:

- minimize the risks of damage to the crossing infrastructure from watercourse channel migration, erosion, and scour through proper crossing siting and design

- avoid the need for future channel realignment or hardening by minimizing the probability of channel contact with the crossing infrastructure

- improve existing crossing structures, where possible, to reduce erosion hazards

2.3 Previous Studies

2.3.1 Kipling West Wetland Design (Kipling Ave and Teston Rd, Vaughan) (TRCA 2020a)

This map and description outline the extent and type of naturalization works that were undertaken by TRCA on Tributary 1 south of Teston Road. The project was designed to create and enhance a wet shrub thicket wetland to improve water quality and habitat diversity for amphibians. The ditch (Tributary 1) was widened into larger contoured wetland pockets, with one 50 cm high berm located approximately 80 m downstream of Teston Road. Tree and shrub plantings were part of the works around the wetland features.

2.3.2 Humber River Watercourse Mapping (clip), (supplied to Matrix in 2020; TRCA 2020b)

Watercourse mapping provided by TRCA was reviewed and included in the geomorphic mapping exercise for this study. The mapping includes a thermal regime classification for reaches within the study area. Tributaries T2 and T3 are classified as cold water, and T1 was not given a thermal classification (further classification is provided by LGL Limited in Section 2.5).

2.3.3 Humber River Fisheries Management Plan (Clayton et al. 2004)

The *Humber River Fisheries Management Plan* acts as a resource to be used to develop and implement rehabilitation projects and to guide and influence where development occurs. The document describes some physical characteristics of the stream network and classifies each watercourse and waterbody into one of seven habitat categories, based on biological, physical, and chemical data. The following description applies to tributaries 2 and 3 within the study area based on their thermal classification:

> *Small Riverine Coldwater Habitat: Watercourses in this habitat category have drainage areas less than 13.5 km^2. This category primarily includes first and second order tributaries, although a few third order watercourses do fall into this group. Most of these watercourses begin on the Niagara Escarpment and Oak Ridges Moraine where coarse soils predominate and allow for greater infiltration of precipitation and groundwater discharge to streams. Some of these watercourses will be intermittent in their main reaches but the majority will have permanent flow. Groundwater inputs also help to maintain continually coldwater temperatures. They also have relatively stable flows as indicated by the high ratio of baseflow (summer low flow) to average annual flow. Predatory and specialized fish species were less numerous than expected in this habitat category. This habitat category is found in the Upper Main, East and West Humber River subwatersheds.* (Clayton et al. 2004)

The stream slope map for the Humber River watershed, based on 1:10 000 Ontario Base Maps, classified watercourses into different ranges of channel slopes. The map indicated that Tributary 1 has a 1.01% to 5.0% slope, while tributaries 2 and 3 have a slope in the range of 0.31% to 1.0%. A map of hydrologic soil groups in the Humber River watershed indicated that Tributary 1 is located on AB soils, while Tributaries 2 and 3 are found in group C soils. AB soils have less than 10% clay content and have sand, sandy loam, loam, or silt loam textures, while type C soils have 20% to 40% clay content and can have loam, silt loam, sandy clay loam, and silty clay loam textures. AB has lower runoff potential than do C soils.

2.3.4 Teston Road Class Environmental Assessment (Weston Road to Pine Valley Drive), Vaughan (HDR), PARISH Geomorphic Ltd. (2016)

York Region completed the Teston Road Environmental Assessment from Weston Road to Pine Valley Drive in 2016. As part of this study, a geomorphic assessment was completed. Six tributaries to Purpleville Creek were assessed. The study included a desktop study, field reconnaissance, meander belt width delineation and identification of erosion hazards, and the development of recommendations for watercourse crossing structures and associated channel works. A 30 m setback was applied to the meander belt to support the evaluation of roadway design alternatives (i.e., embankment design) with respect to impact on Redside Dace habitat.

2.3.5 Teston Road Improvements (West of Pine Valley Drive to Weston Road) 90% Detailed Design, York Region (HDR), Matrix Solutions Inc. (2019)

Matrix undertook the geomorphic assessment and detailed design for crossings of the West Tributary of East Purpleville Creek (WTEPC), located approximately 350 m east of Pine Valley Drive, and the East Tributary of East Purpleville Creek (ETEPC), located approximately 200 m west of Weston Road. The WTEPC is direct fish habitat, a cold-water fishery, and occupied Redside Dace habitat. The ETEPC is indirect fish habitat and a cold-water fishery. As per the 2018 East Purpleville Creek Subwatershed Study, the average bankfull width of the WTPEC was 3.26 m, and the estimated bankfull width of the ETEPC was 4.0 m. At the crossing of the WTPEC, a bridge with a span of 45 m was identified to appropriately accommodate fluvial geomorphic processes and limit risk to the structure from potential future channel erosion as outlined in the Teston Road EA (PARISH 2016). At the crossing of the ETEPC, the existing 1,200 mm diameter corrugated steel pipe (CSP) channel had to be maintained due to site constraints.

2.3.6 Major Mackenzie Road Detailed Design (Islington Avenue to Weston Road), Geomorphic Component, York Region (Regional Municipality of York), Matrix Solutions Inc. (2012)

A geomorphic analysis and detailed design were undertaken for crossings of the East Humber River, Purpleville Creek, and Marigold Creek along Major Mackenzie Drive in Vaughan, south of the Teston Road EA study area. Tributaries 2 and 3 of the current study are tributaries to the Purpleville Creek crossing. A meander belt width update study was completed for these watercourses. Preliminary belt widths were estimated to be 50 m at Purpleville Creek. Using erosion setbacks based on the average 100-year lateral migration rate, the final belt widths at Purpleville Creek reaches crossing Major Mackenzie Road was 70 m. A 30 m Redside Dace setback was applied to the meander belt widths for both watercourses. Purpleville Creek at Major Mackenzie Drive lies in a partially confined valley. Bankfull width ranged from 6.0 to 9.0 m.

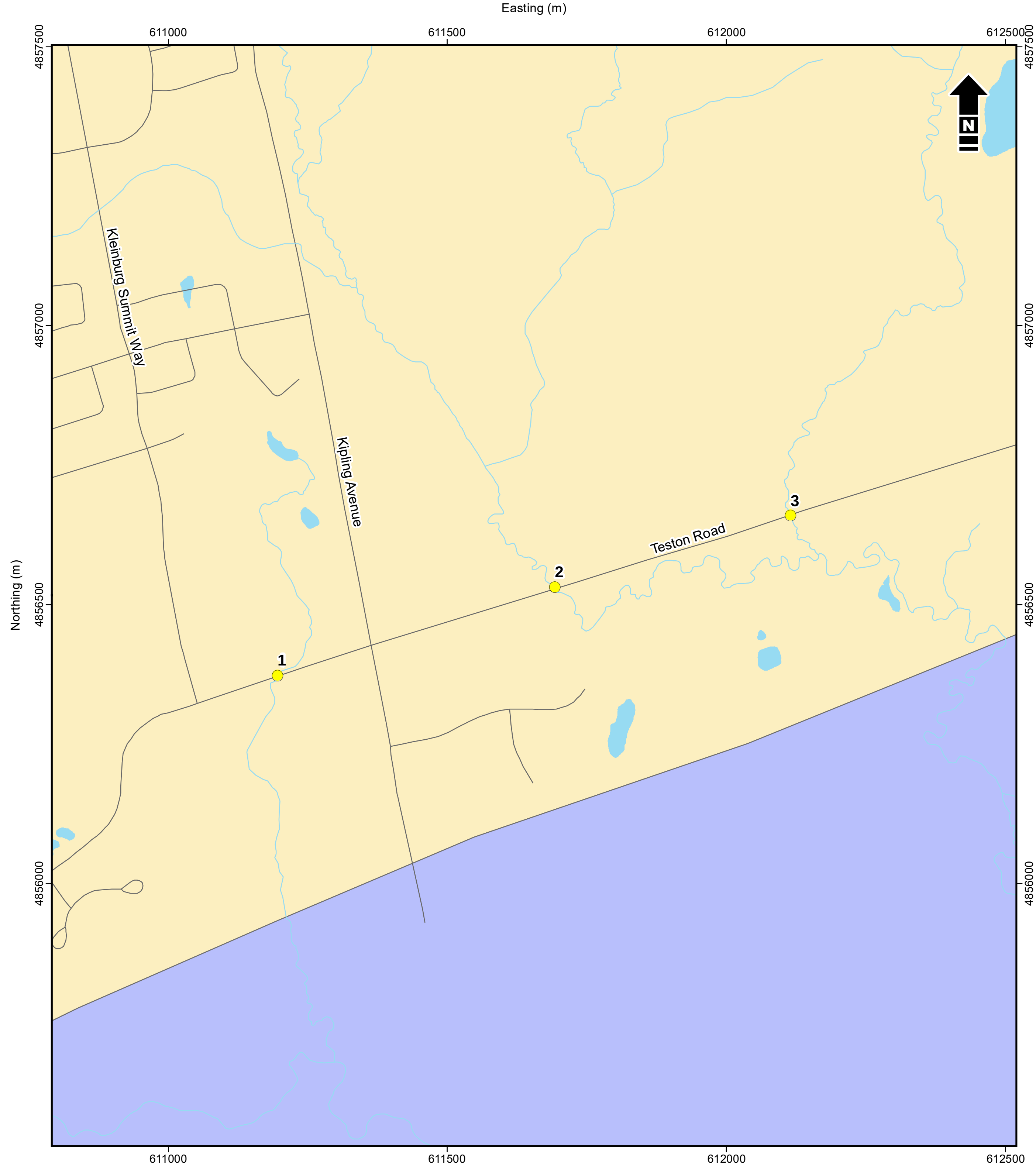
The reach displayed a moderate degree of ecological health and a high RGA score of 0.34. The dominant form of adjustment was channel widening.

2.4 Physiography and Surficial Geology

A review of the regional physiography and surficial geology provides context to understand the geomorphology of the study area. Specifically, for this study, the glacial geology in southern Ontario influences the fluvial geomorphic processes of the streams and rivers that are cut into the post-glacial surface. The glacial and valley landforms influence the stream longitudinal profiles (i.e., stream energy) and the degree of valley confinement. Further, the available glacial deposits supply sediments to the streams, influencing the texture and grain size distribution of the channel banks and bed materials. As such, the glacial legacy in the regional surficial geology plays a role in conditioning the morphology and processes of the stream systems.

For much of the Humber River watershed, the subtle physiographic rise in elevation between Lake Ontario and the topographic highs of the Oak Ridges Moraine is referred to as the “South Slope” (Chapman and Putnam 1984), which is largely composed of poorly drained clay soils and glacial till. The South Slope also includes scattered deglacial lake deposits that are also fine-grained and are collectively known in the region as the “Peel Plain.” The study area is generally situated within the South Slope physiography with a concentration of Peel Plain glaciolacustrine deposits immediately to the south of the site. Following the post-glacial incision of the Humber and East Humber rivers into this landscape, the surrounding tributaries are also typically cut into the surface with defined valleys and steepening channel slopes as they approach their confluences with the main branches. Although the surficial geology is dominated by fine-grained deposits, native sand and gravel materials are also supplied to the fluvial systems from the concentration of clasts derived from the diamictic tills and from local coarse-grained kame, glaciolacustrine, and shoreline deposits.

Figure 2 presents the surficial geology of the study area.



Water Body
Watercourse
Road
Crossing Location

Surficial Geology Region

Peel Plain
South Slope

1:10,000 metres
100 0 100 200
NAD 1983 UTM Zone 17N

Reference: Contains information licensed under the Open Government Licence – Ontario. Imagery (2019) obtained by HDR Corporation.

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Surficial Geology

Date:	Project:	Submitter:	Reviewer:
February 2021	31783	A. Nicoll	R. Phillips

Figure 2

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2.5 Fish Habitat

Tributary 1 is classified as a cool-water system with indirect fish habitat, and Tributaries 2 and 3 are classified as cold-water systems with direct fish habitat. Tributaries 2 and 3 are considered to provide potential seasonal Redside Dace habitat (LGL 2020).

3 DESKTOP ASSESSMENT

3.1 Reach Delineation

Reaches are lengths of channel (typically 200 m to 2 km in length in southern Ontario) that display similarity with respect to valley setting, planform, floodplain materials, and land use/cover. Reach length will vary with channel scale since the morphology of low order watercourses will vary over a shorter distance than those of higher order watercourses. At the reach scale, characteristics of the stream corridor, such as channel slope, alluvial boundary materials, valley confinement, and vegetation, exert a direct influence on channel form, function, and fluvial processes.

The watercourses in the study area were divided into seven reaches. Refer to Figure 3 for a map of the reaches delineated within the study area.

Water Body
Watercourse
Road
Reach Break
Crossing Location

1:10,000 metres
100 0 100 200
NAD 1983 UTM Zone 17N

Reference: Contains information licensed under the Open Government Licence – Ontario. Imagery (2019) obtained by HDR Corporation.

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Reach Map

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February 2021	31783	A. Nicoll	R. Phillips

Figure 3

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4 HISTORICAL ASSESSMENT

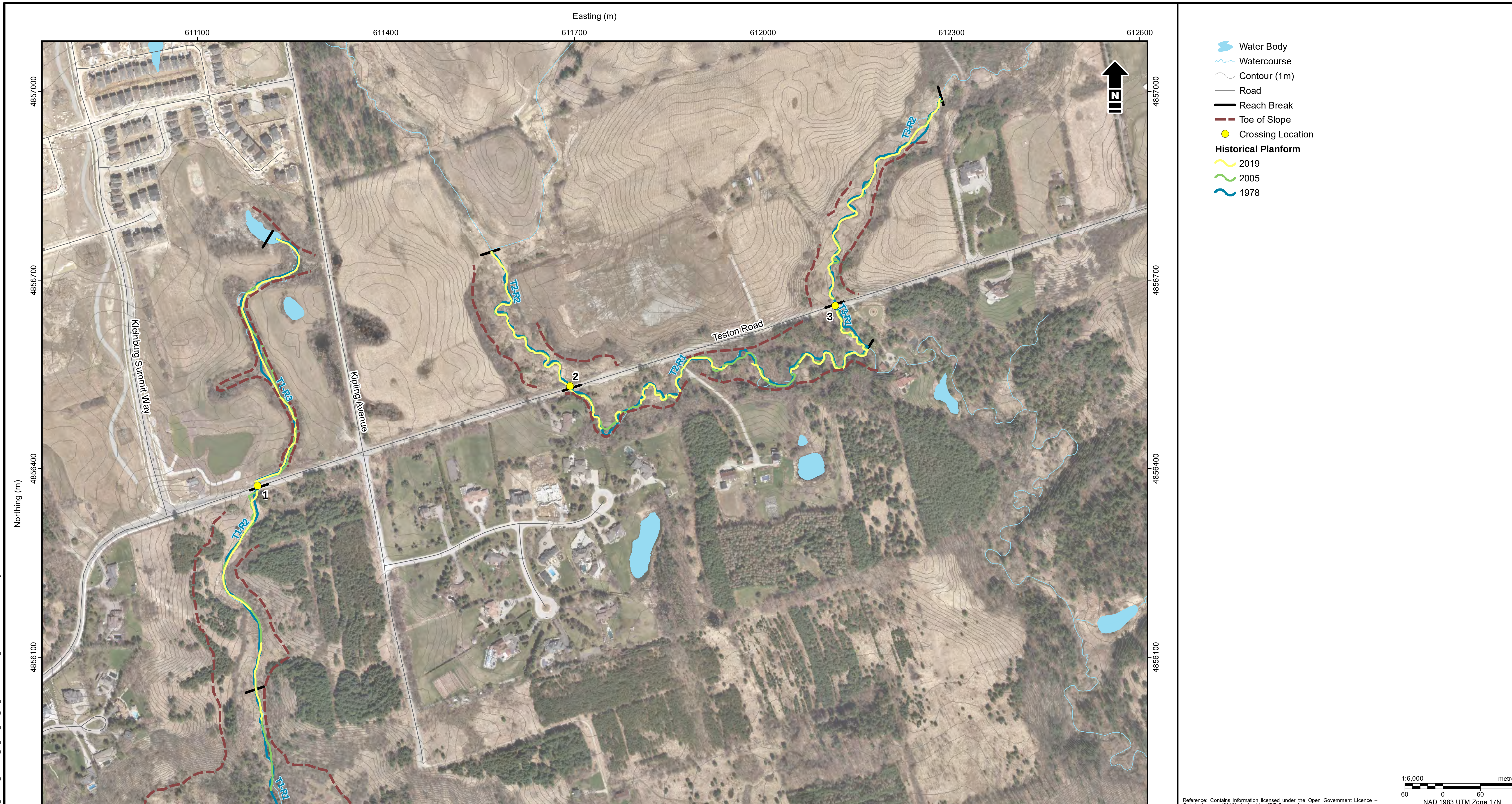
Historic arial photographs from 1970, 1978, 2005, and 2017 were reviewed along with a detailed orthophoto of the study area from 2019. Channel planforms were traced using the 1978, 2005, and 2019 photographs based on photo clarity and overlay alignment. Figure 4 presents the delineated historical channel planforms.

4.1 Tributary 1

T1-R1 flows through a forested area that is part of the riparian corridor of the East Humber River. Due to tree cover, the channel planform was not visible in the middle part of the reach. The channel appears to have had split flow at the confluence with the East Humber in the 1970 photograph or may have intersected a secondary high flow channel on the floodplain of the East Humber River. This reach has been forested through the entire period reviewed.

T1-R2 had been straightened by 1970 and maintained its straight planform in 1978. During this period the tributary lacked riparian vegetation through most of the reach. By 2005, the channel was less distinct and had revegetated with grasses and large portions of the surrounding areas had become forested, particularly south of Teston Road and east of the tributary. The planform was not clearly visible in the 2019 air photograph. The channel does not appear to have changed significantly between the 2005 and 2019 air photographs. Re-naturalization works that were observed in the field on T1-R2 during the site assessments (refer to Section 5) may not have occurred by the time the 2019 orthophotograph was taken.

T1-R3 has occupied the same corridor throughout the period reviewed. The section of the channel immediately upstream of Teston Road has been ditched along the road embankment since the earliest photograph (1970). Upstream of the road right-of-way (RoW), the corridor has had a narrow forested buffer strip through the period reviewed. The farm pond at the upstream extent does not appear to have undergone any notable changes either over the historic period of record. The lands west and north of the tributary corridor were under construction in 2017 and by 2019 had been developed into residential properties. Just north of Teston Road a stormwater (SWM) pond was recently constructed.



Reference: Contains information licensed under the Open Government Licence – Ontario. Imagery (2019) obtained by HDR Corporation.

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Historical Channel Planforms for 1978, 2005, and 2019

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Figure 4

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4.2 Tributary 2

T2-R1 has flowed through a vegetated corridor south of Teston Road since the earliest photograph (1970). The density of the tree cover and understorey appears to have increased over time. The channel has an irregularly meandering planform, which does not appear to have changed significantly since 1970. Slight adjustments in the planform were observed where meanders developed a more complex form due to valley confinement. One meander close to the downstream confluence appears to have widened to the south. In this area, the channel is not confined. Since 1970, a residential lane has crossed the tributary and the channel downstream runs along the Teston Road embankment for an estimated distance of 25 m. In 2019, a pond is present, and the planform is less distinct midway between the residential lane and the confluence. This might be due to the influence of beaver dams as discussed in Section 5. Portions of the channel are also obscured by tree cover.

T2-R2 flows southeast toward Teston Road through a grassy buffer strip in which the channel was distinctly visible. The watercourse has an irregularly meandering planform. The width of the riparian buffer has not notably changed since 1970. The surrounding land use was and remains agricultural. In recent years, the buffer strip has become more forested along its outer edges; however, the predominant vegetation type along the channel is still grass.

4.3 Tributary 3

T3-R1 flows south from Teston Road for approximately 75 m until it joins reach T2-R1. T3-R1 had a modified, straightened planform in 1970 and 1978 and lacked a riparian buffer. By 2005, a residence was constructed nearby, along with an access lane located roughly 12 to 30 m east of the tributary. The lane crosses the watercourse downstream of the reach. Between 1978 and 2005 the riparian area became partially forested and the channel developed a slightly sinuous planform.

T3-R2 meanders through a grassy riparian corridor. The margins of the corridor have become more treed over time since 1970. The surrounding land use is agricultural. A meander has gradually developed near the inlet of the Teston Road culvert over time. In 1978, the channel was in line with the culvert, while in 2005 and 2019 photographs, the planform has adjusted such that the channel approaches the culvert from the west and is no longer aligned with the skew of the culvert. Through the reach several meanders appear to have adjusted between the 1970s and 2000s by shifting in a downstream direction. One meander gradually cut off approximately 55 m north of Teston Road. Toward the upstream end of the reach, the channel appears to be less distinct and flow may be dispersed over a wider area.

5 FIELD RECONNAISSANCE

Natural watercourses are dynamic features on the landscape that migrate within their floodplains over time. The overall geometry and meandering pattern of a watercourse is governed by the interaction between erosive forces (e.g., flow, channel slope) and resisting forces (e.g., vegetation, sediment, geology). In a dynamically stable watercourse, the erosive and resisting forces are in balance and said to be "in regime." When this balance is achieved, the planform and characteristics of a watercourse are generally maintained as it moves within its floodplain. When erosive and resisting forces are out of balance, the channel will adjust its form to minimize the work required to transport water and sediment. This type of adjustment could happen as influencing factors change, for example, when significant land-use changes occur within a watershed such as urbanization.

The purpose of this geomorphic assessment is to characterize channel form and processes and identify any erosion hazards occurring in the study area. It is expected that recommendations from this geomorphic assessment will inform the preferred design alternative for the Teston Road improvements and road widening.

5.1 Methodology

5.1.1 Rapid Geomorphic Assessments

The field component of the fluvial geomorphic assessment consisted of an RGA, a Rapid Stream Assessment Technique (RSAT), and a stream crossing assessment. The RGA was designed by the Ontario Ministry of the Environment (MOE 2003; currently the Ministry of the Environment, Conservation and Parks) to assess stream 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, 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 a channel is in a stable/in regime (score ≤0.20), stressed/transitional (score 0.21 to 0.40), or in an adjustment (score ≥0.40) condition. Refer to Table 1 for a summary of the RGA scoring system.

TABLE 1 Rapid Geomorphic Assessment 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 to 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 widespread.

The RSAT (Galli 1996) provides a broader assessment of the overall health and function of a stream 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, and biological indicators. Scores are divided into three classes of stream health: low (<20), moderate (20 to 35), and high (>35).

On December 4, 2020, RSAT, RGA, and stream crossing assessments were conducted for the watercourse reaches upstream and downstream of culverts 1, 2, and 3 at Teston Road. The site walk encompassed a minimum of 100 m upstream and downstream of each crossing as well as the entire length of Tributary 1 and Reach T2-R1. Refer to Appendix B for site photographs. Matrix personnel were required to comply with legislated, Matrix, TRCA, and City of Vaughan health and safety standards.

5.1.2 Stream Crossing Assessments

Matrix assessed existing watercourse crossing conditions using a standard stream crossing assessment form. This form provides a structured approach to recording crossing information and includes channel dimensions, riparian vegetation, channel disturbances, crossing type and condition, and evidence of flow restriction and scour and erosion.

5.2 Existing Geomorphic Conditions

At four of the seven reaches assessed, the RGA tool was not appliable due to the absence of a formal channel (T1-R2, T1-R3), the equilibrium of the channel (T2-R2), or the degree of human intervention (T3-R1). Of the three reaches where the RGA applied, T1-R1 and T2-R1 were transitional, and T3-R2 was in regime (Table 2). The dominant processes in assessed reaches were degradation and widening. Reach descriptions and RSAT scores are provided in Table 3.

TABLE 2 Summary of Rapid Geomorphic Assessment Scores

Reach	Crossing Name	Factor Value				RGA Stability Index	Condition
		Aggradation	Degradation	Widening	Planimetric Adjustment		
T1-R1	N/A	0.00	0.60	0.86	0.00	0.36	Transitional
T1-R2	Crossing 1	N/A					
T1-R3		N/A					
T2-R1	Crossing 2	0.00	0.29	0.50	0.14	0.23	Transitional
T2-R2		N/A					
T3-R1	Crossing 3	N/A					
T3-R2		0.14	0.33	0.00	0.00	0.12	In Regime

RGA - Rapid Geomorphic Assessment
N/A - not applicable

TABLE 3 Summary of Rapid Stream Assessment Results

Reach	Crossing Name	RSAT Score	Stability Ranking	Reach Description
T1-R1	N/A	37	High	Defined channel with a moderate slope, moderately entrenched where it crosses the valley slope of the East Humber River. Joins the East Humber River at its downstream extent. Along most of its length the channel has a straight planform with poorly defined bedforms. Near the confluence the creek widens, meanders through a cedar forest, and contains point bars and riffles (but not pools). Woody debris is abundant through the reach. Substrate includes sorted sands and gravels with clay overburden exposures. A 15 cm knickpoint was noted mid-reach. Bankfull width: 1.0 to 4.0 m (widens downstream). Bankfull depth: 0.3 to 0.75 m.
T1-R2	Crossing 1	28	Moderate	This reach is located south of Teston Road. The area was recently re-habilitated by the Toronto and Region Conservation Authority. The reach is comprised of a series of wetland pockets connected by moderately- to poorly-defined flow paths. Because this reach lacks a defined channel through most of its length and is not formed by fluvial processes, the RGA was not applicable. The feature is surrounded by plantings, and woody debris has been incorporated into the pockets. Approximately 35 m south of Teston Road there is a 0.6 m drop which is part of the naturalization works. Riparian vegetation includes tall grass, shrubs, and occasional trees. Downstream of the naturalized area the terrain flattens, and the feature becomes a marsh.
T1-R3	Crossing 1	23	Moderate	This reach flows from a former farm pond to Teston Road. The first 40 m (approximately) of channel upstream of Teston Road runs parallel to the roadway and has been ditched. Upstream of the roadway, the creek runs perpendicular to Teston Road through a defined valley. Here the feature has no defined channel and flow is dispersed across the valley floor. The RGA is not applicable, but the dominant process is aggradation in the form of mud and tree leaves. The valley bottom width varies from approximately 10 to 15 m. Mid reach, there is a confluence with a small channel that joins from the west. Upstream of the confluence is a farm crossing, and the reach ends at the outlet of a farm pond. The pond appears to overtop its bank and spill into the valley only occasionally and surface flow may only feed the downstream creek in the spring.
T2-R1	Crossing 2	39	High	This reach extends south of Teston Road from Crossing 2 for approximately 80 m before flowing east to the confluence with T3-R1. The reach is partially confined by the south valley slope, which is up to 12 m high in the reach. The channel is well-defined and meanders through a forested area. The left bank is well connected to a wide floodplain. The channel is locally widened (3.6 m) downstream of the Teston Road crossing. Evidence of slight incision as well as channel widening (such as erosion on both banks) was observed. There is little deposition in the reach. Downstream of a private crossing at 5011 Teston Road the channel runs along the toe of the road embankment slope for approximately 25 m. Downstream of this area the channel is flooded by beaver dams. The beaver-impacted area is considered a subreach to T2-R1. Bankfull width: 2.5 to 3.5 m. Bankfull depth: 0.6 to 0.75 m.

Reach	Crossing Name	RSAT Score	Stability Ranking	Reach Description
T2-R2	Crossing 2	30	Moderate	This reach is located upstream of Crossing 2 north of Teston Road. The channel is narrow and well-defined, widening locally around shrubs. The channel is well-connected to a wide floodplain. A valley slope is located east of the reach, set back from the channel. No erosion concerns were noted. The channel bed is grassy in some areas. The RGA is not considered to be applicable because the reach appears to be in equilibrium at the decadal scale. Bankfull width: 0.75 to 1.0 m. Bankfull depth: 0.5 m.
T3-R1	Crossing 3	28	Moderate	This reach is located downstream of Crossing 3 and ends at the confluence with T2-R1. This is a relatively short reach which includes a well-defined channel with an irregular planform. Midway through the reach (estimated 50 m south of Teston Road) there is a 1.5 m drop in the creek bed which is maintained by tree roots and has also been armoured with stone. The channel becomes entrenched downstream of the armoured drop, with banks heights up to 1.2 m. In this area bank erosion and undercut banks are common. The riparian area includes lawn. Some gravel is present however it appears to have been transported down from the road. Upstream of the drop, log revetments have been installed in one area, and an ornamental bridge crosses the channel. Bankfull width: 1.5 to 2 m. Bankfull depth: 0.6 m.
T3-R2	Crossing 3	29	Moderate	This reach is located upstream of Crossing 3. The creek has a defined two-stage channel including a smaller bankfull channel within a larger floodway channel. The reach has a sinuous planform and flows through a wide floodplain within a hummocky valley. Banks are grassy and riparian vegetation includes grasses, herbaceous species, and shrubs. The channel is slightly entrenched, with some evidence of incision. The grassy vegetation appears to be a control on channel form. Substrate includes clay till underlying loose mud with occasional patches of gravel. Bankfull width: 1.5 to 2 m. Bankfull depth: 0.6 m.

RSAT - Rapid Stream Assessment Technique
RGA - Rapid Geomorphic Assessment
N/A - not applicable

5.3 Existing Structures

Table 4 summarizes the characteristics of the existing Teston Road crossings within the study area. Crossing dimensions were measured in the field and skew angles were measured from aerial photographs.

TABLE 4 Summary of Existing Crossings in the Study Area

	Crossing Number		
	1	2	3
Upstream Reach	T1-R3	T2-R2	T3-R2
Downstream Reach	T1-R2	T2-R1	T3-R1
Crossing Location	180 m eest of Kipling Street	340 m east of Kipling Street	800 m east of Kipling Street

		Crossing Number		
		1	2	3
Structure	Type	CSP	Open Foot Concrete Box	CSP
	Opening Width (m)	0.9	3.3	2.3
	Skew Angle[(1)] (degrees)	<5[(2)]	10	0
Typical Bankfull Dimensions Near Inlet	Width (m)	N/A (1.3 in Teston RoW)	1 m (upstream) 2.5 m (downstream) 3.6 m (local scour near outlet)	1.5
	Depth (m)	0.45	0.5	0.9
Channel Width Relative to Opening Width		Wider	Narrower (upstream only)	Narrower
Flow Restriction		Vegetation (reeds)	None	None
Notes		20 cm drop at outlet; channel typically not defined		~50 m downstream, 1.5 m drop in grade
Appendix A Photographs		9, 10	29, 30, 31	36, 37

(1) Skew angles were measured between alignment of the crossing structures and the Teston Road centreline. The skew angle is 0° where the crossing structure is perpendicular to the Teston Road centreline.
(2) Outlet location obscured in air photograph.
CSP – corrugated steel pipe
RoW – right-of-way

Crossings associated with stormwater outfall channels did not form part of the geomorphic assessment. It is noted that one 1,800 mm by 900 mm concrete box stormwater outfall culvert is located approximately 10 m west of Crossing 1.

5.3.1 Crossing 1

The creek is ditched upstream and turns at a 90-degree angle to enter the culvert. It is noted that the channel is generally not well defined outside of the Teston Road RoW. The channel dimensions listed in Table 4 represent modified conditions within the RoW and may not be indicative of the natural condition. The existing culvert is approximately perpendicular to Teston Road. The crossing contained 4 cm of muddy substrate. At the outlet, the culvert is perched by 20 cm above grade, and, at the time of the site visit, the drop in water level was 8 cm. The culvert outlets into a treed area. Approximately 20 m downstream, the creek disperses into opportunistic flow (no defined channel) as it traverses a recently re-naturalized wetland area. Within this area, approximately 35 m downstream of the culvert outlet, a drop in grade was noted. It has been confirmed that this drop was created as part of the re-naturalization works, the design of which was reviewed by TRCA water resource engineers to ensure no negative impacts on the roadway or nearby infrastructure (TRCA 2020, HDR correspondence 2020).

5.3.2 Crossing 2

The channel is considerably narrower upstream of the crossing (bankfull width = 1.0 m) than downstream (bankfull width = 3.6 m) due in part to local overwidening caused by scour associated with the crossing. Erosion on the right bank begins approximately 7 m downstream of the outlet and extends to approximately 25 m from the outlet along a valley wall contact. There is a residential property located west of this valley slope. The skew of the existing culvert alignment directs flow toward a valley contact at the outlet. The valley slope is approximately 2 m high with a slope of 2:1, and the toe erosion is approximately 0.5 m high, with some shallow undercutting. No evidence of instability was noted at the culvert inlet. The creek is centered in the culvert at the inlet and runs along the east abutment at the outlet. The structure is in poor condition with leaning guardrails and deteriorated concrete. Cracks were noted on the asphalt pavement above the culvert.

5.3.3 Crossing 3

This crossing consists of an embedded CSP culvert. The width is 2,300 mm while the opening height is 1,500 mm, and the structure appears to be in good condition. Substrate within the culvert is fine-grained. The watercourse meanders west of the culvert inlet but there are no current stability concerns. At the inlet of the culvert there is a small hollow which poses a minor risk of potential scour; however, this area is currently stable. Several boulders have been placed in the channel on the outer bank of the meander near the inlet, and the road embankment is stabilized with riprap and vegetation. The west creek bank is entrenched. At the outlet, the channel is backwatered by vegetation and the channel bed is stable with mud deposits. From the outlet the channel meanders slightly to the west. Approximately 50 m downstream of the crossing, there is a drop in channel elevation of 1.5 m that is armoured with stone.

6 EROSION HAZARD ASSESSMENT

Sustainable long-term management strategies for watercourses and crossings promote natural fluvial process to occur by limiting development within an erodible corridor or an erosion hazard limit. In addition to applying measured or generic erosion allowances on either side of the existing channel, erosion hazards for unconfined stream reaches are also delineated based on meander belt widths.

The meander belt defines the area that a meandering watercourse currently occupies and is expected to occupy in the future. The meander belt encompasses the natural erosion hazard associated with active channel migration and avulsion, outside of which adjacent property and infrastructure are at a lower risk to damage. Furthermore, the meander belt helps to protect the long-term integrity and natural processes of watercourses. This hazard is delineated using planform characteristics, historical aerial photographs, and empirical relationships.

The purpose of the meander belt assessment completed for this study is to provide a maximum span necessary to avoid conflict with fluvial process at the crossing. To that end, meander belts were not delineated in this study to define erosion hazards for reaches beyond the immediate vicinity of the crossing, and erosion hazard setbacks for confined or partially confined reaches were not delineated. Smaller crossing spans may be considered (refer to Section 7) with the expectation that some erosion mitigation and/or maintenance would still be required commensurate with the sizing of the crossing relative to the recommended meander belt width.

Matrix estimated meander belt widths in accordance the procedures by PARISH (2004), as follows:

- A preliminary meander belt width was established bounding the outer meanders within a reach using aerial photographs of planform.

- Where possible, the 100-year lateral migration rate was calculated based on changes observed from historical aerial photographs. In general, due to canopy cover, channel alterations, beaver dams, small or poorly defined channels and the quality of historical aerial photographs, 100-year migration rates could not be estimated.

- In lieu of a 100-year migration limit, a 20% factor of safety was added to the preliminary meander belt widths to establish the final meander belt widths. A factor of safety of 20% is conservatively sufficient for the crossings in the study area based on the current stability observed during field investigations.

- Empirical relationships to estimate meander belt widths were assessed for all reaches, specifically for Tributary 1 which could not be assessed by mapping procedures, and for the remaining reaches to compare with mapped meander belt widths and valley bottom widths.

6.1 Meander Belt Width Empirical Relationships

The empirical relationships in Table 5 were considered to delineate the meander belt widths at the Teston Road crossing of Tributary 1. These relations were selected because they are based on drainage area, slope, and discharge rates rather than channel dimensions, which are poorly defined on Tributary 1. Table 5 also includes empirical meander belt results for reaches on tributaries 2 and 3, which were calculated to provide additional context to the meander belt widths delineated based on mapping. The drainage area (Aw) and 2-year discharge as representative bankfull discharge (Q_{BF}) were calculated using the Ontario Flow Assessment Tool (OFAT). The reach-scale channel slope (S) was calculated using 1 m contour data.

TABLE 5 Empirical Meander Belt Width Relationships

Source	Equation	T1-R1(1)	T1-R2	T1-R3(1)	T2-R1	T2-R2	T3-R1	T3-R2
Dunne and Leopold (1978)	$120Aw^{0.43}$	-	19	-	59	58	35	35
PARISH (2004)	8.32*ln(Aw*9806*Qbf*S)-14.83	-	56	-	85	75	81	81
Annable (1996) (all types)	35.2 x QBF^0.53	-	20	-	67	67	40	40
Average		-	32	-	70	67	52	52

(1) Not assessed.

Sources:
Water in Environmental Planning (Dunne and Leopold 1978)
Belt Width Delineation Procedures (PARISH 2004)
Morphologic Relationships of Rural Watercourses in Southern Ontario and Selected Field Methods in Fluvial Geomorphology.
Natural Channel Systems - Adaptive Management of Stream Corridors in Ontario (Annable 1996)

6.2 Meander Belt Width Delineation

Table 6 summarizes the final meander belt widths delineated at the crossing reaches following Procedure 2: accurate belt width delineation where no change in hydrology is anticipated (PARISH 2004).

TABLE 6 Meander Belt Width Results

Reach	Preliminary Meander Belt Width (m)(1)	Average of Empirical Methods (m)	Valley Bottom Width (m)(2)	Final Meander Belt Width (m)	Notes
T1-R1	N/A	N/A	N/A	N/A	• reach begins 300 m south of Teston Road; does not require assessment
T1-R2	N/A	32	60-100	38	• headwater feature with no defined channel outside of Teston Road RoW • formerly ditched reach has been recently regraded as a wetland • the preliminary meander belt width delineated using empirical methods • 20% factor of safety applied to preliminary meander belt width of 32 m
T1-R3	N/A	N/A	10-15	N/A	• headwater feature with no defined channel outside of Teston Road RoW • feature has been ditched along Teston Road for approximately 40 m • confined by narrow valley upstream of ditched section; valley floor estimated to be 10 to 15 m wide.
T2-R1	50 (3)	70	70-100	60(3)	• preliminary meander belt width delineated using aerial photography • partially confined reach: mapped and empirically-derived belt widths do not consider confinement • the confined portions of the reach would need to be evaluated based on Provincial Policy guidelines for confined watercourses (MNR 2002) • historical and contemporary planform does not support empirically-derived unconfined meander belt widths; however, the empirical results are similar to the valley bottom width • erosion was observed along outer banks and downstream of culvert outlet identified during field assessment; RGA score indicated channel is in transitional condition • channel is fairly straight downstream of Crossing 2; toe erosion was noted along the west valley contact downstream of the crossing • impacted by driveway crossing at 5011 Teston Road • impacted by beaver dams in the lower half of the reach • 20% factor of safety applied to preliminary meander belt width of 50 m

Reach	Preliminary Meander Belt Width (m)[1]	Average of Empirical Methods (m)	Valley Bottom Width (m)[2]	Final Meander Belt Width (m)	Notes
T2-R2	30	66	60-80	36	• preliminary meander belt width delineated using aerial photography • no erosion issues identified during field assessment; channel in equilibrium • historical and contemporary planform does not support empirically-derived unconfined meander belt widths; however, the empirical results are similar to the valley bottom width • 20% factor of safety applied to preliminary meander belt width of 30 m • flows within a semi-defined valley which is considerably wider than the channel planform; as such the reach is effectively unconfined
T3-R1	30	52	70-100	36	• preliminary meander belt width delineated using aerial photography • significant drop in channel grade (1.5 m) approximately 50 m south of culvert • historical and contemporary planform does not support the empirically-derived meander belt widths; dominant process is degradation (downcutting) and T3-R1 flows within the larger T2-R1 valley • reach is modified with recovering sinuosity • 20% factor of safety applied to preliminary meander belt width of 30 m
T3-R2	30	52	40-60	36	• preliminary meander belt width delineated using aerial photography • no erosion issues identified during field assessment; channel in regime • historical and contemporary planform does not support the empirically derived meander belt widths; dominant process is degradation (downcutting) • 20% factor of safety applied to preliminary meander belt width of 30 m • flows within a semi-defined valley which is considerably wider than the channel planform; due to the creek's proximity to the east valley slope, the reach is partially confined

(1) Clayton et al. (2004) mapping procedures.
(2) See Figure 4.
(3) Applicable to unconfined portions of the reach.
RoW - right-of-way
RGA - Rapid Geomorphic Assessment

Sources:
Humber River Fisheries Management Plan (Clayton et al. 2004)
Technical Guide, River and Stream Systems: Erosion Hazard Limit (MNR 2002)

For the purposes of this study, meander belt widths were determined for reaches near each crossing to inform the conceptual design of road crossings and do not consider erosion hazard setbacks for confined or partially confined reaches.

Reach T1-R3 flows within a defined valley that has an approximate depth of 2 o 3 m and a width of 10 to 15 m. The valley ends just north of the Teston Road RoW. Downstream of Teston Road the tributary is unconfined. It is possible that a small portion of the erosion hazard setback in reach T1-R3 could be impacted by the proposed works, as some regrading of the west valley slope may be required to better connect the upstream channel into the new culvert.

Reach T2-R1 flows within a defined valley that has a depth of 1 m and a width of approximately 70 to 90 m. The Teston Road embankment cuts through the valley and acts as the north valley slope. Throughout much of the reach, the creek is partially confined by the south valley slope but has access to a wide floodplain to the north. The exception to this trend is at a pinch point in the valley width at the crossing of the 5011 Teston Road driveway. Downstream of this crossing the channel is confined to the north by the Teston Road embankment. In Reach T2-R1, the erosion hazard setback could be impacted by road widening or culvert replacement west of the creek at Crossing 2 as well as along the road embankment near the 5011 Teston Road crossing.

Conceptual design recommendations and associated channel works are discussed in Section 7.

7 CROSSING DESIGN RECOMMENDATIONS

The existing crossings are used as a starting point against which to evaluate geomorphic risk of the watercourses and make recommendations to inform the preferred design alternative for Teston Road improvements. Matrix understands that HDR is evaluating crossing design from a hydraulics and flooding perspective. Additionally, final crossing designs will need to evaluate and compare the requirements from a geomorphic and ecological (i.e., wildlife passage or fisheries setbacks) perspective.

Recommendations for crossing span and skew are provided to address risks associated with lateral and downstream channel migration. The following site-specific conditions are evaluated to inform the development of crossing recommendations:

- **Channel Size**: the potential for lateral channel movement and erosion generally increases with channel size. Erosive forces in larger watercourses often exceed the resistive forces of vegetation, resulting channel erosion and migration. In contrast, headwater streams typically exhibit low rates of erosion and migration due to the stabilizing properties of vegetation. Two of the three watercourses that cross Teston Road within the study area are headwater tributaries (T1 and T3). Channel sizes in these reaches are small (bankfull width of 2 m or less) or poorly defined.

- **Valley Setting**: watercourses with wide, flat floodplains and low valley setting tend to migrate laterally across the floodplain over time. Watercourses that are confined in narrow, well-drained valleys are less likely to erode laterally but are susceptible to downcutting and channel widening. In the immediate vicinity of the crossings in the study area, the watercourses are generally unconfined in their valley settings, apart from Reach T2-R1, which is partially confined near the Teston Road RoW.

- **Meander Belt Width**: a meander belt width defines the area that a meandering watercourse currently occupies and is expected to occupy in the future. This value has been used by regulatory agencies for corridor delineation of natural hazards. The use of the meander belt width for structure sizing had been established as a criterion for some regulatory agencies. This criterion represents a very conservative approach for crossing design and is promoted as the most sustainable long-term management strategy where feasible.

- **RGA**: the RGA provides a measure of channel stability. Channels that are unstable tend to be actively adjusting. Conservative crossing design approaches are required to accommodate unstable, actively adjusting channels. The channels along the crossings were assessed to be stable or poorly defined, apart from Reach T2-R1 which is had a transitional RGA score due to evidence of widening, degradation and, to a lesser extent, planimetric adjustment.

- **100-year Migration Rates**: migration rates are estimated using historical aerial photography. Higher migration rates indicate a more unstable system and higher geomorphic risk. Due to canopy cover, channel alterations, beaver dams, small or poorly defined channels, and the quality of historical aerial photographs, 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.

  A risk-based assessment method was applied to develop geomorphic span options using the following categories:

  - **No risk:** spans the recommended erosion hazard width at the crossing.
  - **Low risk:** spans local meander amplitude plus 100-year migration rate or local valley bottom.
  - **Moderate risk:** spans three times the bankfull width.

  For both the moderate- and high-risk span options, erosion control treatment will need to be considered at detailed design.

TABLE 7 Geomorphic Assessment Summary and Crossing Recommendations

Crossing No.	Bankfull Width (m)	Upstream Meander Amplitude (m)	RGA Score	Final Meander Belt Width (m)	Valley Bottom Width (m)	Existing Structure			Recommended Structure				
						Type	Span (m)	Skew Angle (degrees)	Type	Span (m)			Skew
										Moderate Risk (Minimum 3x Bankfull Channel)	Low Risk (Upstream meander amplitude)	No Risk (Final Meander Belt)	
1	N/A (1.3 in Teston RoW)	N/A	N/A	38	Upstream: 10-15 Downstream: Unconfined	CSP	0.9	<5(1)	Open foot culvert	4	10	38	Maintain or increase
2	1.0 (upstream) 2.5 (downstream)	20	0.23	36	Upstream: 60-80 Downstream: 70-100	Open Foot Concrete Box	3.3	10	Open foot culvert	7.5	20	36	Increase skew
3	1.5	12	0.12	36	Upstream: 40-60 Downstream: Unconfined	CSP	2.3	0	Open foot culvert	4.5	12	36	Maintain existing

(1) Outlet location obscured in air photographs
RoW - right-of-way
N/A - not applicable
CSP - corrugated steel pipe

7.1 Discussion

The following discussion details geomorphic recommendation for crossings, but several other factors should be considered in the selection of a crossing size and type such as wildlife passage, hydraulic conveyance, and habitat requirements.

7.1.1 Crossing 1

At Crossing 1, no natural channel definition was observed upstream or downstream of the crossing RoW. Within the RoW, the feature had been ditched upstream and downstream of the crossing. The upstream ditch runs parallel to Teston Road for approximately 40 m, is choked with reeds, and appears to be backwatered by the undersized existing CSP culvert. The ditch meets and enters the culvert at a 90-degree angle. At its outlet, the culvert is perched by approximately 20 cm. At the outlet the feature flows through a short (<5 m long) channelized area with a width of 1.3 m, which dispersed into opportunistic flow within a re-naturalized wetland feature immediately downstream of the RoW. Approximately 35 m downstream of the culvert outlet, a 0.6 m drop in floodplain grade was observed, which was constructed as part of the re-naturalization of the area. The feature was flowing at the time of the site visit (<5 cm of water within the CSP). A SWM outfall culvert is located approximately 6 m west of the existing culvert.

It is recommended that the existing CSP culvert is replaced with an open-foot culvert containing a low flow channel (to be sized based on hydraulic modeling) flanked on both sides by wildlife benches, with substrate composed of a gradation of native material and hydraulically sized pea gravels or river stone. The elevation of the low flow channel should be constructed to provide a continuous bed through the crossing to eliminate the 20 cm perch at the existing culvert outlet.

Three conceptual span options are discussed below.

Moderate Risk Option

The minimum geomorphic span recommendation is 4 m, which is based on three times the average channel width of 1.3 m in the Teston Road RoW. This would provide limited space for channel adjustment through the crossing and may require erosion protection at the inlet and outlet of the crossing. As the channel has been modified within the RoW, the channel width of 1.3 m should be confirmed in later stages of the design using hydraulic modeling to confirm the minimum three times channel width span of the crossing.

Low Risk Option

The low risk option would have a span of 10 m, which is based on the estimated valley bottom width upstream of the crossing. This would provide additional space for channel adjustment through the crossing and is not likely to require significant erosion protection.

No Risk Option

The option that would pose no erosion risk would have a span of 38 m, which is based on the final meander belt width downstream of the crossing. A span of this width would encompass the entire corridor that the channel may occupy over the long term. It is understood that spanning the meander belt is not generally feasible in terms of cost and constraints (such as accommodating such a structure within the road profile) but is presented here to provide insight into geomorphic risk. This option could widen to the east of the existing culvert centreline.

Three conceptual alignment options are discussed below.

Alignment Option 1: Long Skew

This alignment would connect diagonally from just upstream of the ditched area to the existing culvert outlet. This option would not require channel realignment and would reduce the angle at which the creek enters and exits the crossing. This option has the longest structure length and greatest skew in relation to Teston Road. This option could be applied to all three span options and may impact the SWM outfall culvert to the west.

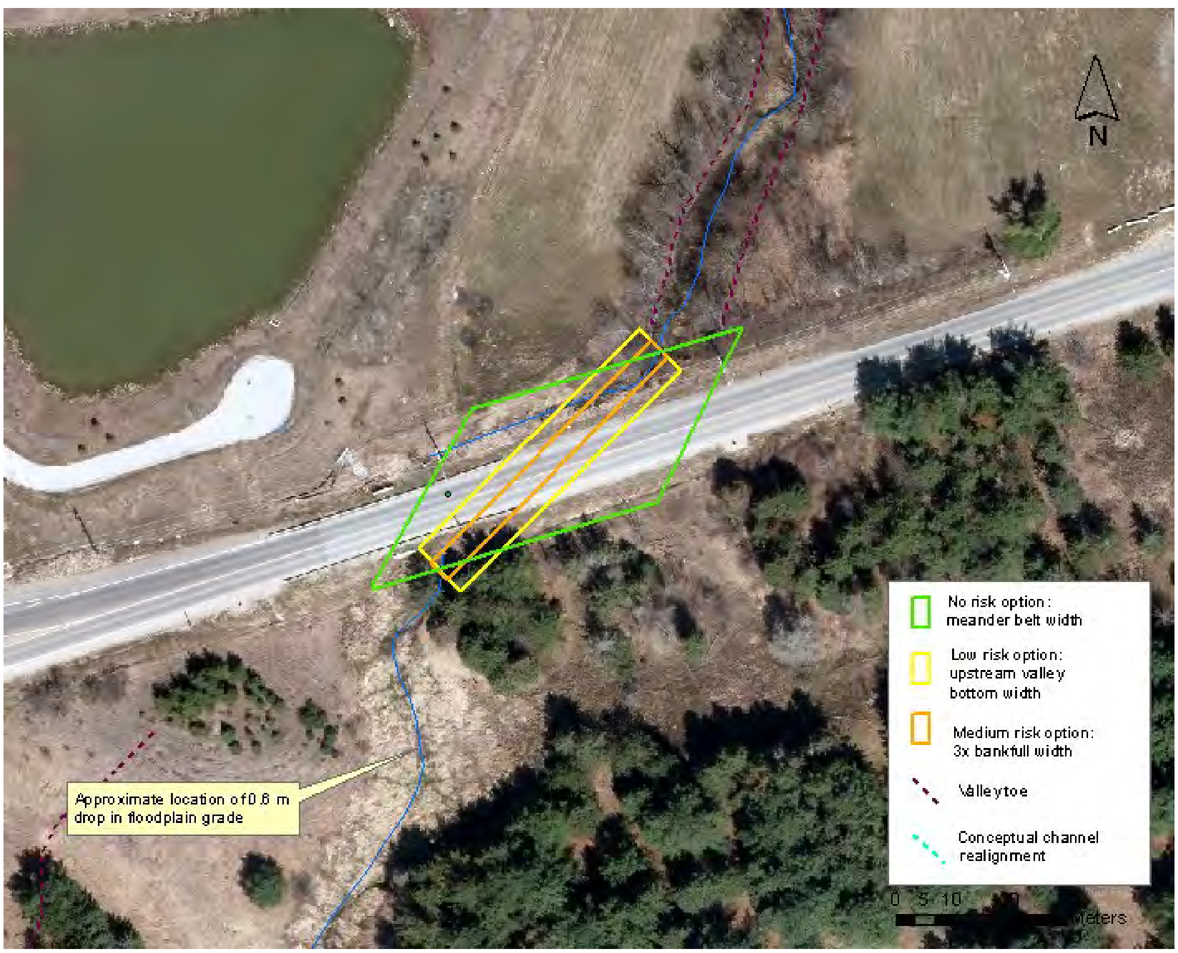


FIGURE 5a Crossing 1 Alignment Option 1: Long Skew

Alignment Option 2: Upstream Realignment

This alignment would skew the structure inlet to the east of existing and maintain the same outlet location. Should road widening occur to the north, the ditched portion of the creek on the north side of Teston Road would require realignment over an estimated distance of 30 m. Minor grading may be required at the west valley slope north of Teston Road as part of the channel realignment. While it is typically preferred to minimize alterations to watercourses for road works, in this case realignment would provide the opportunity to restore a more natural form to this degraded portion of the reach. The natural form of the channel is generally poorly defined, based on conditions in adjacent reaches, and as such it may be advisable to consider replicating a broad wetland area with a small low flow channel through the realignment. Consultation with TRCA is advised to develop an appropriate realignment design, as the TRCA has completed re-naturalization works immediately downstream of Teston Road in Reach T1-R2. Minimal channel work would be required to tie into the wetland area downstream of the crossing. This option may impact the SWM outfall culvert to the west.

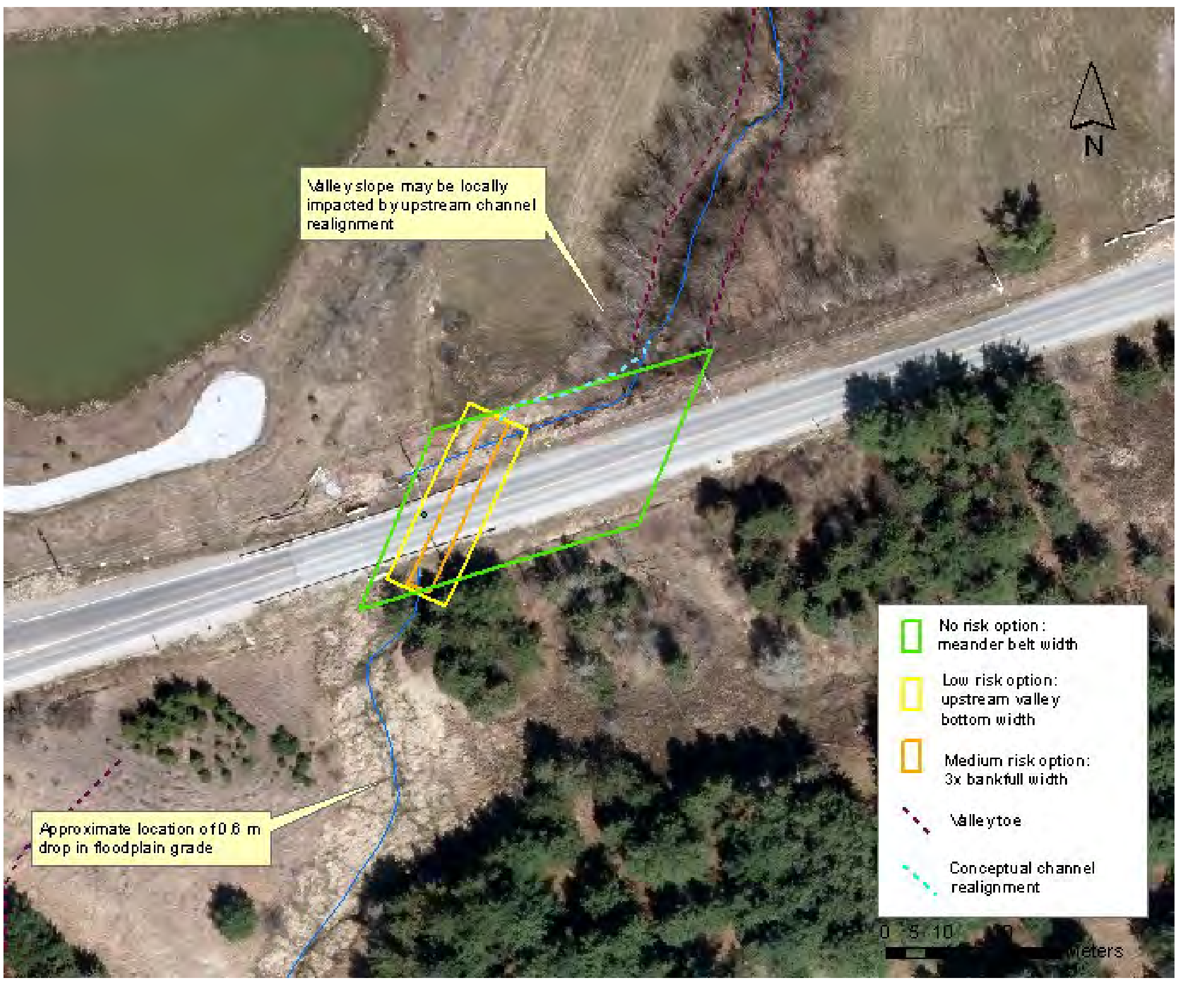


FIGURE 5b Crossing 1 Alignment Option 2: Upstream Realignment

Alignment Option 3: Downstream Realignment

This alignment would shift the culvert inlet east to the align with the creek corridor upstream. This option would require realignment downstream to connect to the existing feature downstream over an estimated distance of 30 m. This option would remove the ditched area north of Teston Road and would replace it with a similar length of channel south of Teston Road which could be an improvement over the existing ditch. The natural form of the channel is generally poorly defined, based on conditions in adjacent reaches, and as such any it may be advisable to consider replicating a broad wetland area with a small low flow channel through the realignment. Consultation with TRCA is advised to develop an appropriate realignment design, as the TRCA has completed re-naturalization works immediately downstream of Teston Road in Reach T1-R2. The realignment may require some tree removal on the south side of Teston Road; however, there are also existing low-lying wet areas around trees that could be targeted in design to ensure maintenance with shallow groundwater connections. Because the crossing would be located east of the existing structure, the new structure could be built while the existing crossing remains open without the need for bypass pumping.

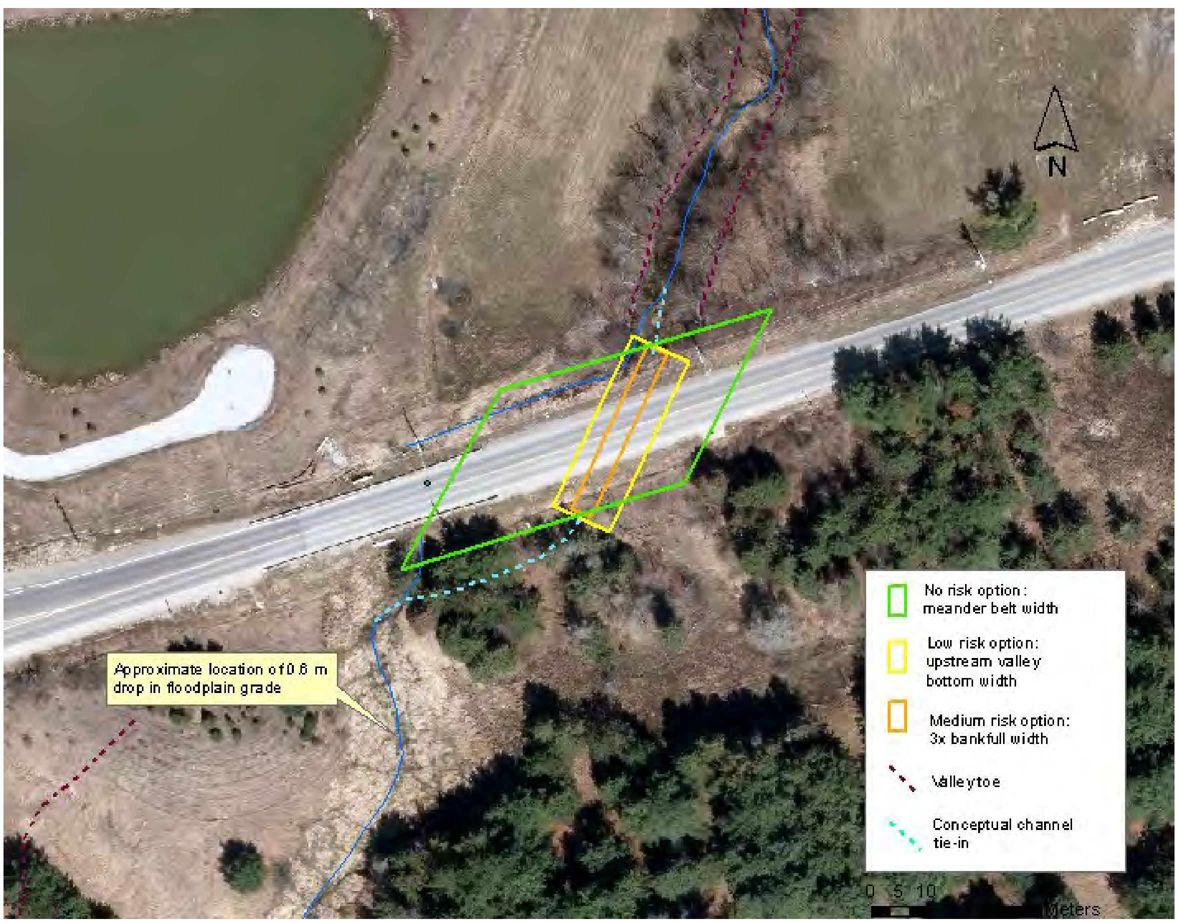


FIGURE 5c Crossing 1 Alignment Option 3: Downstream Realignment

For all span and alignment options, the drop in floodplain grade downstream of the RoW should be considered in future stages of the design. It is understood that the drop in floodplain grade downstream of the RoW at the tie-in of the wetland corridor (constructed series of wetland pockets) was designed by TRCA to be stable. At detailed design, it is recommended that the elevation and location of the drop is confirmed with topographic survey, and that post-construction monitoring is completed to ensure no adjustments take place.

7.1.2 Crossing 2

Upstream of Crossing 2 there is a well defined 0.75 to 1.0 m wide channel. The channel approaches the culvert at a slight angle from the west, and a gradual meander with an amplitude of 9 m is found upstream of the crossing. Downstream of the crossing evidence of bed and bank scour was observed during the field assessment. Within several meters of the outlet, the creek locally widens to up to 3.6 m where it runs along the toe of the west valley slope. There is evidence of erosion and undercutting along the toe of slope, and a private residence is located west of the valley slope. The creek is unconfined to the east at the culvert outlet. The existing culvert appears to be open foot but is in poor condition: the guardrails are leaning at the inlet and outlet, and the concrete is cracked. The inlet and outlet are almost in line with the edges of the concrete on Teston Road. As such, the structure will require replacement and extension if the road is widening.

It is recommended that the existing culvert be replaced with a new open-foot culvert containing a low flow channel (to be sized based on hydraulic modeling) flanked on both sides by wildlife benches, with substrate composed of a gradation of native material and hydraulically sized pea gravels or river stone. It is also recommended that the culvert skew be increased slightly by angling the culvert outlet further to the east, which would better align the structure with the channel axis upstream and would redirect flow away from the downstream valley slope. As well, local erosion protection works could be considered along the toe of the valley slope. The skew could be adjusted without requiring major channel works. It is recommended that any tie-in works maintain the existing channel length.

Three conceptual span options are discussed below.

Moderate Risk Option

The minimum geomorphic span recommendation is 7.5 m, which is based on three times the average bankfull width of 2.5 m in the reach downstream of Teston Road. This would provide limited space for channel adjustment through the crossing and may require erosion protection at the inlet and outlet of the crossing. This option could be aligned over the existing culvert centreline or shifted 10 to 20 m east without requiring major channel works.

Low Risk Option

The low risk option would have a span of 20 m, which is based on the amplitude of the meander upstream of the crossing. This would provide additional space for channel adjustment through the crossing and is not likely to require erosion protection. This option could widen to the east of the existing culvert centreline.

No Risk Option

The option that would pose no erosion risk would have a span of 36 m, which is based on the final meander belt width upstream of the crossing. A span of this width would encompass the entire corridor in which the channel may meander over the long term. To accommodate the valley form, the structure would widen to the east and channel tie in works would be required. It is understood that spanning the meander belt is not generally feasible in terms of cost and constraints (such as accommodating such a structure within the road profile) but is presented here to provide insight into geomorphic risk. This option could widen to the east of the existing culvert centreline.

FIGURE 6 Crossing 2 Options

7.1.3 Crossing 3

During the field assessment there was a well defined 1.5 m wide channel upstream and downstream of the culvert. The upstream reach (T3-R2) is in regime. The creek approaches the culvert from the west, and a meander with an amplitude of 6 m is located upstream of the crossing. The west bank of this meander is entrenched and is eroding. At the inlet of the culvert there is a small hollow which poses a minor risk of potential scour; however, this area is currently stable. Several boulders have been placed in the channel on the outer bank of the meander near the inlet, and the road embankment is stabilized with riprap and vegetation. The existing culvert is a 2.3 m wide CSP which appears to be new and in good condition. The culvert inlet and outlet extend beyond the existing edge of pavement. No scour was observed at the culvert outlet. From the outlet the channel meanders slightly to the west. Approximately 50 m downstream of the crossing, there is a drop in channel elevation of 1.5 m that is armoured with stone. Downstream of the drop the creek is entrenched and widens to 2 m at bankfull elevation and 3 m top width.

Four conceptual span options are discussed below.

Higher Risk Option

Extend the existing culvert. As the existing structure appears to be in good condition and is longer than the existing road is wide, it may be possible to extend the existing culvert. The culvert is sufficiently embedded to provide natural substrate through the crossing. While there is no scour at the existing culvert outlet, the culvert is less than two times the channel bankfull width, which does not provide sufficient room for migration processes or wildlife passage and does not meet minimum geomorphic standards. There is a risk of meander migration from upstream, as well as incision due to potential knickpoint migration of the 1.5 m drop downstream. Erosion protection works would be required to provide long-term stability at the inlet and outlet. This option is least preferred from a geomorphic standpoint.

Moderate Risk Option

Culvert replacement with an open-foot culvert with a span of 4.5 m, which is equivalent to three times the bankfull width of 1.5 m upstream and downstream of Teston Road. For this option, a short channel tie-in would be required at the inlet to connect to the creek upstream. It is recommended that the culvert would contain a low flow channel (to be sized based on hydraulic modeling) flanked on both sides by wildlife benches, with substrate composed of a gradation of native material and hydraulically sized pea gravels or river stone. The substrate gradation should include a stable component to act as a grade control should knickpoint migration occur in the future. In addition, as part of the culvert replacement and design it is recommended that a grade control such as a cobble riffle be constructed downstream of the crossing. The grade control structure would need to be installed to a depth that would ensure channel stability in the case of knickpoint migration. The 4.5 m span option would be considered the minimum recommended geomorphic span.

Low Risk Option

Culvert replacement with an open-foot culvert with a span of 12 m, which is equivalent to the amplitude of the meander immediately upstream of Teston Road. This would provide additional space for channel adjustment through the crossing and is not likely to require erosion protection. For this option, a short channel tie-in may be considered at the inlet to connect to the creek upstream. Similar to the moderate risk option, it is recommended that the culvert contain a low flow channel (to be sized based on hydraulic modeling) flanked on both sides by wildlife benches, with substrate composed of a gradation of native material and hydraulically sized pea gravels or river stone. The substrate gradation should include a stable component to act as a grade control should knickpoint migration occur in the future. In addition, as part of the culvert replacement and design, it is recommended that a grade control such as a cobble riffle be constructed downstream of the crossing. The grade control structure would need to be installed to a depth that would ensure channel stability in the case of knickpoint migration.

No Risk Option

The option that would pose no erosion risk would have a span of 36 m, which is based on the final meander belt width upstream and downstream of the crossing. A span of this width would encompass the entire corridor in which the channel may meander over the long term. It is understood that spanning the meander belt is not generally feasible in terms of cost and constraints (such as accommodating such a structure within the road profile) but is presented here to provide insight into geomorphic risk.

For any option, post-construction monitoring of the downstream drop in elevation is recommended. All options presented would be aligned with the existing culvert centerline.

FIGURE 7 Crossing 3 Options

7.1.4 Road Embankment East of Private Laneway Crossing (5011 Teston Road)

Downstream of the 5011 Teston Road driveway crossing, the creek runs along the toe of the road embankment for approximately 25 m. Active erosion was not observed along the toe of slope during the field investigation; however, it is noted that the water levels were moderate at the time of the site visit. This portion of the creek is currently backwatered by beaver dams downstream.

Three conceptual options have been considered for road works in this area.

- **Option 1 widening road to the north (no widening toward the south)**: approximately ~25+/-5 m of toe protection would be required to stabilize the toe of slope. This option is preferred because it requires the least alteration to the existing channel.

- **Option 2 widening road from centreline of existing Teston Road alignment**: should the road be widened to the north and south, a minor channel realignment would be required, along with ~25+/-5 m of toe protection along the embankment. This option is the less preferred because it would require more alteration to the existing channel than Option 1.

- **Option 3 widen road to south**: this option would require more substantial channel realignment and toe erosion protection works and would likely require work on the private crossing structure south of Teston Road. This option is the least preferred because it would require considerable alteration to the existing channel and valley corridor.

FIGURE 8a   Road Embankment Option 1: Road Widening to the North, Proposed Toe Erosion

FIGURE 8b Road Embankment Option 2: Road Widening Along Existing Centreline, Proposed Toe Erosion Protection, and Channel Realignment

FIGURE 8c Road Embankment Option 3: Road Widening to the South, Proposed Toe Erosion Protection, and Channel Realignment

7.2 Summary

The preceding sections outlined Moderate and Low and No risk options for each crossing. Low risk options are recommended from a geomorphic perspective at all crossings, but moderate risk options can be proposed given erosion and scour protection are addressed at detailed design. The geomorphic recommendations were brought forward through the review of the preliminary design of the preferred alternative provided in Section 8.

8 RECOMMENDATIONS AND OPPORTUNITIES FOR THE PREFERRED DESIGN

The preliminary design of the preferred option was evaluated to provide guidance on how to mitigate erosion risks for the proposed crossings and to identify opportunities for improvements. The proposed crossings were reviewed with reference to the three geomorphic span options and recommended crossing skew. Existing and proposed hydraulic information was also reviewed to develop recommendations on the need for bed or bank erosion protection or scour pool construction. Peak flows and velocities for existing and proposed conditions are presented in Tables 10 and 11. The length and location of the proposed structures were also reviewed with respect to their configuration to the surrounding topography and channel alignments.

TABLE 8 Proposed Crossing Spans

Crossing	Span (m)	Opening Height (m)	Length (m)	Slope (%)	Type	Equivalent Geomorphology Span Option	Existing crossing span (m)	Existing Crossing Type
C1	4.267	1.525	24.91	2.53	Open foot culvert	Moderate Risk (4 m)	0.9	Corrugated steel pipe
C2	12.192	1.525	23.86	0.25	Open foot culvert	Between Moderate Risk (7.5 m) and Low Risk (20 m)	3.3	Open foot concrete box
C3	4.877	3.050	19.19	0.51	Open foot culvert	Moderate Risk (4.5 m)	0.9	Corrugated steel pipe

8.1 Crossing 1

The existing 0.9 m CSP culvert is proposed to be replaced with an open foot culvert with a span of 4.27 m. This will be a moderate improvement over the existing culvert, as the span will increase by 3.37 m. The proposed span is roughly equivalent to the Moderate Risk span option of 4.0 m (three times the bankfull width of 1.3 m), which is considered the minimum geomorphic span (see Section 7.1.1). The open foot structure will provide the opportunity to install natural substrate and create a low flow channel through the crossing.

Teston Road in the vicinity of Crossing 1 will be widened approximately 2 m to the north and 4 m to the south (measured from existing edge of pavement to proposed sidewalk). The proposed footprint of the road extends over the ditched portion of the upstream reach that currently runs along the edge of the road embankment. The proposed crossing will be skewed to the southwest in relation to Teston Road to connect the upstream and downstream reaches more directly than existing. This is in line with Crossing 1 Alignment Option 2: Upstream Realignment. The culvert length will increase to 24.91 m from the existing 15.90 m.

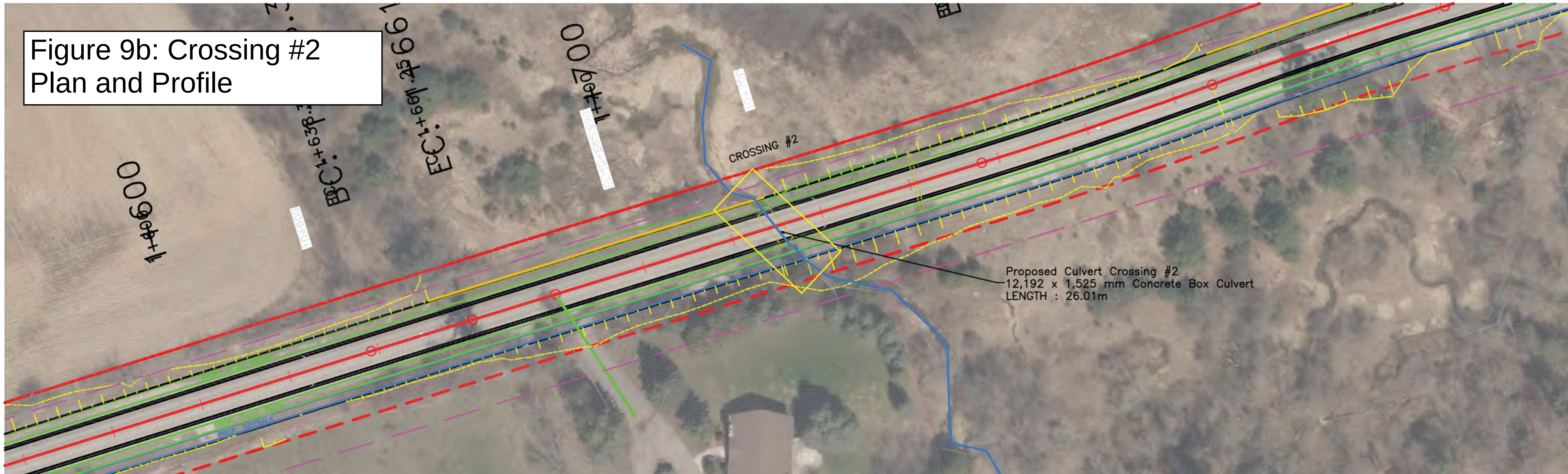
The proposed alignment provides an opportunity to naturalize a portion of the upstream reach by realigning the creek away from the road. This will provide additional space to create a channel corridor in which for channel processes, such as meandering, may occur without risk to the road embankment. A 15 m wide corridor is recommended based on valley floor widths upstream of the proposed realignment.

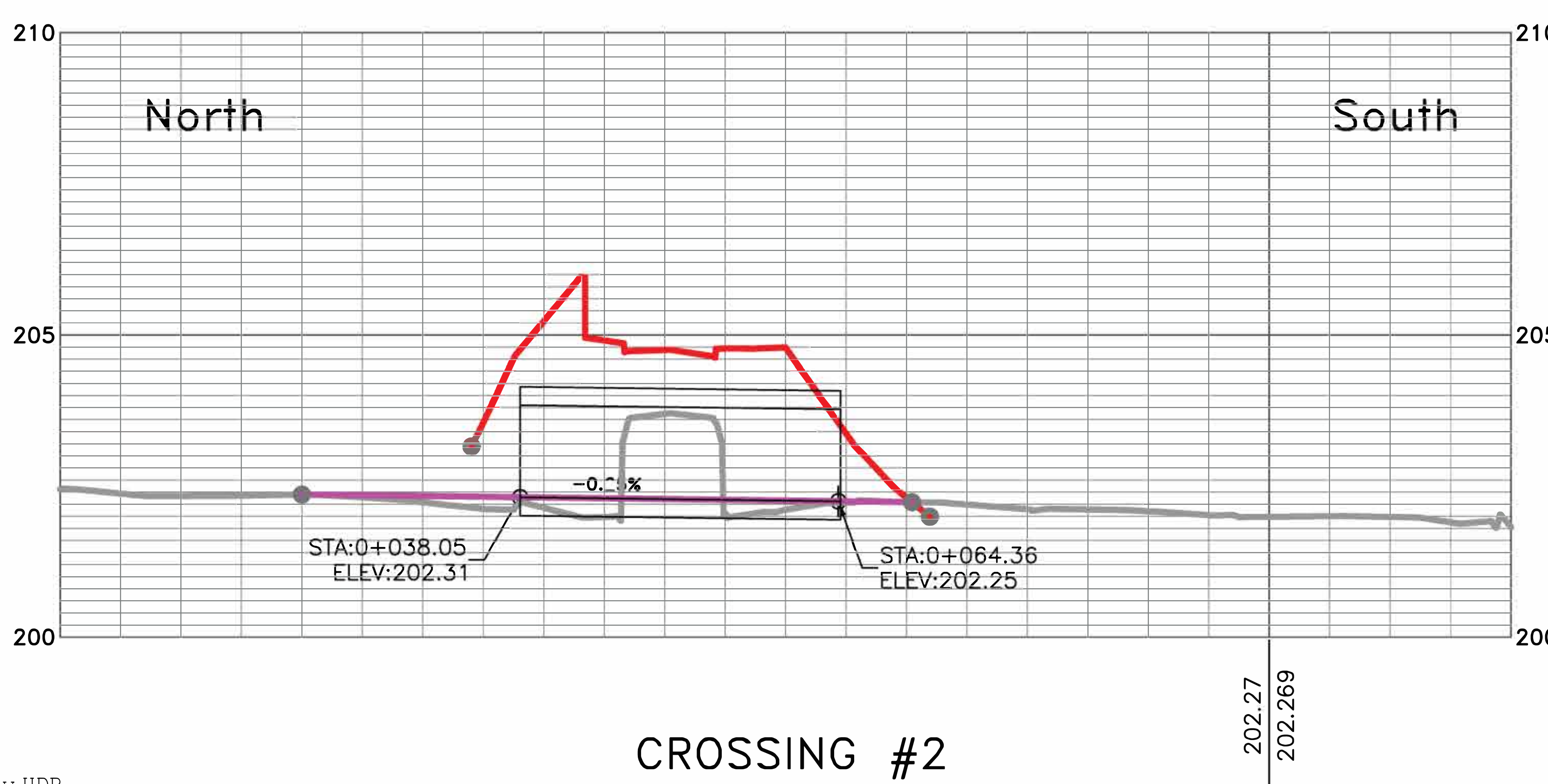
Conceptual corridor limits and a conceptual channel centerline for the upstream realignment are presented in Figure 9a. The realignment introduces a sinuous planform which extends beyond the proposed right-of-way. Table 9 provides the channel length, slope, and sinuosity for the conceptual planform. The tie-in elevations and planform and corridor parameters should be revisited and confirmed in later design stages.

Figure 9a: Crossing #1 Plan and Profile

Preliminary design for road and culvert by HDR

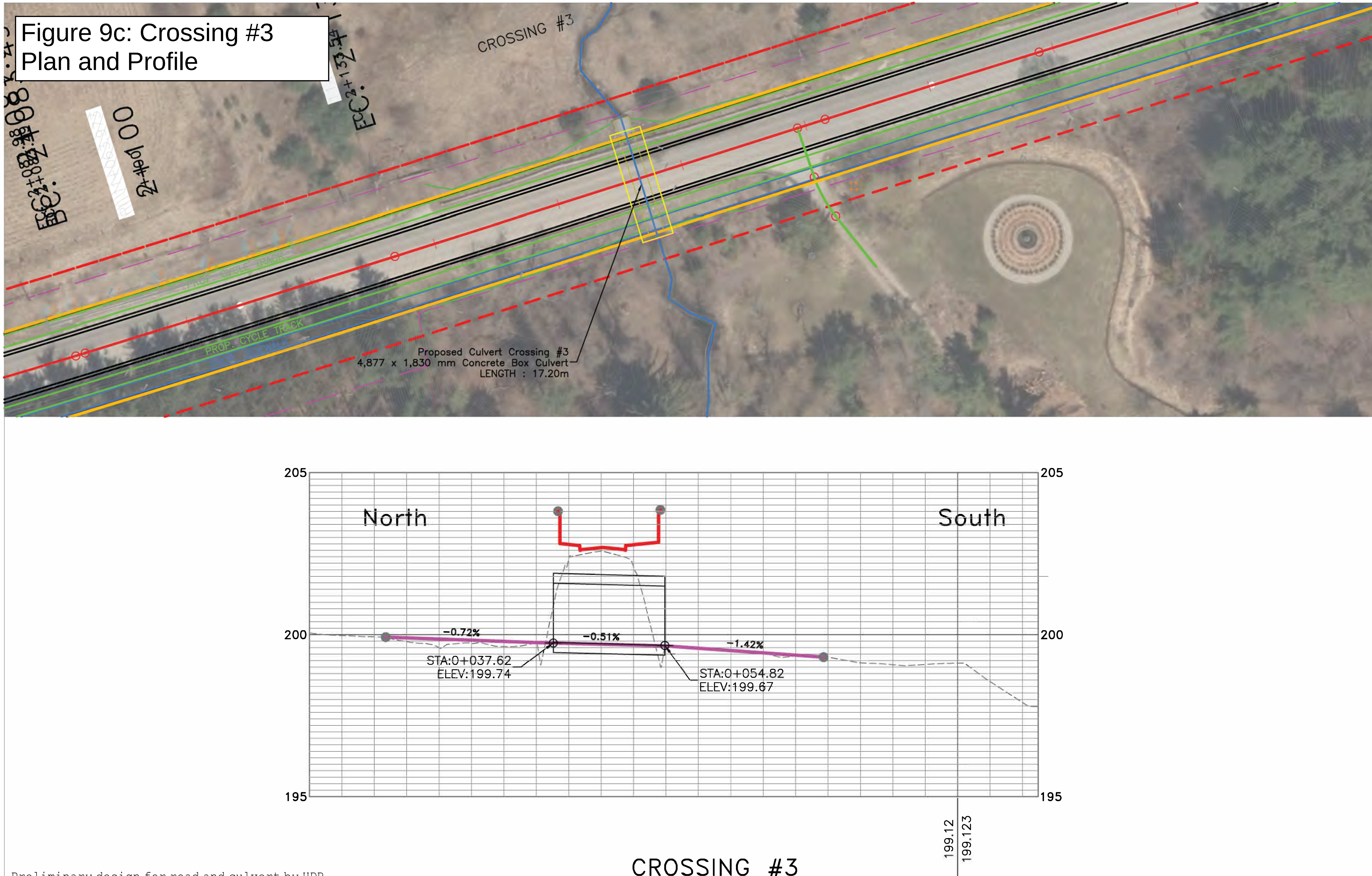
Figure 9b: Crossing #2 Plan and Profile





Preliminary design for road and culvert by HDR

Figure 9c: Crossing #3 Plan and Profile



Preliminary design for road and culvert by HDR

The preliminary slope through the crossing and upstream channel realignment is 2.53%. The slope of the channel tie-in downstream of the crossing is 2.64%. These values represent straight-line channel distances and do not incorporate additional stream length from channel sinuosity. The slopes have been defined based on cover requirements at the roadway and may be refined at detailed design.

A conceptual channel cross-section for the upstream realignment was developed to provide high-level guidance for detailed design. The cross-section represents a run-type morphology and is based on the 2-year flow and downstream channel dimensions (Reach T2-R1). The cross-section is 1.0 m wide, 0.30 m deep, with 1:1 side slopes. This geometry may be increased at detailed design depending on the expectations for seasonal flow conditions and encroachment of vegetation into the channel, which would reduce the conveyance capacity. Based on the bankfull velocity, a gravel to small cobble substrate mixture would provide channel stability, to be sized at detailed design. It is recommended that distinct pool and run-type cross-sections be developed at detailed design, along with a channel profile with variation in slope corresponding to these morphological units. Based on the slope and preliminary bankfull velocity, construction of an outlet pool may also be considered to dissipate flows. Parameters are provided in Table 9.

A downstream tie-in may be required to connect to Reach T1-R2. Although the tributary downstream of the crossing is poorly defined (comprised of wetland pockets), it will be necessary to direct flows from the crossing into the main flow path area to maintain hydrologic and ecological function through the rehabilitated wetland downstream. The downstream tie-in cross-section may resemble the design channel upstream of the crossing, but details should be developed at detailed design.

Existing and proposed outlet and tailwater velocities were modeled by HDR using HY8 (see Table 11). Outlet velocities will decrease and tailwater velocities will increase under proposed conditions. The maximum velocity under proposed conditions is 1.70 m/s at the 100-year flow. Bed and bank protection and the creation of a scour pool at the culvert outlet will likely be required to provide stability and dissipate flows (as recommended for Moderate Risk option in Section 7).

TABLE 9 Crossing 1 - Conceptual Channel Realignment Parameters

Crossing 1 T1-R3 realignment	Parameter
Corridor Characteristics	
Upstream tie-in elevation (m)	205.4
Culvert inlet elevation (m)	204.15
Length (m)	55
Slope (m/m)	2.53%
Sinuosity	-
Corridor Width (m)	15
Conceptual Channel Cross-section	
Bankfull Discharge (m^3/s)	0.19
Bankfull width (m)	1.0
Bottom width (m)	0.6

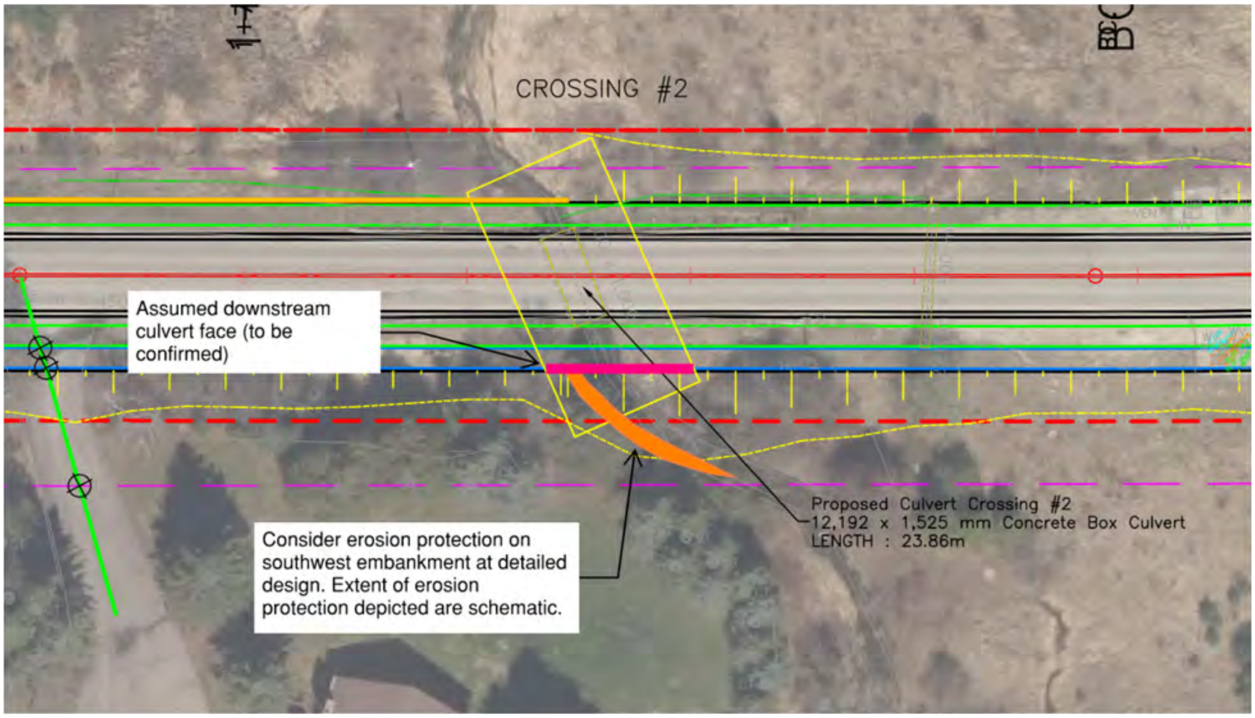
Crossing 1 T1-R3 realignment	Parameter
Bankfull depth (m)	0.3
Side slopes (H:V)	1:1
Velocity at bankfull (m/s)	0.97
Conceptual substrate type	gravel – small cobble with native fines

8.2 Crossing 2

Teston Road in the vicinity of Crossing 2 will be widened by approximately 2.9 m to the north and 4.6 m to the south (measured from edge of pavement to edge of proposed sidewalk). Crossing 2 is proposed to be replaced with an open foot culvert with a span of 12.19 m. This will be a considerable improvement over the existing 3.3 m concrete box culvert as the span will increase by 8.89 m. The proposed span falls between the Moderate Risk span option of 7.5 m and the Low Risk span options of 20 m (based on three times the bankfull width of 2.5 m and the upstream meander amplitude of 20 m, respectively). As such it is greater than the minimum geomorphic span but still carries some risk (see Section 7.1.2). The proposed crossing will provide the opportunity to re-establish natural substrate and create a low-flow channel through the crossing.

The proposed crossing will have a slightly greater skew to the southeast compared to the existing crossing to better align with the channel downstream, to mitigate encroachment of the structure into the southwest creek embankment and to direct flow away from that embankment, where toe erosion was observed. This is in line with the geomorphic recommendations for Crossing 2. The recommended skew is approximately 28 degrees from perpendicular to Teston Road. The culvert length will increase to 23.86 m from the existing 8.22 m. The preliminary slope through the crossing will be 0.25%. Slopes will be refined at detailed design.

Channel velocities under proposed conditions will be similar to existing at the inlet under all but the Regional flow, which will increase due to reduced flow restriction. At the culvert outlet velocities will increase at the 5-year to Regional flows by 10% to 26% (Table 11). Bed and bank protection and the creation of a scour pool at the culvert outlet may be required to provide stability and dissipate flows (as identified for residual erosion hazards for proposed span between Moderate and Low risk). Further downstream, the southwest creek embankment may also require bank protection to prevent further erosion along the toe of slope. "Soft" treatments such as plantings and live brush mattresses are recommended to be used where possible. Downstream tie-in works should also be considered at detailed design to shift the channel and direct flow away from the west embankment. A schematic depiction of the recommended erosion protection works at Crossing 2 is presented in Figure 10.



Note: Preliminary design for road and culvert by HDR

FIGURE 10 Crossing 2 Recommended Erosion Protection

8.3 Crossing 3

The crossing is proposed to be replaced with an open foot culvert with a span of 4.88 m. This will be an improvement over the existing 2.30 m embedded CSP culvert, as the span will increase by 2.58 m. The proposed span is roughly equivalent to the Moderate Risk span option of 4.5 m (three times the bankfull width of 1.5 m), which is considered the minimum geomorphic span (see Section 7.1.3). The proposed open foot culvert will provide the opportunity to install natural substrate and create a low-flow channel through the crossing.

Teston Road in the vicinity of Crossing 2 will be widened by approximately 2 m to the north and 5 m to the south (estimated from edge of pavement to edge of proposed sidewalk).

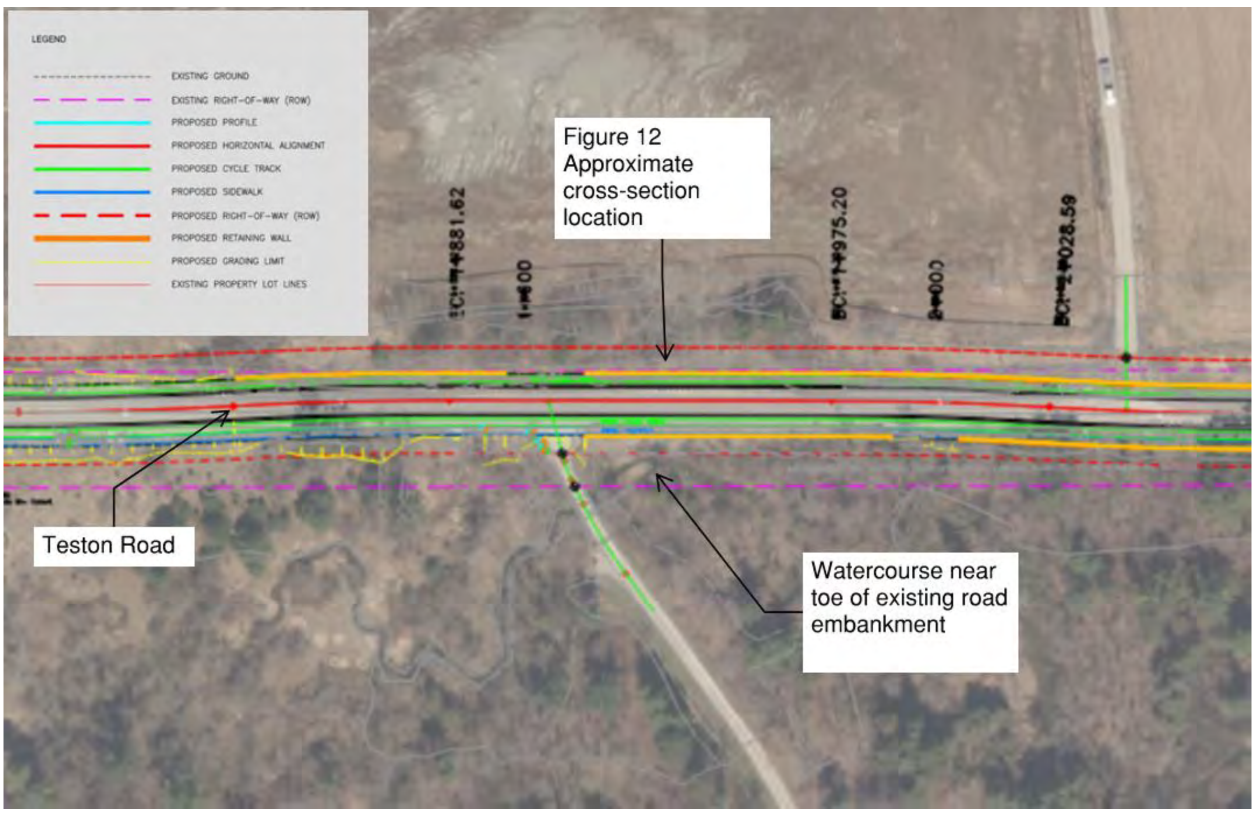
The proposed crossing maintains the existing crossing skew, which is in line with the geomorphic recommendation. The preliminary slope through the upstream tie-in, the proposed crossing and the downstream tie-in are 0.72%, 0.51%, and 1.42%, respectively. Slopes will be refined at detailed design.

Channel velocities under proposed conditions will be similar to existing at the inlet under all flows. However, stabilization works should be considered at the inlet and outlet to lateral and vertical erosion risks (as recommended for Moderate Risk option in Section 7). Erosion protection will be required at the culvert inlet on the west bank, which is currently protected by boulders. This bank is prone to erosion as it is the outer bank of a meander. Any future works at Crossing 3 should also consider the existing drop in channel elevation downstream of the future right-of-way. To ensure stability, the channel through the culvert and downstream tie-in should be composed of a graded substrate mixture with a stable core and buried stone protection should also be installed to act as a grade control. During- and post-construction monitoring is recommended to ensure the channel profile is stable.

8.4 Road Embankment East of Private Laneway (5011 Teston Road)

Teston Road is proposed to widen approximately 6.3 m to the north and 2.5 m to the south in the vicinity of the road embankment east of 5011 Teston Road (measured from current edge of pavement to proposed retaining walls). Retaining walls are proposed to be built on both sides of the roadway through this area. The retaining wall will be located approximately 4.5 m from the edge of the watercourse (to be confirmed with topographic survey at detailed design).

A plan view of the proposed road alignment and retaining wall is presented in Figure 11.



Note: Preliminary design for road and culvert by HDR

FIGURE 11 Proposed Plan View of Proposed Works at Station 1+940

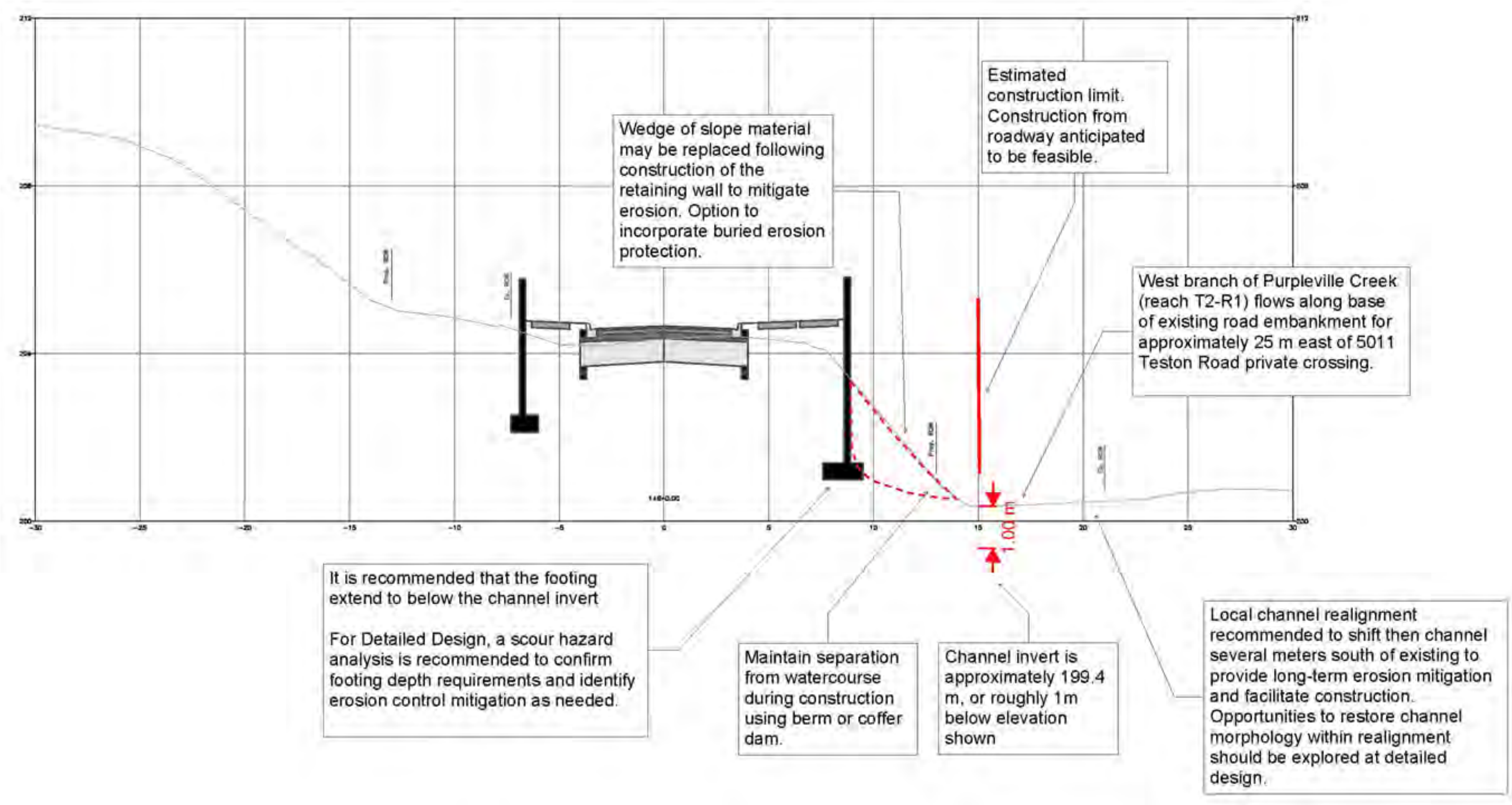
8.4.1 Comments on the Preliminary Retaining Wall Design

The preliminary plan (Figure 11) and profile (Figure 12) of the roadway were reviewed. The footing of the retaining wall should extend at a minimum to the existing creek invert, and potentially deeper based on a scour hazard assessment for detailed design (see Section 8.5). The creek in near 1+190 is estimated to be at least 1 m deep, based on observations made during the 2020 site visit, at an estimated elevation of 199.4 m. The elevation of the channel bed along the retaining wall should be confirmed through in-water survey at detailed design. The slope material may be restored over the lower portion of the retaining wall to provide reinforcement and erosion protection, while also incorporating softer bioengineering approaches to locally enhance the riparian and aquatic habitat in the area of disturbance for construction.

8.4.2 During-construction Impacts

Due to the proximity of the retaining wall to the creek, construction will directly impact the bankfull channel. Assuming that the retaining wall may be constructed from the roadway, excavation and ground disturbance may extend at least 15 m (estimated) from the road centreline, extending into the creek. Excavation would be required for the retaining wall footing. Should construction from the roadway be infeasible, a larger construction footprint and greater impacts to the creek, riparian vegetation and floodplain would be required due to valley access by heavy equipment. As such, construction from the roadway is preferred.

An annotated cross-section of the proposed road profile is presented in Figure 12 which depicts recommendations and estimated construction limits.



Note: Preliminary design for road and culvert by HDR

FIGURE 12 Proposed Road Cross-section at Station 1+940

Temporary impacts related to erosion and sediment control (ESC) are anticipated. To isolate the work area from the watercourse, an earth berm or temporary coffer dam should be constructed between the excavation area and the channel. A comprehensive ESC plan should be developed and implemented during construction under the supervision of a qualified ESC inspector.

8.4.3 Permanent Impacts, Erosion Protection, and Restoration Opportunities

The proposed retaining wall is located within the theoretical meander belt width. At a local scale, the flood hydraulics coming through the 5011 Teston Road driveway crossing just upstream might exacerbate erosion risk to the retaining wall.

Local realignment of the creek is recommended to relocate the channel outside of the work area and provide horizontal separation between the bankfull channel and the retaining wall. Channel realignment would facilitate temporary construction works and reduce long term erosion risks associated with long-term channel migration. A conceptual channel centreline for a minimal realignment option is provided in Figure 8b above (Section 7.1.4). This option would increase the horizontal distance to the retaining wall while minimizing impacts to the riparian zone. The proposed realignment may extend for approximately 25 m and would shift the creek centerline approximately one channel width to the south. This option would require a slight decrease in channel length as part of a meander would be straightened, however this option also provides the opportunity to restore channel morphology and fish habitat.

At a minimum, bank protection will be required along the north creek bank along with bank restoration following construction. Buried toe protection may also be considered, and is recommended for this particular case. The size, type, depth, and placement should be determined at detailed design, following the completion of a scour analysis (see Section 8.5). The need for bank protection and local channel modifications will need to be evaluated further in subsequent design stages.

TABLE 10 Existing and Proposed Peak Flows (m^3/s)

Crossing	Condition	Peak Flows (Years)						
		2	5	10	25	50	100	Regional
Crossing 1	Existing	0.19	0.47	0.69	0.98	1.20	1.43	1.42*
	Proposed	0.19	0.47	0.69	0.98	1.20	1.43	19.91*
Crossing 2	Existing	0.64	1.16	1.57	2.14	2.60	3.10	22.03
	Proposed	0.64	1.16	1.57	2.14	2.60	3.10	22.03
Crossing 3	Existing	0.14	0.26	0.35	0.47	0.57	0.67	3.63
	Proposed	0.14	0.26	0.35	0.47	0.57	0.67	3.63

*Overtopping values

TABLE 11 Hydraulic Modeling - Existing Velocities

Crossing	Data Source	Station	Location	Condition	Velocity (m/s)						
					2-year	5-year	10-year	20-year	50-year	100-year	Regional
Crossing 1	HY8	N/A	Outlet	Existing	1.44	1.86	2.05	2.22	2.45	2.7	-
				Proposed	0.18	1.03	1.2	0.49	0.55	1.59	-
				Difference	-1.26	-0.83	-0.85	-1.73	-1.9	-1.11	
		N/A	Tailwater	Existing	0.57	0.72	0.8	0.88	0.92	0.96	-
				Proposed	1.03	1.29	1.42	1.55	1.63	1.70	-
				Difference	+0.46	+0.57	+0.62	+0.67	+0.71	+0.74	-
Crossing 2	HEC-RAS	793.89	Inlet	Existing	1.34	1.46	1.56	1.64	1.78	2.00	0.58
				Proposed	1.34	1.46	1.56	1.66	1.78	1.99	1.16
				Difference	0.00	0.00	0.00	+0.02	0.00	-0.01	+0.58
		752.78	Outlet	Existing	0.23	0.30	0.34	0.39	0.42	0.67	2.26
				Proposed	0.23	0.33	0.40	0.47	0.53	0.79	2.60
				Difference	0.00	+0.03	+0.06	+0.08	+0.11	+0.12	+0.34
Crossing 3	HEC-RAS	106.37	Inlet	Existing	0.24	0.32	0.37	0.42	0.46	0.49	0.73
				Proposed	0.27	0.39	0.46	0.56	0.63	0.69	1.46
				Difference	+0.03	+0.07	+0.09	+0.14	+0.14	+0.20	+0.73
		76.92	Outlet	Existing	0.61	0.65	0.68	0.73	0.75	0.77	1.13
				Proposed	0.61	0.65	0.68	0.73	0.75	0.77	1.13
				Difference	0.00	0.00	0.00	0.00	0.00	0.00	0.00

8.5 Scour Hazards

TRCA (2015) provides general requirements for scour analysis, but the guideline does not include detailed methods. The CVC (2019) Fluvial Geomorphic Guidelines: Factsheet VI: Scour Analysis provides guidelines for scour assessment studies, building on MTO definitions for watercourse hydraulic design (MTO 2016). CVC defines scour assessment as the technical and professional evaluation of the long-term risks due to potential vertical erosion and/or degradation of stream and river channels. A variety of rational and empirical methods are available to quantify the potential scour of a watercourse in anticipation of new infrastructure and hazard delineation. CVC (2019) aims to guide such evaluations.

- Scour assessment to identify the scour hazard limit at each watercourse crossing for which alterations to the crossing structure or watercourse are proposed, and where road embankment works adjacent to watercourses are proposed. For the current study, this would include the proposed culvert replacements of Crossings 1, 2 and 3, as well as within Reach T2-R1 at the retaining wall east of 5011 Teston Road.

- Where engineering to the 100-year scour hazard limit is not practical or feasible with respect to impacting adjacent land uses and/or habitats, hazard mitigation and management plans will be required to the satisfaction of TRCA and other stakeholders.

It is recommended that this assessment be completed by a qualified engineer and/or geoscientist at detailed design.

9 CLOSING

The above geomorphic assessment provides an understanding of the existing conditions of area watercourses in terms of function, stability, and the interactions with road crossings beneath Teston Road. Based on the documented existing conditions, conceptual recommendations have been provided for crossing improvements and localized channel works. The results of the assessment are intended to satisfy geomorphic requirements for Phase 1 of the EA and inform subsequent phases of the EA with respect to assessing the geomorphic impacts and mitigation options for preliminary design of the preferred alternative.

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APPENDIX A
Site Photographs

Matrix Supplied
December 4, 2020

1. T1-R1 confluence with East Humber River

Matrix Supplied
December 4, 2020

2. TI-R1 meandering on the East Humber River floodplain.

Matrix Supplied
December 4, 2020

3. T1-R1 substrate in downstream section of reach.

Matrix Supplied
December 4, 2020

4. TI-R1 looking upstream mid-reach. Channel is slightly entrenched and woody debris is abundant.

Matrix Supplied
December 4, 2020

5. Looking downstream in transitional are near reach break between reaches T1-R2 and T1-R1.

Matrix Supplied
December 4, 2020

6. Reach T1-R2 looking across the feature to the west in the downstream portion of the reach. In this area the feature is a marsh with no defined channel.

Matrix Supplied
December 4, 2020

7. Reach T1-R2 looking upstream toward Teston Road. Re-naturalized marsh area.

Matrix Supplied
December 4, 2020

8. Reach T1-R2 looking downstream within re-naturalized marsh area.

Matrix Supplied
December 4, 2020

9. Crossing 1 outlet.

Matrix Supplied
December 4, 2020

10. Looking downstream from Crossing 1 outlet.

Matrix Supplied
December 4, 2020

11. Crossing 1: Looking west toward culvert inlet. Inlet was obscured by reeds and snow.

Matrix Supplied
December 4, 2020

12. Reach T1-R3 looking west along ditched portion of the reach, north of Teston Road.

Matrix Supplied
December 4, 2020

13. T1-R3 looking south (downstream) toward Teston Road at the south end of the defined valley.

Matrix Supplied
December 4, 2020

14. T1-R3 looking north (upstream) within the defined valley.

Matrix Supplied
December 4, 2020

15. Farm pond at upstream extent of Reach T1-R3.

Matrix Supplied
December 4, 2020

16. Confluence of reaches T2-R1 and T3-R1.

Matrix Supplied
December 4, 2020

17. T2-R1: Meandering channel photographed from top of south valley slope.

Matrix Supplied
December 4, 2020

18. T2-R2 looking upstream toward beaver dam.

Matrix Supplied
December 4, 2020

19. T2-R1: View of beaver dam.

Matrix Supplied
December 4, 2020

20. T2-R1: Beaver pond.

Matrix Supplied
December 4, 2020

21. T2-R1 beaver pond looking south toward valley slope.

Matrix Supplied
December 4, 2020

22. T2-R1 channel upstream of beaver pond.

Matrix Supplied
December 4, 2020

23. T2-R1 looking east (downstream) from 5011 Teston Road crossing. Channel runs along the toe of the embankment slope.

Matrix Supplied
December 4, 2020

24. Reach T2-R1: 5011 Teston Road crossing outlet.

Matrix Supplied
December 4, 2020

25. T2-R1 upstream of 5011 Teston Road crossing in an area where the channel is unconfined. Photo looking upstream, valley slope in background.

Matrix Supplied
December 4, 2020

26. Reach T2-R1 meandering channel and bank erosion at a valley contact

Matrix Supplied
December 4, 2020

27. Reach T2-R1 looking downstream along valley contact south of Teston Road crossing. Channel runs along the valley toe.

Matrix Supplied
December 4, 2020

28. Reach T2-R1: Valley contact along slope in proximity to residence south of Teston Road.

Matrix Supplied
December 4, 2020

29. T2-R1 looking downstream from Teston Road crossing (Crossing 2). The channel is overwidened several meters downstream of the culvert outlet where it reaches a valley contact.

Matrix Supplied
December 4, 2020

30. Inlet of Crossing 2, reach T2-R2.

Matrix Supplied
December 4, 2020

31. Reach T2-R2, Crossing 2 inlet.

Matrix Supplied
December 4, 2020

32. Reach T2-R2 typical channel.

Matrix Supplied
December 4, 2020

33. Reach T3-R1: Entrenched portion of reach looking downstream toward confluence.

Matrix Supplied
December 4, 2020

34. Reach T3-R1: 1.5m drop in channel bed elevation.

Matrix Supplied
December 4, 2020

35. Reach T3-R1: Channel looking upstream of 1.5m drop.

Matrix Supplied
December 4, 2020

36. Outlet of Crossing 3, reach T3-R1.

Matrix Supplied
December 4, 2020

37. Crossing 3 inlet looking upstream to reach T3-R2.

Matrix Supplied
December 4, 2020

38. Crossing 3 inlet, looking downstream. Channel approaches inlet from the west.

Matrix Supplied
December 4, 2020

39. Reach R3-T2 looking upstream at meander near Crossing 3 inlet.

Matrix Supplied
December 4, 2020

40. Reach R3-T2 looking upstream.

APPENDIX A
HEC-RAS Output

HEC-RAS

Crossing 2

River	Reach	River Sta	Profile	Plan	E.G. Elev	W.S. Elev	Vel Head	Frctn Loss	C & E Loss	Q Left	Q Channel	Q Right	Top Width	Vel Chnl
					(m)	(m)	(m)	(m)	(m)	(m3/s)	(m3/s)	(m3/s)	(m)	(m/s)
purplevile19_6	19.6 lower	846.3868	2 Yr	HDR Ex	202.82	202.82	0.00	0.20	0.01		0.64		28.25	0.15
purplevile19_6	19.6 lower	846.3868	2 Yr	HDR Pr 2	202.82	202.82	0.00	0.20	0.01		0.64		28.25	0.15
purplevile19_6	19.6 lower	846.3868	5 Yr	HDR Ex	202.89	202.89	0.00	0.17	0.01		1.16		32.31	0.18
purplevile19_6	19.6 lower	846.3868	5 Yr	HDR Pr 2	202.89	202.89	0.00	0.17	0.01		1.16		32.31	0.18
purplevile19_6	19.6 lower	846.3868	10 Yr	HDR Ex	202.94	202.94	0.00	0.16	0.01		1.57		34.78	0.20
purplevile19_6	19.6 lower	846.3868	10 Yr	HDR Pr 2	202.94	202.94	0.00	0.16	0.01		1.57		34.78	0.20
purplevile19_6	19.6 lower	846.3868	25 Yr	HDR Ex	202.99	202.98	0.00	0.16	0.01		2.14		38.22	0.22
purplevile19_6	19.6 lower	846.3868	25 Yr	HDR Pr 2	202.99	202.99	0.00	0.16	0.01		2.14		38.28	0.22
purplevile19_6	19.6 lower	846.3868	50 Yr	HDR Ex	203.02	203.02	0.00	0.16	0.01		2.60		40.28	0.23
purplevile19_6	19.6 lower	846.3868	50 Yr	HDR Pr 2	203.02	203.02	0.00	0.16	0.01		2.60		40.29	0.23
purplevile19_6	19.6 lower	846.3868	100 Yr	HDR Ex	203.06	203.06	0.00	0.16	0.01		3.10		41.94	0.24
purplevile19_6	19.6 lower	846.3868	100 Yr	HDR Pr 2	203.06	203.06	0.00	0.16	0.01		3.10		41.95	0.24
purplevile19_6	19.6 lower	846.3868	Regional	HDR Ex	203.93	203.93	0.01	0.01	0.00		22.03		76.13	0.33
purplevile19_6	19.6 lower	846.3868	Regional	HDR Pr 2	203.64	203.62	0.01	0.05	0.00		22.03		70.58	0.49
purplevile19_6	19.6 lower	793.89	2 Yr	HDR Ex	202.61	202.53	0.09			0.01	0.61	0.02	6.34	1.34
purplevile19_6	19.6 lower	793.89	2 Yr	HDR Pr 2	202.61	202.53	0.09			0.01	0.61	0.02	6.33	1.34
purplevile19_6	19.6 lower	793.89	5 Yr	HDR Ex	202.71	202.63	0.09			0.12	0.91	0.13	12.29	1.46
purplevile19_6	19.6 lower	793.89	5 Yr	HDR Pr 2	202.71	202.63	0.09			0.12	0.91	0.13	12.28	1.46
purplevile19_6	19.6 lower	793.89	10 Yr	HDR Ex	202.76	202.67	0.09			0.22	1.10	0.24	15.21	1.56
purplevile19_6	19.6 lower	793.89	10 Yr	HDR Pr 2	202.76	202.67	0.09			0.22	1.10	0.24	15.21	1.56
purplevile19_6	19.6 lower	793.89	25 Yr	HDR Ex	202.82	202.73	0.09			0.41	1.32	0.41	19.03	1.64
purplevile19_6	19.6 lower	793.89	25 Yr	HDR Pr 2	202.82	202.73	0.09			0.40	1.33	0.41	18.84	1.66
purplevile19_6	19.6 lower	793.89	50 Yr	HDR Ex	202.86	202.76	0.10			0.54	1.52	0.54	28.84	1.78
purplevile19_6	19.6 lower	793.89	50 Yr	HDR Pr 2	202.86	202.76	0.10			0.54	1.52	0.54	24.97	1.78
purplevile19_6	19.6 lower	793.89	100 Yr	HDR Ex	202.89	202.77	0.12			0.67	1.75	0.68	30.96	2.00
purplevile19_6	19.6 lower	793.89	100 Yr	HDR Pr 2	202.89	202.77	0.12			0.67	1.75	0.68	27.03	1.99
purplevile19_6	19.6 lower	793.89	Regional	HDR Ex	203.92	203.92	0.00			12.97	1.66	7.40	151.81	0.58
purplevile19_6	19.6 lower	793.89	Regional	HDR Pr 2	203.58	203.57	0.01			12.93	2.62	6.48	115.20	1.16
purplevile19_6	19.6 lower	780.41			Culvert									
purplevile19_6	19.6 lower	752.78	2 Yr	HDR Ex	202.52	202.52	0.00	0.03	0.00	0.00	0.64		13.12	0.23
purplevile19_6	19.6 lower	752.78	2 Yr	HDR Pr 2	202.52	202.52	0.00	0.02	0.00		0.64		7.64	0.23
purplevile19_6	19.6 lower	752.78	5 Yr	HDR Ex	202.61	202.60	0.00	0.04	0.01	0.03	1.13		19.42	0.30
purplevile19_6	19.6 lower	752.78	5 Yr	HDR Pr 2	202.60	202.59	0.01	0.03	0.01		1.16		8.28	0.33
purplevile19_6	19.6 lower	752.78	10 Yr	HDR Ex	202.66	202.66	0.01	0.05	0.01	0.07	1.49		21.61	0.34
purplevile19_6	19.6 lower	752.78	10 Yr	HDR Pr 2	202.66	202.65	0.01	0.04	0.01		1.57		8.73	0.40
purplevile19_6	19.6 lower	752.78	25 Yr	HDR Ex	202.72	202.71	0.01	0.05	0.01	0.15	2.00		22.14	0.39
purplevile19_6	19.6 lower	752.78	25 Yr	HDR Pr 2	202.73	202.71	0.01	0.05	0.01		2.14		9.26	0.47
purplevile19_6	19.6 lower	752.78	50 Yr	HDR Ex	202.76	202.76	0.01	0.05	0.01	0.21	2.39		22.51	0.42
purplevile19_6	19.6 lower	752.78	50 Yr	HDR Pr 2	202.77	202.76	0.01	0.06	0.01		2.60		9.62	0.53
purplevile19_6	19.6 lower	752.78	100 Yr	HDR Ex	202.68	202.66	0.02	0.05	0.01	0.15	2.95		21.62	0.67
purplevile19_6	19.6 lower	752.78	100 Yr	HDR Pr 2	202.68	202.65	0.03	0.05	0.01		3.10		8.72	0.79
purplevile19_6	19.6 lower	752.78	Regional	HDR Ex	203.19	202.96	0.23	0.25	0.06	2.74	19.29		24.35	2.26
purplevile19_6	19.6 lower	752.78	Regional	HDR Pr 2	203.43	203.08	0.35	0.27	0.09		22.03		12.25	2.60
purplevile19_6	19.6 lower	725.1825	2 Yr	HDR Ex	202.49	202.46	0.03	1.31	0.01		0.64		6.00	0.79
purplevile19_6	19.6 lower	725.1825	2 Yr	HDR Pr 2	202.50	202.47	0.03	1.32	0.00		0.64		6.14	0.74
purplevile19_6	19.6 lower	725.1825	5 Yr	HDR Ex	202.56	202.49	0.07	1.30	0.02		1.16		6.51	1.16
purplevile19_6	19.6 lower	725.1825	5 Yr	HDR Pr 2	202.56	202.49	0.07	1.30	0.02		1.16		6.51	1.16
purplevile19_6	19.6 lower	725.1825	10 Yr	HDR Ex	202.61	202.52	0.09	1.19	0.02		1.57		7.04	1.30
purplevile19_6	19.6 lower	725.1825	10 Yr	HDR Pr 2	202.61	202.52	0.09	1.21	0.02		1.57		7.04	1.30
purplevile19_6	19.6 lower	725.1825	25 Yr	HDR Ex	202.67	202.57	0.10	1.14	0.02		2.14		7.78	1.40
purplevile19_6	19.6 lower	725.1825	25 Yr	HDR Pr 2	202.67	202.57	0.10	1.12	0.02		2.14		7.78	1.40
purplevile19_6	19.6 lower	725.1825	50 Yr	HDR Ex	202.71	202.60	0.11	1.02	0.03		2.60		8.35	1.45
purplevile19_6	19.6 lower	725.1825	50 Yr	HDR Pr 2	202.71	202.60	0.11	1.02	0.03		2.60		8.35	1.45
purplevile19_6	19.6 lower	725.1825	100 Yr	HDR Ex	202.62	202.62	0.00	0.36	0.00	2.23	0.86		69.81	0.44
purplevile19_6	19.6 lower	725.1825	100 Yr	HDR Pr 2	202.62	202.62	0.00	0.36	0.00	2.23	0.86		69.81	0.44
purplevile19_6	19.6 lower	725.1825	Regional	HDR Ex	202.88	202.84	0.04	0.14	0.01	16.29	5.74		79.30	1.46
purplevile19_6	19.6 lower	725.1825	Regional	HDR Pr 2	202.88	202.84	0.04	0.14	0.01	16.29	5.74		79.32	1.45
purplevile19_6	19.6 lower	433.76	2 Yr	HDR Ex	200.81	200.73	0.09	0.02	0.02		0.64		2.58	1.32
purplevile19_6	19.6 lower	433.76	2 Yr	HDR Pr 2	200.84	200.80	0.04	0.01	0.01	0.00	0.64		4.26	0.92
purplevile19_6	19.6 lower	433.76	5 Yr	HDR Ex	200.94	200.84	0.10	0.03	0.02	0.02	1.14		7.90	1.38
purplevile19_6	19.6 lower	433.76	5 Yr	HDR Pr 2	200.94	200.84	0.10	0.02	0.02	0.02	1.14		7.90	1.38
purplevile19_6	19.6 lower	433.76	10 Yr	HDR Ex	200.99	200.89	0.10	0.04	0.02	0.09	1.47		11.27	1.46
purplevile19_6	19.6 lower	433.76	10 Yr	HDR Pr 2	200.99	200.90	0.10	0.03	0.02	0.11	1.46		11.38	1.41
purplevile19_6	19.6 lower	433.76	25 Yr	HDR Ex	201.05	200.95	0.10	0.05	0.01	0.29	1.85	0.00	12.48	1.50
purplevile19_6	19.6 lower	433.76	25 Yr	HDR Pr 2	201.05	200.95	0.10	0.04	0.02	0.29	1.85	0.00	12.48	1.50
purplevile19_6	19.6 lower	433.76	50 Yr	HDR Ex	201.09	200.98	0.11	0.06	0.01	0.43	2.17	0.00	12.92	1.62
purplevile19_6	19.6 lower	433.76	50 Yr	HDR Pr 2	201.09	200.98	0.11	0.04	0.02	0.43	2.17	0.00	12.92	1.62
purplevile19_6	19.6 lower	433.76	100 Yr	HDR Ex	201.13	201.01	0.12	0.07	0.00	0.59	2.50	0.00	13.56	1.71
purplevile19_6	19.6 lower	433.76	100 Yr	HDR Pr 2	201.13	201.01	0.12	0.05	0.01	0.59	2.50	0.00	13.56	1.71
purplevile19_6	19.6 lower	433.76	Regional	HDR Ex	202.71	202.69	0.01	0.00	0.01	13.63	6.68	1.73	42.67	0.85
purplevile19_6	19.6 lower	433.76	Regional	HDR Pr 2	202.71	202.69	0.02	0.00	0.01	13.06	7.13	1.84	41.48	0.91
purplevile19_6	19.6 lower	427.23	2 Yr	HDR Ex	200.77	200.76	0.01			0.00	0.63	0.00	5.01	0.45
purplevile19_6	19.6 lower	427.23	2 Yr	HDR Pr 2	200.82	200.81	0.01			0.00	0.63	0.01	5.28	0.39
purplevile19_6	19.6 lower	427.23	5 Yr	HDR Ex	200.83	200.81	0.03			0.01	1.14	0.01	5.24	0.72
purplevile19_6	19.6 lower	427.23	5 Yr	HDR Pr 2	200.89	200.87	0.02			0.01	1.13	0.01	5.56	0.62
purplevile19_6	19.6 lower	427.23	10 Yr	HDR Ex	200.88	200.84	0.04			0.01	1.54	0.02	5.39	0.90
purplevile19_6	19.6 lower	427.23	10 Yr	HDR Pr 2	200.93	200.90	0.03			0.02	1.53	0.02	5.74	0.77
purplevile19_6	19.6 lower	427.23	25 Yr	HDR Ex	200.94	200.87	0.06			0.02	2.09	0.03	5.60	1.12
purplevile19_6	19.6 lower	427.23	25 Yr	HDR Pr 2	200.98	200.94	0.05			0.03	2.07	0.04	5.94	0.98
purplevile19_6	19.6 lower	427.23	50 Yr	HDR Ex	200.98	200.90	0.08			0.03	2.53	0.04	5.72	1.30
purplevile19_6	19.6 lower	427.23	50 Yr	HDR Pr 2	201.03	200.96	0.06			0.04	2.51	0.05	6.08	1.13
purplevile19_6	19.6 lower	427.23	100 Yr	HDR Ex	201.02	200.91	0.11			0.04	3.01	0.05	5.80	1.49
purplevile19_6	19.6 lower	427.23	100 Yr	HDR Pr 2	201.07	200.99	0.08			0.05	2.98	0.06	6.20	1.28
purplevile19_6	19.6 lower	427.23	Regional	HDR Ex	202.69	202.59	0.10			4.85	14.98	2.20	27.56	1.69
purplevile19_6	19.6 lower	427.23	Regional	HDR Pr 2	202.69	202.60	0.09			5.43	14.46	2.14	27.50	1.62

HEC-RAS (Continued)

River	Reach	River Sta	Profile	Plan	E.G. Elev	W.S. Elev	Vel Head	Frctn Loss	C & E Loss	Q Left	Q Channel	Q Right	Top Width	Vel Chnl
					(m)	(m)	(m)	(m)	(m)	(m3/s)	(m3/s)	(m3/s)	(m)	(m/s)
purplevile19_6	19.6 lower	418			Culvert									
purplevile19_6	19.6 lower	412.61	2 Yr	HDR Ex	200.77	200.77	0.00	0.02	0.00		0.64		11.54	0.22
purplevile19_6	19.6 lower	412.61	2 Yr	HDR Pr 2	200.82	200.82	0.00	0.02	0.00	0.00	0.64		8.18	0.26
purplevile19_6	19.6 lower	412.61	5 Yr	HDR Ex	200.83	200.82	0.01	0.04	0.00		1.16		12.03	0.33
purplevile19_6	19.6 lower	412.61	5 Yr	HDR Pr 2	200.88	200.87	0.01	0.04	0.00	0.00	1.15		8.61	0.40
purplevile19_6	19.6 lower	412.61	10 Yr	HDR Ex	200.87	200.86	0.01	0.05	0.00		1.57		12.37	0.40
purplevile19_6	19.6 lower	412.61	10 Yr	HDR Pr 2	200.92	200.91	0.01	0.06	0.00	0.00	1.56		8.89	0.48
purplevile19_6	19.6 lower	412.61	25 Yr	HDR Ex	200.91	200.90	0.01	0.06	0.00		2.14		12.77	0.48
purplevile19_6	19.6 lower	412.61	25 Yr	HDR Pr 2	200.97	200.95	0.02	0.07	0.00	0.01	2.13		9.20	0.59
purplevile19_6	19.6 lower	412.61	50 Yr	HDR Ex	200.95	200.93	0.01	0.07	0.00		2.60		13.05	0.53
purplevile19_6	19.6 lower	412.61	50 Yr	HDR Pr 2	201.01	200.98	0.02	0.09	0.00	0.01	2.59		9.42	0.67
purplevile19_6	19.6 lower	412.61	100 Yr	HDR Ex	200.98	200.96	0.02	0.08	0.00		3.10		13.30	0.59
purplevile19_6	19.6 lower	412.61	100 Yr	HDR Pr 2	201.04	201.01	0.03	0.10	0.00	0.01	3.09		9.63	0.75
purplevile19_6	19.6 lower	412.61	Regional	HDR Ex	201.59	201.41	0.18	0.16	0.00	0.03	21.77	0.23	17.60	1.89
purplevile19_6	19.6 lower	412.61	Regional	HDR Pr 2	201.78	201.44	0.35	0.24	0.03	0.11	21.55	0.37	12.95	2.63
purplevile19_6	19.6 lower	397.89	2 Yr	HDR Ex	200.75	200.74	0.01	1.08	0.00	0.64			11.43	
purplevile19_6	19.6 lower	397.89	2 Yr	HDR Pr 2	200.80	200.78	0.01	1.12	0.00	0.64	0.00		10.03	0.04
purplevile19_6	19.6 lower	397.89	5 Yr	HDR Ex	200.79	200.77	0.02	1.05	0.00	1.16			12.18	
purplevile19_6	19.6 lower	397.89	5 Yr	HDR Pr 2	200.84	200.81	0.03	1.10	0.00	1.14	0.02		13.76	0.36
purplevile19_6	19.6 lower	397.89	10 Yr	HDR Ex	200.82	200.78	0.03	1.03	0.01	1.57			12.68	
purplevile19_6	19.6 lower	397.89	10 Yr	HDR Pr 2	200.87	200.82	0.04	1.08	0.01	1.51	0.06		17.96	0.48
purplevile19_6	19.6 lower	397.89	25 Yr	HDR Ex	200.85	200.80	0.05	1.02	0.01	2.13	0.01		15.79	0.36
purplevile19_6	19.6 lower	397.89	25 Yr	HDR Pr 2	200.90	200.84	0.05	1.04	0.01	1.93	0.21		20.17	0.77
purplevile19_6	19.6 lower	397.89	50 Yr	HDR Ex	200.88	200.82	0.06	1.01	0.01	2.56	0.04		19.84	0.44
purplevile19_6	19.6 lower	397.89	50 Yr	HDR Pr 2	200.92	200.85	0.06	1.02	0.01	2.24	0.36		20.62	0.96
purplevile19_6	19.6 lower	397.89	100 Yr	HDR Ex	200.90	200.84	0.06	0.99	0.01	2.96	0.14		22.42	0.68
purplevile19_6	19.6 lower	397.89	100 Yr	HDR Pr 2	200.94	200.87	0.07	0.99	0.01	2.50	0.60		21.32	1.12
purplevile19_6	19.6 lower	397.89	Regional	HDR Ex	201.43	201.25	0.18	0.92	0.02	10.80	11.05	0.18	27.85	2.34
purplevile19_6	19.6 lower	397.89	Regional	HDR Pr 2	201.51	201.26	0.25	0.99	0.04	8.92	12.89	0.22	24.27	2.64
purplevile19_5	19.5	115.18	2 Yr	HDR Ex	199.88	199.86	0.02	0.01	0.01		0.14		1.56	0.64
purplevile19_5	19.5	115.18	2 Yr	HDR Pr 2	199.87	199.84	0.03	0.02	0.01		0.14		1.49	0.74
purplevile19_5	19.5	115.18	5 Yr	HDR Ex	199.96	199.93	0.03	0.02	0.01		0.26		1.77	0.77
purplevile19_5	19.5	115.18	5 Yr	HDR Pr 2	199.93	199.89	0.05	0.03	0.01		0.26		1.63	0.98
purplevile19_5	19.5	115.18	10 Yr	HDR Ex	200.00	199.97	0.04	0.02	0.01		0.35		1.92	0.85
purplevile19_5	19.5	115.18	10 Yr	HDR Pr 2	199.98	199.91	0.07	0.04	0.02		0.35		1.72	1.13
purplevile19_5	19.5	115.18	25 Yr	HDR Ex	200.06	200.02	0.04	0.02	0.01		0.47		2.14	0.91
purplevile19_5	19.5	115.18	25 Yr	HDR Pr 2	200.03	199.94	0.09	0.05	0.02		0.47		1.80	1.34
purplevile19_5	19.5	115.18	50 Yr	HDR Ex	200.10	200.06	0.05	0.02	0.01		0.57		2.28	0.96
purplevile19_5	19.5	115.18	50 Yr	HDR Pr 2	200.07	199.96	0.11	0.06	0.03		0.57		1.90	1.44
purplevile19_5	19.5	115.18	100 Yr	HDR Ex	200.14	200.09	0.05	0.02	0.01		0.67		2.41	0.99
purplevile19_5	19.5	115.18	100 Yr	HDR Pr 2	200.10	199.99	0.11	0.06	0.03		0.67		2.01	1.50
purplevile19_5	19.5	115.18	Regional	HDR Ex	200.89	200.85	0.05	0.01	0.01	0.64	2.90	0.10	9.17	1.09
purplevile19_5	19.5	115.18	Regional	HDR Pr 2	200.68	200.44	0.23	0.08	0.04	0.12	3.48	0.04	6.62	2.17
purplevile19_5	19.5	106.37	2 Yr	HDR Ex	199.86	199.86	0.00				0.14		3.01	0.24
purplevile19_5	19.5	106.37	2 Yr	HDR Pr 2	199.84	199.84	0.00				0.14		2.94	0.27
purplevile19_5	19.5	106.37	5 Yr	HDR Ex	199.93	199.93	0.01				0.26		3.20	0.32
purplevile19_5	19.5	106.37	5 Yr	HDR Pr 2	199.89	199.88	0.01				0.26		3.07	0.39
purplevile19_5	19.5	106.37	10 Yr	HDR Ex	199.98	199.97	0.01				0.35		3.33	0.37
purplevile19_5	19.5	106.37	10 Yr	HDR Pr 2	199.92	199.91	0.01				0.35		3.15	0.46
purplevile19_5	19.5	106.37	25 Yr	HDR Ex	200.03	200.02	0.01				0.47		3.49	0.42
purplevile19_5	19.5	106.37	25 Yr	HDR Pr 2	199.96	199.94	0.02				0.47		3.24	0.56
purplevile19_5	19.5	106.37	50 Yr	HDR Ex	200.07	200.06	0.01				0.57		3.60	0.46
purplevile19_5	19.5	106.37	50 Yr	HDR Pr 2	199.98	199.96	0.02				0.57		3.31	0.63
purplevile19_5	19.5	106.37	100 Yr	HDR Ex	200.11	200.10	0.01				0.67		3.73	0.49
purplevile19_5	19.5	106.37	100 Yr	HDR Pr 2	200.01	199.98	0.02				0.67		3.37	0.69
purplevile19_5	19.5	106.37	Regional	HDR Ex	200.88	200.85	0.03			0.12	3.49	0.02	8.47	0.73
purplevile19_5	19.5	106.37	Regional	HDR Pr 2	200.47	200.36	0.11			0.00	3.63		4.85	1.46

Crossing 3

purplevile19_5	19.5	101			Culvert									
purplevile19_5	19.5	76.92	2 Yr	HDR Ex	199.80	199.79	0.02	0.16	0.00		0.14		2.82	0.61
purplevile19_5	19.5	76.92	2 Yr	HDR Pr 2	199.80	199.79	0.02	0.16	0.00		0.14		2.82	0.61
purplevile19_5	19.5	76.92	5 Yr	HDR Ex	199.85	199.83	0.02	0.16	0.00		0.26		4.36	0.65
purplevile19_5	19.5	76.92	5 Yr	HDR Pr 2	199.85	199.83	0.02	0.16	0.00		0.26		4.36	0.65
purplevile19_5	19.5	76.92	10 Yr	HDR Ex	199.88	199.85	0.02	0.16	0.00		0.35		5.14	0.68
purplevile19_5	19.5	76.92	10 Yr	HDR Pr 2	199.88	199.85	0.02	0.16	0.00		0.35		5.14	0.68
purplevile19_5	19.5	76.92	25 Yr	HDR Ex	199.91	199.88	0.03	0.16	0.00		0.47		5.98	0.73
purplevile19_5	19.5	76.92	25 Yr	HDR Pr 2	199.91	199.88	0.03	0.16	0.00		0.47		5.98	0.73
purplevile19_5	19.5	76.92	50 Yr	HDR Ex	199.93	199.90	0.03	0.15	0.00		0.57		6.59	0.75
purplevile19_5	19.5	76.92	50 Yr	HDR Pr 2	199.93	199.90	0.03	0.15	0.00		0.57		6.59	0.75
purplevile19_5	19.5	76.92	100 Yr	HDR Ex	199.94	199.91	0.03	0.15	0.00		0.67		7.15	0.77
purplevile19_5	19.5	76.92	100 Yr	HDR Pr 2	199.94	199.91	0.03	0.15	0.00		0.67		7.15	0.77
purplevile19_5	19.5	76.92	Regional	HDR Ex	200.22	200.16	0.06	0.10	0.01	0.07	3.56		13.56	1.13
purplevile19_5	19.5	76.92	Regional	HDR Pr 2	200.22	200.16	0.06	0.10	0.01	0.07	3.56		13.56	1.13
purplevile19_5	19.5	68.18	2 Yr	HDR Ex	199.64	199.60	0.04	0.22	0.01		0.14		1.72	0.93
purplevile19_5	19.5	68.18	2 Yr	HDR Pr 2	199.64	199.60	0.04	0.22	0.01		0.14		1.72	0.93
purplevile19_5	19.5	68.18	5 Yr	HDR Ex	199.69	199.65	0.04	0.26	0.01		0.26		3.12	0.93
purplevile19_5	19.5	68.18	5 Yr	HDR Pr 2	199.69	199.65	0.04	0.26	0.01		0.26		3.12	0.93
purplevile19_5	19.5	68.18	10 Yr	HDR Ex	199.72	199.67	0.05	0.29	0.01		0.35		3.62	0.98
purplevile19_5	19.5	68.18	10 Yr	HDR Pr 2	199.72	199.67	0.05	0.29	0.01		0.35		3.62	0.98
purplevile19_5	19.5	68.18	25 Yr	HDR Ex	199.75	199.70	0.05	0.32	0.01		0.47		4.18	1.04
purplevile19_5	19.5	68.18	25 Yr	HDR Pr 2	199.75	199.70	0.05	0.32	0.01		0.47		4.18	1.04
purplevile19_5	19.5	68.18	50 Yr	HDR Ex	199.77	199.71	0.06	0.34	0.02		0.57		4.59	1.07
purplevile19_5	19.5	68.18	50 Yr	HDR Pr 2	199.77	199.71	0.06	0.34	0.02		0.57		4.59	1.07
purplevile19_5	19.5	68.18	100 Yr	HDR Ex	199.79	199.73	0.06	0.36	0.02	0.00	0.67		5.02	1.11

HEC-RAS (Continued)

River	Reach	River Sta	Profile	Plan	E.G. Elev	W.S. Elev	Vel Head	Frctn Loss	C & E Loss	Q Left	Q Channel	Q Right	Top Width	Vel Chnl
					(m)	(m)	(m)	(m)	(m)	(m3/s)	(m3/s)	(m3/s)	(m)	(m/s)
purplevile19_5	19.5	68.18	100 Yr	HDR Pr 2	199.79	199.73	0.06	0.36	0.02	0.00	0.67		5.02	1.11
purplevile19_5	19.5	68.18	Regional	HDR Ex	200.12	199.98	0.14	0.68	0.03	0.12	3.35	0.15	12.54	1.72
purplevile19_5	19.5	68.18	Regional	HDR Pr 2	200.12	199.98	0.14	0.68	0.03	0.12	3.35	0.15	12.54	1.72