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Appendix D

Fluvial Geomorphology Assessment

Appendix D

Park 505 – Phase One: Fluvial Geomorphology Assessment

FINAL REPORT

Prepared for

R.J. Burnside & Associates Limited

292 Speedvale Ave. Unit 20
Guelph, ON N1H 1C4

May 1, 2020
Project No. P2019-364

Prepared by

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Version History

Version	Date	Issue	Description	Author	Approved
01	2019/11/14	Draft	Issued to Client for review	BDP	JPH
02	2020/01/15	Draft	Revised per City comments	BDP	JPH
03	2020/05/01	Final	Final Report	BDP	JPH

FINAL REPORT

GeoProcess RESEARCH ASSOCIATES

Knowledge
Research
Consulting

May 1, 2020

Tricia Radburn, M.Sc.(Pl), MCIP, RPP
R.J. Burnside & Associates Limited
292 Speedvale Ave. Unit 20
Guelph, ON N1H 1C4

Re: Fluvial Geomorphology Study
City of Mississauga – Park 505 Phase One Development

Dear Ms. Radburn:

GeoProcess Research Associates Inc. (GRA) has conducted a geomorphological assessment of the Credit River and Fletcher's Creek as part of the Park 505 Phase One development for the City of Mississauga. The assessment characterized the watercourses' dominant geomorphic processes and historical erosion trends pertinent to locations where pedestrian crossings are proposed. Additionally, the meander belt limits of Fletcher's Creek were determined for the purpose of establishing the redside dace setback limits. Please don't hesitate to contact the undersigned with any questions or comments.

Regards,

GEOPROCESS RESEARCH ASSOCIATES INC

Jeffrey Hirvonen, MASc
Principal

Ben Plumb, PhD, P.Eng.
River Engineer

GeoProcess RESEARCH ASSOCIATES

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1. Introduction

GeoProcess Research Associates (GRA) was retained by R.J. Burnside (Burnside) to complete a fluvial geomorphology assessment of the Credit River and Fletcher's Creek in the vicinity of the Park 505 Phase One development area (the Study Area). The objective of the assessment was to characterize the geomorphic conditions and erosion trends of these watercourses at locations where crossings are proposed as part of the development. The assessment consisted of field, desktop and modelling investigations to characterize the geomorphic processes and erosion potential at the crossings.

2. Background and Spatial Context

The Credit River has a watershed area of approximately 1000 km^2. It originates near Orangeville and outlets to Lake Ontario in Mississauga. Land-use throughout the watershed is primarily rural and agricultural (~50%), with ~17% urban land-use that is concentrated in the lower portion of the watershed.

Fletcher's Creek, a tributary to the Credit River, has a watershed area of approximately 45 km^2, originating in Brampton and outletting to the Credit River downstream of Highway 401. This watershed is dominated by urban land-use (~70%) with only a small portion of its headwaters remaining agricultural.

Figure 1: Park 505 Phase One fluvial geomorphology study area.

The Study Area (illustrated as blue stream segments in Figure 1) is located immediately south of Highway 401. The area includes the Credit River from Highway 401 (upstream) to Creditview Road (downstream) and Fletcher's Creek from Highway 401 (upstream) to its confluence with the Credit (downstream). The area is within the South Slope Physiographic Region, with surficial geology consisting of heavy textured till (Oneida and Chinguacousy) and modern alluvial deposits (from the Credit) (Hoffman and Richards, 1953).

3. Methods

3.1. Field Investigation

A reconnaissance investigation was undertaken for the entirety of the study reaches, identifying instances of sediment sources and sinks. Indicators representative of changing channel morphology were identified and recorded. For example, vertical or undercut streambanks void of vegetation are indicators of channel widening, which can have implications for the long-term stability of infrastructure located adjacent to the river (i.e. bridge crossings). The primary objective of the reconnaissance investigation was to classify the overall stability of the study reach (e.g. stable, in transition, in adjustment) using known geomorphic indicators and principles of channel evolution.

To augment the qualitative reconnaissance assessment, a detailed geomorphic survey was undertaken for both river reaches in the study area. The detailed survey included a longitudinal profile, where significant breaks in bed slope and geomorphic features were measured, with a maximum survey spacing of one channel width in longitudinal distance. Cross-sections were surveyed at morphological features of interest, characterizing both riffle and pool morphologies. The survey data is used to verify observations made at the reconnaissance level pertaining to active channel processes. All measurements were conducted using an RTK survey-grade GPS (±0.01 m) and an Acoustic Doppler Profiler (ADP) (±1% of max depth) for areas where flow depths exceeded safe wadable limits. Substrates were also sampled using the modified Wolman pebble count method with sample sizes of 100 particles or greater.

3.2. Erosion Assessment

Planform migration was assessed using historical, georeferenced aerial photographs obtained from the City of Mississauga. Streambanks were digitized for the Credit River and the stream centreline was digitized for Fletcher's Creek (the air photo resolution was not sufficient to identify the banks of the smaller, Fletcher's Creek). Erosion characteristics in the vicinity of the crossings were assessed.

There is no single, comprehensive method for estimating scour potential in gravel-bed rivers. This is owing to the inherent variability of scouring and bed mobility in gravel-bed systems. In these types of rivers, bed scour is known to produce an armour layer as smaller, more mobile particles are selectively entrained from the bed. In turn, the armour layer becomes more resistant to erosion.

In consideration of this complex process and the inherent uncertainty, to evaluate the susceptibility of the river bottom to vertical erosion bed scour was estimated using multiple approaches, seeking convergence on a defensible result. All scour models used the sampled D_{50} particle size, which yielded a conservative estimate since this size doesn't account for the coarseness of the ultimate armour layer (often corresponding to the D_{84} or D_{90} particle size). Scour models that were employed included:

- Models that predict the estimated scour depth that produces an armour layer. Simply stated, at the depths predicted using these models (which are based on the D_{50} size) the bed will become coarser and, thus, more resilient to erosion (Borah, 1989; Julien, 2002).
- Regime equations and empirical models (Pemberton and Lara, 1984; Haschenburger, 1999).

The meander belt width was delineated following the TRCA (2001) protocol. The objective of delineating the meander belt was to identify the redside dace regulatory setback, which is defined as 30 m beyond the meander belt limit. Meander belts were not delineated for the purposes of erosion hazard identification.

4. Results

4.1. Existing Geomorphological Conditions

Locations of surveyed profiles, cross-sections and substrate sampling locations are illustrated in Map 1and Map 2.

4.1.1. Credit River

The river in this reach can be characterized as a wide, meandering, gravel-bed river. There are several locations where the river flows coincident with the toe of the valley wall. Engineered erosion protection is present at several of these locations to mitigate potential toe erosion risks. Localized instances of bank erosion are present but, overall, the banks are well-vegetated, and the reach does not exhibit system-wide symptoms of instability.

The bankfull slope in the study reach was measured to be 0.12%. Table 1 summarizes the bankfull characteristics, taken at riffle cross-sections. The bankfull width ranges between approximately 31 m and 38 m, with an average width of 35.4 m. The bankfull depth ranges between approximately 0.8 m and 1.3 m, with an average of 1.0 m. Pools (Table 2) have considerably more variance in the measured dimensions, owing to the inherent variability of pool shapes in natural watercourses. Detailed cross-sectional geometry summaries are provided in Appendix A. The substrate composition (Table 3) ranges from fine gravel to cobbles and confirms the classification of a gravel-bed dominated stream.

Table 1: Credit River bankfull characteristics - riffles.

	Min	Max	Avg
Area (m^2)	25.3	47.8	35.9
Top Width (m)	30.9	38.2	35.4
Mean Depth (m)	0.8	1.3	1.0
Max Depth (m)	0.9	1.7	1.3
Wetted Perimeter (m)	31.5	39.1	36.1
Hydraulic Radius (m)	0.8	1.3	1.0
Width-Depth Ratio	28.7	41.3	35.9
Velocity (m/s)	0.9	1.2	1.0
Discharge (m^3/s)	21.7	58.7	37.4
Froude number	0.3	0.3	0.3
Shear Stress (Pa.)	9.4	14.8	11.6
Shear Velocity (m/s)	0.1	0.1	0.1
Unit Stream Power (watts/m^2)	8.3	18.7	12.3

Table 2: Credit River bankfull characteristics - pools.

	Min	Max	Avg
Area (m^2)	27.8	71.9	44.1
Top Width (m)	22.1	49.4	34.9
Mean Depth (m)	1.0	1.5	1.2
Max Depth (m)	1.2	2.4	1.8
Wetted Perimeter (m)	23.7	50.7	36.2
Hydraulic Radius (m)	1.0	1.4	1.2
Width-Depth Ratio	17.5	39.8	28.3

Table 3: Credit River substrate distribution.

	PC-CR1	PC-CR2	Avg
D_{16}	13.0	19.2	16.1
D_{35}	33.3	33.4	33.4
D_{50}	41.6	41.3	41.5
D_{65}	53.1	54.2	53.7
D_{84}	77.1	82.2	79.6
D_{95}	130.2	128.0	129.1

Photo 1: Credit River representative photos. At existing pedestrian bridge near upstream end of reach (top left), at confluence with Fletcher's Creek (top right), at upstream proposed crossing (bottom left), at downstream proposed crossing (bottom right).

4.1.2. Fletcher's Creek

Fletcher's Creek exhibits geomorphic indicators consistent with river incision and widening processes. This condition is representative of watercourses in active adjustment and of watersheds that have been subject to significant land-use change. Woody debris and fine sediment deposition are present throughout the reach. The riffles' substrate composition is consistent with channel armouring processes (another indicator that the stream has undergone adjustment). Also, the oversized nature of the channel implies that the floodplain is not frequently accessed by flood flows, thus there is less energy dissipation (than in floodplain connected reaches) occurring during higher flows.

The bankfull slope in this reach was measured to be 0.38%. Table 4 summarizes the measured bankfull characteristics, recorded at riffle cross-sections. The bankfull width ranges between approximately 12 m and 15 m, with an average of 13.2 m. The bankfull depth ranges between approximately 0.7 m and 1.1 m, with an average of 0.9 m. Pools (Table 5) are more variable, consistent with the Credit, however with a larger spread that is consistent with a channel that has undergone adjustment. Detailed cross-sectional geometry summaries are provided in Appendix A. The substrate composition (Table 6) has a wider range of particle sizes, as compared to the Credit, confirming the field observations of bed armouring.

Table 4: Fletcher's Creek bankfull characteristics - riffles.

	Min	Max	Avg
Area (m^2)	9.8	13.9	11.8
Top Width (m)	12.2	14.9	13.2
Mean Depth (m)	0.7	1.1	0.9
Max Depth (m)	1.1	1.6	1.4
Wetted Perimeter (m)	13.0	15.6	14.1
Hydraulic Radius (m)	0.6	1.0	0.8
Width-Depth Ratio	11.5	22.8	15.7
Velocity (m/s)	1.3	1.9	1.6
Discharge (m^3/s)	12.7	25.9	19.6
Froude number	0.5	0.6	0.6
Shear Stress (Pa.)	23.2	37.6	31.4
Shear Velocity (m/s)	0.2	0.2	0.2
Unit Stream Power (watts/m^2)	32.0	76.0	56.7

Table 5: Fletcher's Creek bankfull characteristics - pools.

	Min	Max	Avg
Area (m^2)	4.7	19.8	14.5
Top Width (m)	9.1	20.6	14.9
Mean Depth (m)	0.5	1.4	0.9
Max Depth (m)	0.8	2.2	1.8
Wetted Perimeter (m)	9.5	21.6	15.9
Hydraulic Radius (m)	0.5	1.3	0.9
Width-Depth Ratio	9.8	21.6	16.7

Table 6: Fletcher's Creek substrate distribution.

	PC-FC1	PC-FC2	Avg
D_{16}	10.6	5.0	7.8
D_{35}	21.4	19.1	20.2
D_{50}	30.6	46.6	38.6
D_{65}	46.4	128.5	87.4
D_{84}	76.3	195.1	135.7
D_{95}	117.9	246.9	182.4

Photo 2: Fletcher's Creek representative photos. At existing pedestrian bridge near upstream end of reach (top left), at confluence with Fletcher's Creek (top right), at upstream proposed crossing (bottom left), at downstream proposed crossing (bottom right).

4.2. Historic Planform Characteristics

The historical conditions were assessed, and a summary is included in Table 7. The delineated banks and centreline are illustrated in Map 3 and Map 4.

Table 7: Summary of historical conditions.

Year	Summary
1954	Due to image quality and vegetation, it was difficult to accurately delineate the Credit River banks or Fletcher's Creek centreline. The chute cutoff observed in the field was observed in the photo on Fletcher's Creek, near 0+700. Bank and centreline locations were estimated however they are not considered representative of lateral erosion rate estimates due to their uncertainty (poor image resolution).
1977	**Fletcher's Creek:** The lower reach was visible in this photo and the centreline was estimated. Some uncertainty is still present as the photo resolution is poor and it is difficult to differentiate the creek from the riparian vegetation. The first 200 m of the reach was channelized between 1954 and 1977, likely to accommodate the construction of Highway 401. **Credit River:** The Credit River was not delineated for this year as 1980 offered better resolution.
1980	**Fletcher's Creek:** The centreline delineation downstream of 0+600 is uncertain due to photo resolution and differentiation between the creek and riparian vegetation. **Credit River:** The river appeared to be in flood stage during this photo as the top width of flow was wider than other years. However limited planform changes were observed.
2002	**Fletcher's Creek:** The meander bend immediately upstream of the confluence has been cut off sometime between 1980 and 2002. **Credit River:** Limited planform changes were observed. Bank toe protection was noted at 0+900 and 1+800.
2010	**Fletcher's Creek:** Limited planform changes were noted between 2002 and 2010. **Credit River:** Limited planform changes were noted between 2002 and 2010.
2017	**Fletcher's Creek:** Limited planform changes were noted between 2010 and 2017. **Credit River:** Limited planform changes were noted between 2010 and 2017.

4.3. Meander Belt and Redside Dace Setback

The meander belt for Fletcher's Creek was measured for the purposes of delineating the Redside Dace regulatory setback (30 m beyond the meander belt). The Fletcher's Creek valley form is partially confined upstream of the proposed pedestrian bridge location (Stn. 0+550 on Map 2). Downstream of here, Fletchers Creek flows within the Credit River valley bottom and is unconfined. The creek exhibits a compound meander pattern through this downstream reach (downstream of Stn. 0+550 to the confluence with the Credit River on Map 2), with most of the channel migration following the minor meander belt axis. Owing to the uncertainty in delineating the stream centrelines (due to image resolution) from the historical aerial imagery (per the summary in Table 7), an accurate estimate of historic erosion rates difficult to ascertain. To account for this, the major meander belt axis was used as the primary reference line downstream of the proposed pedestrian bridge (resulting in a conservative belt width). The resulting meander belt and 30 m redside dace setbacks are illustrated on Map 4. Within the Park 505 limits, the meander belt ranges between approximately 73 m and 150 m.

The measured meander belt was compared against empirical meander geometry relationships derived by Williams (1986) which relate meander belt to both bankfull width and bankfull area. Using the measured bankfull geometry (Table 4) and the empirical meander relationships, meander belt estimates based on the average bankfull width and area are 83.1 and 90.4, respectively. These estimates are within the range of meander belt widths estimated from the aerial imagery, further supporting this analysis and helping to reconcile some of the uncertainty associated with poor image resolution in certain years.

4.4. Erosion Assessment

The proposed Park 505 crossing locations are illustrated in Map 5. Fletcher's Creek in the vicinity of the crossing has not changed significantly during the observed period of record, with only approximately 1 m difference between the centrelines of all years. This difference is within the uncertainty associated with delineating the historical centrelines. It is, thus, concluded that the stream has not changed locations considerably. This conclusion is corroborated by the topography at the proposed crossing location, which confines the channel alignment here. The confined setting should be considered when positioning the crossing abutments, as the creek flows coincident to the toe of the left bank. Field observations indicate that the bed and toe of the left bank are armoured with coarse material (Photo 2), which may mitigate potential erosion at this location.

Both of the Credit River's proposed crossing locations show negligible changes in riverbank position between 2002 and 2017. The 1980 and 1954 aerials were of poor quality and had riparian vegetation that obscured a clear identification of banks in these locations. Also, the 1980 photo has a larger stream width in many locations, implying the photo was taken at a time of higher flows. At both crossing locations, however, the riverbanks are stable and well-vegetated (Photo 1), supporting the assessment of historical conditions. In summary, the lateral migration at all the proposed locations is considered low.

To further estimate lateral erosion, the average bank erosion rates were estimated at each crossing location on the Credit River between 2002 and 2017. It is acknowledged that these photos span a relatively short period, however, the older photos inferred more uncertainty (due to poor image resolution) with respect to the exact bank locations, thus predicting potentially erroneous migration rates. Approximately twenty measurements were taken at roughly 3 m intervals and were averaged for each bank, covering a channel width upstream and downstream of each crossing. At Crossing 2, the measured bank recession rates were considered to be within the uncertainty associated with the image resolution. Results for Crossing 1 are illustrated in Table 8.

Table 8: Average annual migration rates and 100-year migration.

	Left Bank	Right Bank
Average Annual Migration Rate (m/yr)	0.03	0.02
Average 100-Year Migration (m)	3.32	2.30

Vertical scour was assessed for the field estimated bankfull conditions. Riffles were assessed as they are the grade-controlling features in gravel-bed rivers. The scour estimates are reflective of general scour at riffles and do not account for localized scour associated with bridge abutments and it is recommended that bridge scour be evaluated as part of the detailed design phase for the crossings. It should be noted that, at the time of writing, scour for the 100-year flow condition has not yet been addressed, but will be assessed in the final version, in collaboration with the Burnside water resources team. The results for the bankfull discharge are summarized in Table 9.

Table 9: Vertical scour analysis results (m).

	Scour Depth to Armour Layer				Empirical		Regime (Pemberton-Lara)			
	Julien		Borah		Haschenburger		Lacey		Blench	
	Bankfull	100-year	Bankfull	100-year	Bankfull	100-year	Bankfull	100-year	Bankfull	100-year
Credit River	0.08	0.08	0.01	**	0.01	**	0.11	**	0.11	**
Fletcher's Creek	0.08	0.08	0.07	**	0.02	**	0.09	**	0.14	**

The various models indicate that scour estimates for the field-identified bankfull discharge range from 0.01 m to 0.11 m for the Credit River and 0.02 m to 0.14 m for Fletcher's Creek. These relatively small values are consistent with anticipated scour in gravel-bed rivers, which is typically less than scour in sand-bed systems. Armour layers (common to gravel-bed rivers), tend to reduce scour depths in floods. As discussed in Section 3.2, these models used the D_{50} particle obtained from the sampled substrate data, which adds further conservatism as the D_{50} is typically smaller than the dominant particles in the armour layer (typically characterized by the D_{84} or D_{90} percentiles). As scour occurs, selective entrainment of finer particles also occurs, which results in a coarser bed that is more resistant to erosion.

5. Constraints, Opportunities and Design Recommendations for Crossings

The following sections discuss considerations for the proposed crossings, in light of the findings of this study. There are two major categories of design consideration for bridge crossings pertinent to fluvial geomorphology: process and form. While these two categories are interrelated (i.e. fluvial processes influence, and are influenced by, fluvial forms), distinct design considerations can be classified into these two categories.

5.1. Process-Based

The primary process-based design consideration is to maintain a bankfull conveyance to ensure no localized or reach scale disruptions to sediment transport will be created by the crossing. This is ideally achieved by ensuring the crossing spans the entire bankfull width and that no piers or abutments encroach on the banks. Additionally, some floodplain conveyance should be achieved to ensure that floodplain flows that overtop the bankfull channel can be conveyed downstream without being forced back into the main channel, conditions that would create a hydraulic contraction that could increase the scour potential.

5.2. Form-Based

This pertains to the placement of crossings within the river; specifically, the morphologic feature that the bridge crossing is spanning. River bends will commonly erode on the outer bank and aggrade on the inner bank. These are natural processes that influence meandering; however, it is undesirable to have a structure spanning a bend since they are naturally dynamic locations. Crossovers (e.g., riffles and runs) are less dynamic and remain relatively stable in a system that is not undergoing significant adjustment (i.e. instability due to persistent channel widening). Additionally, they are natural grade control features, having the most stable bed sections within a riffle-pool dominated morphology. As such, it is recommended to locate the bridge crossings at riffles.

5.3. Fletcher's Creek

The proposed Fletcher's Creek crossing is situated at a riffle having a coarse grain-size distribution and which is at a location where the valley setting is confined. This facilitates a span that will not interfere with sediment transport continuity. The confined setting poses a potential for toe erosion risk; thus, the design should consider positioning the abutment to be set back from the top of the slope (note this may require a stable slope assessment which is outside of the scope of this study and should be completed by a geotechnical engineer). This planned bridge location, however, is the most appropriate for a crossing as further downstream the reach is more dynamic, exhibiting more lateral migration in its unconfined setting.

5.4. Credit River

The upstream proposed crossing (Crossing 1) is located on a straight section of river immediately upstream of a riffle (XS-CR7). While bank erosion/migration potential was determined to be low here, abutments or piers should be set back from the top of banks by a minimum of 3.5 m (to account for uncertainty in the aerial photo delineation and the 100-year migration from Table 8). The crossing is immediately downstream of a valley wall contact location (on the right bank) and, as such, will have less impact on sediment transport continuity or floodplain obstruction on the right bank.

The downstream proposed crossing (Crossing 2) is located on a bend. Although lateral migration rates were assessed to be low in this location, locating crossings on bends is not recommended as these are naturally dynamic areas (as discussed above). If possible, the crossing location should be moved downstream to be closer to the downstream riffle (XS-CR10). Aerial photos revealed an area of localized bank erosion at XS-CR10 (shown on Map 5). This area is low-lying and experiences overbank flows (as illustrated in the 1980 photo). As such, the crossing should be situated approximately 25 m upstream of XS-CR10 (or approximately 55 m downstream of the original proposed location of Crossing 2), which is upstream of the low-lying area and exhibits historically stable banks. It is recommended that the abutments be set back a minimum of 3.5 m, remaining consistent with Crossing 1.

5.5. Erosion Protection

The need for abutment erosion protection should be evaluated based on the elevation of the abutments relative to return-period flood stages. Given that the Credit River crossings are situated in the floodplain, there is a potential that flows exceeding the bankfull channel may cause erosion around the abutments. This evaluation should be undertaken at a later design phase and appropriate erosion protection (e.g. riprap at the abutment toes) specified by the bridge designer if required.

The Credit River crossings are at locations that have relatively low bank migration potential. However, if additional protection (added long term conservatism) from erosion is warranted, a buried stone revetment can be incorporated between the abutment and the bank. This may require additional set back distances so as not to disturb the existing bank structure and vegetation.

6. Conclusions

A fluvial geomorphology assessment was completed for the Credit River and Fletcher's Creek in the vicinity of the Park 505 Phase One development area. The objective was to characterize the geomorphic conditions and erosion trends of these watercourses at locations where bridge crossings are proposed as part of the park development. The following are key conclusions drawn from the findings of the assessment:

- The Credit River is geomorphically stable in the study area and has experienced only minor lateral migration in the historic record (per aerial photo interpretation).
- Fletcher's Creek exhibits indicators of channel adjustment by incision and widening. Historic planform migration is evident but is the level of uncertainty is high due to the poor resolution and of the historic aerial photos.
- Fletcher's Creek at the proposed crossing location has experienced only minor planform adjustment during the historic record. The proposed crossing is located at a riffle (which is recommended). The location is also coincident with the valley slope on the left bank and, as such, the abutment should consider geotechnical stability and related setbacks to mitigate long-term toe erosion risk (at the detailed design stage).
- Credit River at both proposed bridge crossing locations has experienced only minor planform adjustment in the period of record, indicating a stable planform. The upstream crossing location is preferred from a geomorphic perspective as it is situated immediately upstream of a riffle However, the downstream crossing can be relocated a short distance downstream to coincide with a riffle.
- Scour estimates for the bankfull discharge indicated a potential depth-of-scour range between 0.01 m to 0.11 m for the Credit River and 0.02 m to 0.14 m for Fletcher's Creek. These estimates are representative of general (reach-wide) scour and do not consider localized scour associated specifically with the crossing structures (such as abutments or piers) themselves.

7. References

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PARK 505 – PHASE ONE: FLUVIAL GEOMORPHOLOGY ASSESSMENT - FINAL

Prepared for R.J. Burnside & Associates Limited

May 1, 2020

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River Engineer

Reviewed by:

Jeff Hirvonen, MASc
Principal

Disclaimer

We certify that the services performed by GeoProcess Research Associates were conducted in a manner consistent with the level of care, skill and diligence to be reasonably exercised by members of the engineering and science professions.

Information obtained during the site investigations or received from third parties does not exhaustively cover all possible environmental conditions or circumstances that may exist in the study area. If a service is not expressly indicated, it should not be assumed that it was provided. Any discussion of the environmental conditions is based upon information provided and available at the time the conclusions were formulated.

This report was prepared exclusively for R.J. Burnside & Associates Limited and the City of Mississauga by GeoProcess Research Associates. The report may not be relied upon by any other person or entity without our written consent and that of R.J. Burnside & Associates Limited and the City of Mississauga. Any uses of this report or its contents by a third party, or any reliance on decisions made based on it, are the sole responsibility of that party. GeoProcess Research Associates accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions taken based on this report.

Project Number P2019-364

Maps

GeoProcess RESEARCH ASSOCIATES

LEGEND
- Cross-section location
- Substrate sampling location
- Proposed crossing location
- Revised (fluvial) crossing location

Credit River Cross-Section and Substrate Sampling Locations

Scale: 1:5000	Drawn By: BDP	Map No. 1
Date Issued: Jan 8, 2020	Checked By: JPH	

GeoProcess RESEARCH ASSOCIATES

LEGEND
- Cross-section location
- Substrate sampling location
- Proposed crossing location

Fletcher's Creek Cross-Section and Substrate Sampling Locations

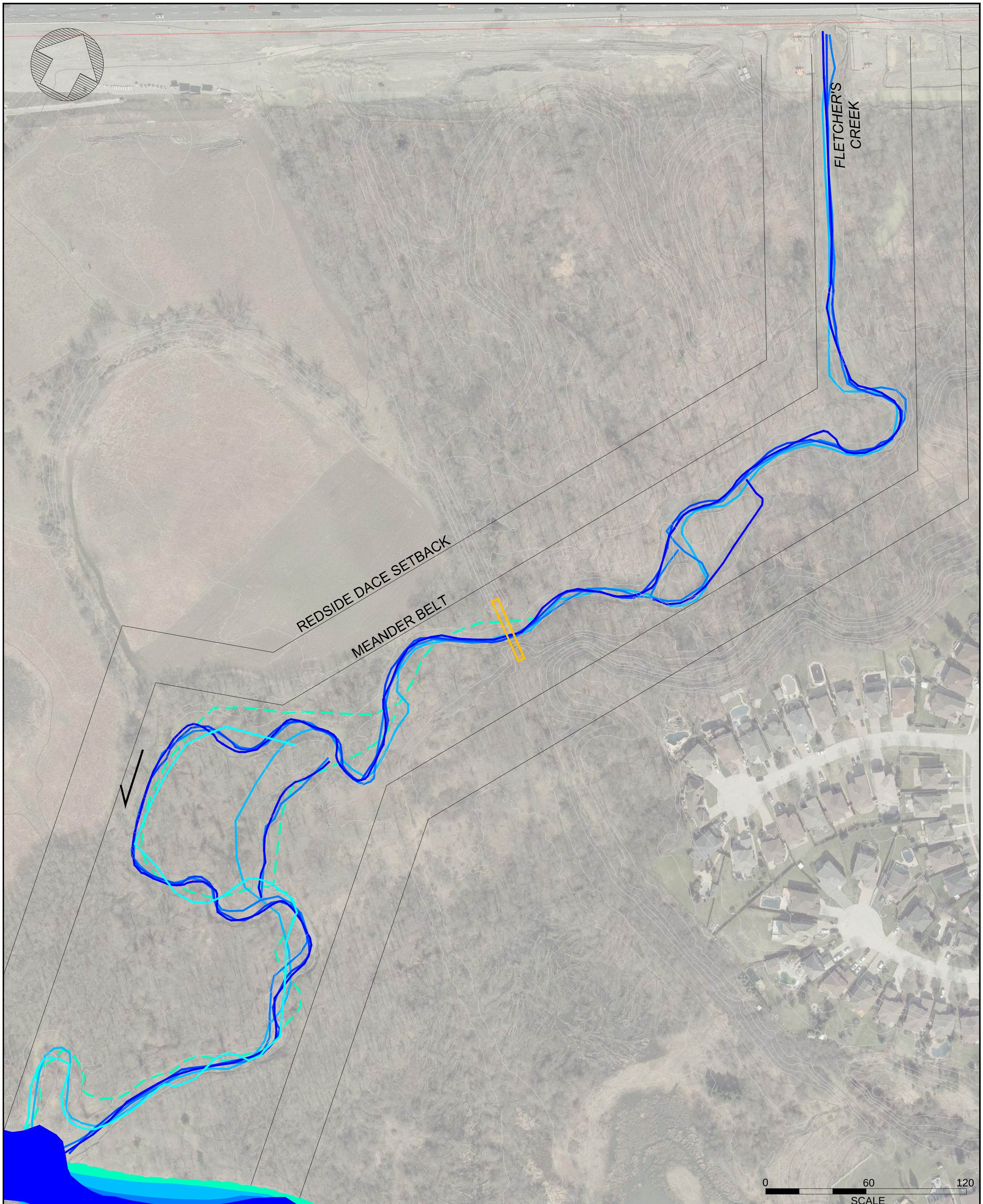
Scale: 1:3000	Drawn By: BDP	Map No. 2
Date Issued: Jan 8, 2020	Checked By: JPH	

GeoProcess RESEARCH ASSOCIATES

LEGEND
- 2017 channel alignment
- 1980 channel alignment
- 1954 channel alignment
- Proposed crossing location
- Revised (fluvial) crossing location

Credit River Historical Channel Alignments

Scale: 1:5000	Drawn By: BDP	Map No.
Date Issued: Jan 8, 2020	Checked By: JPH	3

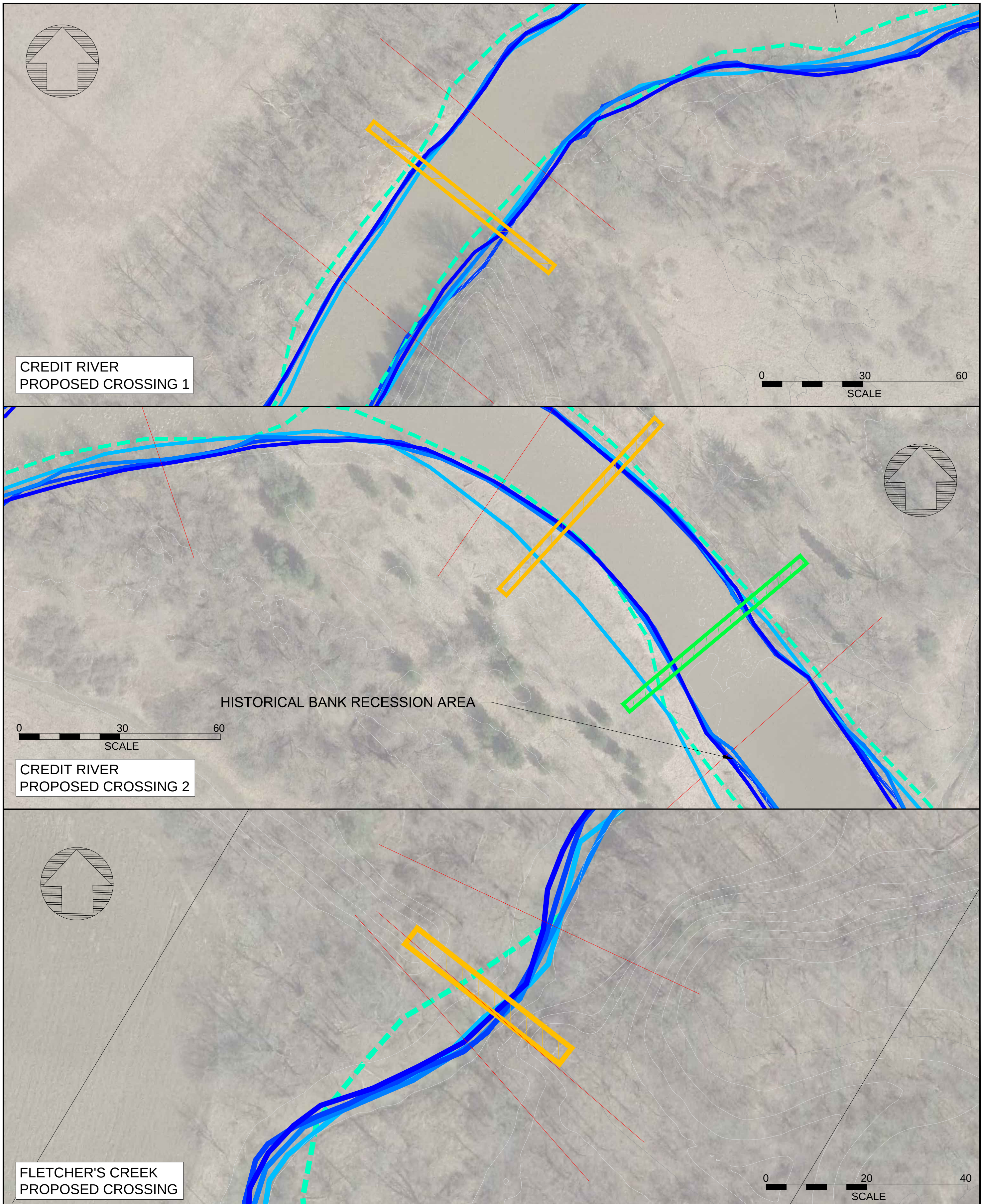


GeoProcess RESEARCH ASSOCIATES

LEGEND
2017 channel alignment
2010 channel alignment
2002 channel alignment
1980 channel alignment
Proposed crossing location
1977 channel alignment
1954 channel alignment
Redside Dace Setback
Meander Belt

Fletcher's Creek Historical Channel Alignments

Scale: 1:3000	Drawn By: BDP	Map No. 4
Date Issued: Jan 8, 2020	Checked By: JPH	



GeoProcess
RESEARCH ASSOCIATES

LEGEND
- 2017 channel alignment
- 2010 channel alignment
- 2002 channel alignment
- 1980 channel alignment
- 1977 channel alignment
- 1954 channel alignment
- Proposed crossing location
- Revised (fluvial) crossing location

Proposed Crossing Locations

Scale: As Shown	Drawn By: BDP	Map No. 5
Date Issued: Jan 8, 2020	Checked By: JPH	

Appendix A

Detailed Cross-Sectional Results

Credit River Riffles

	CR2	CR3	CR5	CR7	CR10	CR12	CR14
Area (m^2)	36.4	47.8	30.7	25.3	46.3	34.3	30.4
Top Width (m)	38.2	37.0	31.0	30.9	38.0	37.4	35.4
Mean Depth (m)	1.0	1.3	1.0	0.8	1.2	0.9	0.9
Max Depth (m)	1.3	1.7	1.2	0.9	1.6	1.1	1.1
Wetted Perimeter (m)	39.1	37.9	31.5	31.5	39.0	37.9	36.0
Hydraulic Radius (m)	0.9	1.3	1.0	0.8	1.2	0.9	0.8
Width-Depth Ratio	40.0	28.7	31.2	37.7	31.2	40.8	41.3
Velocity (m/s)	1.0	1.2	1.0	0.9	1.2	0.9	0.9
Discharge (m^3/s)	35.7	58.7	31.0	21.7	54.4	32.5	27.5
Froude number	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Shear Stress (Pa.)	11.0	14.8	11.5	9.4	14.0	10.7	9.9
Shear Velocity (m/s)	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Unit Stream Power (watts/m^2)	11.0	18.7	11.8	8.3	16.9	10.2	9.1

Credit River Pools

	CR1	CR4	CR6	CR8	CR9	CR11	CR13
Area (m^2)	44.8	35.7	33.3	71.9	56.6	27.8	38.4
Top Width (m)	38.1	28.0	29.3	49.4	38.5	22.1	39.1
Mean Depth (m)	1.2	1.3	1.1	1.5	1.5	1.3	1.0
Max Depth (m)	1.6	1.9	1.4	2.0	2.4	2.0	1.2
Wetted Perimeter (m)	39.3	29.6	30.5	50.7	39.8	23.7	39.7
Hydraulic Radius (m)	1.1	1.2	1.1	1.4	1.4	1.2	1.0
Width-Depth Ratio	32.4	22.0	25.8	34.0	26.3	17.5	39.8

Fletcher's Creek Riffles

	FC1	FC3	FC8
Area (m^2)	9.8	11.6	13.9
Top Width (m)	14.9	12.2	12.7
Mean Depth (m)	0.7	1.0	1.1
Max Depth (m)	1.1	1.6	1.4
Wetted Perimeter (m)	15.6	13.0	13.8
Hydraulic Radius (m)	0.6	0.9	1.0
Width-Depth Ratio	22.8	12.7	11.5
Velocity (m/s)	1.3	1.7	1.9
Discharge (m^3/s)	12.7	20.2	25.9
Froude number	0.5	0.6	0.6
Shear Stress (Pa.)	23.2	33.4	37.6
Shear Velocity (m/s)	0.2	0.2	0.2
Unit Stream Power (watts/m^2)	32.0	62.0	76.0

Fletcher's Creek Pools

	FC2	FC4	FC5	FC6	FC7	FC9
Area (m^2)	4.7	19.8	9.8	16.5	16.2	19.8
Top Width (m)	9.1	20.6	14.6	15.3	16.0	14.0
Mean Depth (m)	0.5	1.0	0.7	1.1	1.0	1.4
Max Depth (m)	0.8	2.2	1.4	2.2	2.1	2.1
Wetted Perimeter (m)	9.5	21.6	15.6	16.4	16.9	15.2
Hydraulic Radius (m)	0.5	0.9	0.6	1.0	1.0	1.3
Width-Depth Ratio	17.4	21.5	21.6	14.1	15.9	9.8