# 1200 King Road Property –Fluvial Geomorphology Characterization and Recommendations

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# Contents

# 1. Introduction

Parish Geomorphic Ltd. (PGL) has been retained by Metropolitan Consulting to undertake a fluvial geomorphology assessment in advance of proposed development of the 1200 King Road property located in Burlington, Ontario. The property contains three separate creeks; a small tributary of Grindstone Creek, Falcon Creek, and a tributary of Indian Creek. The Grindstone Creek tributary runs through an online pond located on the property, with a designed inlet channel. At the southern boundary of the study area the Indian Creek tributary ties into a section that has been designed to facilitate a CN Rail grade separation project at King Road. This will figure heavily into the assessment of the Indian Creek tributary for the 1200 King Road property. As part of the development, the construction of a portion of South Service Road has been proposed from King Road to the Eastbound Highway 403 onramp located along the north side of the Aldershot GO Station parking lot. This requires additional consideration as the road alignment will cross the three watercourses in the study area.

## 1.1 Study Area

The 1200 King Road property is located south of Highway 403 and north of the CN Rail line (**Figure 1.1**). It extends westward from King Road to the existing Aldershot GO station. The three creeks vary in size; Falcon Creek is the largest and most active system while the Indian Creek and Grindstone Creek tributaries are substantially smaller.

## 1.2 Work Plan

The purpose of the study is to complete a fluvial geomorphic assessment of the three creeks within the limits of the study area. In support of the study, the following tasks were undertaken:

- Background review of available materials (reports, mapping, aerial photography);
- Delineation of reach boundaries based on analysis of topographic mapping and available digital aerial photography;
- Characterization of existing geomorphic conditions through rapid assessment techniques;
- Detailed field work quantifying channel dimensions and characterizing boundary conditions along erosion-sensitive reaches, and;
- A channel design overview detailing inputs, constraints, and details on the cross-section, long profile, and planform design geometries.

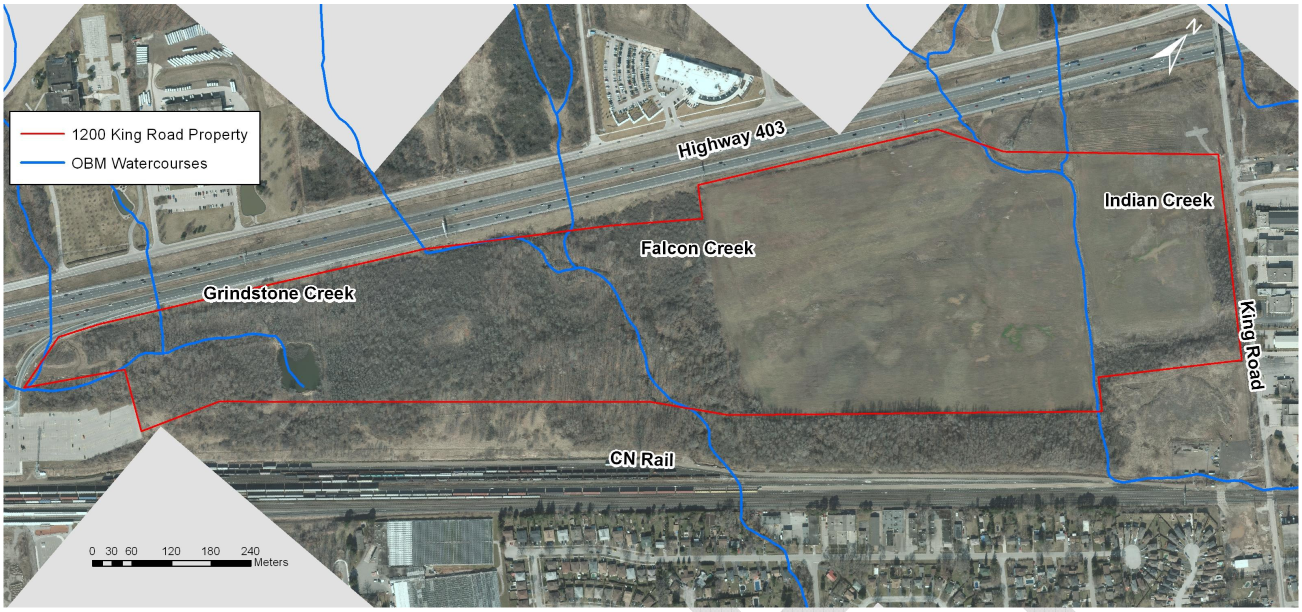


**Figure 1.1: 1200 King Road Study Area**

# 2. Background Review

A background review was undertaken in order to build on current understanding of the watershed and site characteristics that may influence the subject waterways. The review also aims to identify any disturbances to the watershed or waterways that may have, or may be, impacting channel dynamics.

## 2.1 Geology and Physiography

The 1200 King Road study area is situated in the physiographic region of the Iroquois Plain representative of the Glacial Lake Iroquois shoreline. This region is a relatively flat area that lies at the base of the Niagara Escarpment and consists of glacio-lacustrine sands, silts, and gravels (OGS, 2003). As watercourses in this area descend down the steep slope of the Escarpment their energy increases and leads to incision into the shale bedrock along the base of the Escarpment. Due to the proximity of the study area to the Escarpment the watercourses flow through exposed shale bedrock in the north and then transition into the sandy plain material in the south (**Figure 2.1**).

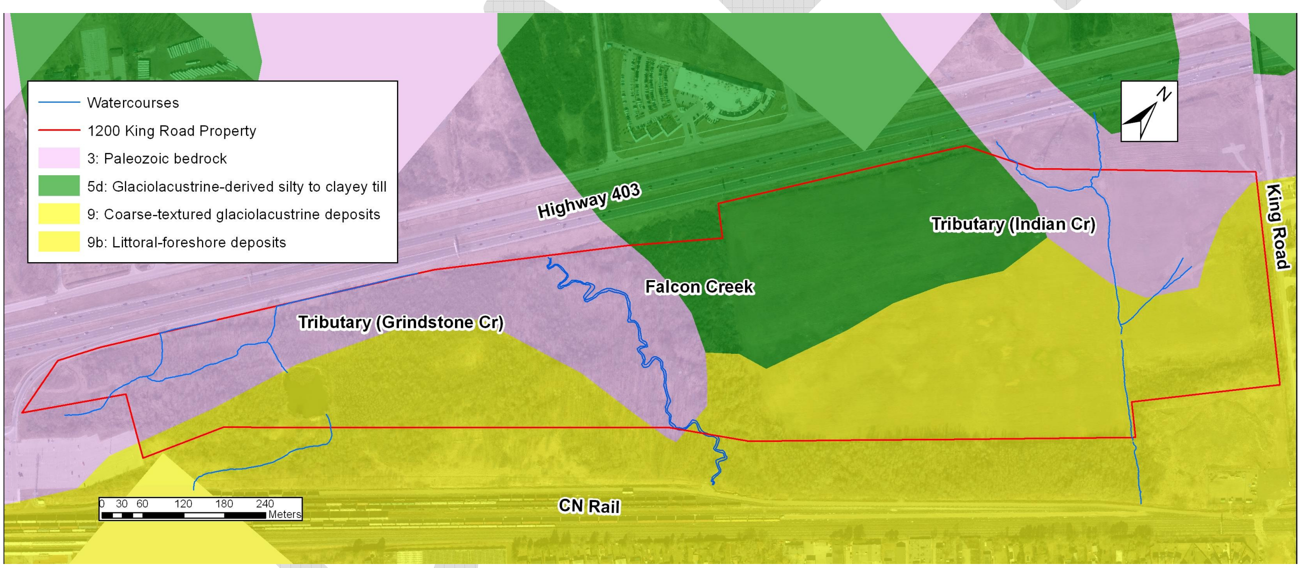


**Figure 2.1:** Surficial geology of study area (OGS, 2003)



## 2.2 Falcon Creek Erosion Assessment (PARISH Geomorphic Ltd., May 2012)

A detailed erosion assessment was completed by PARISH Geomorpic Ltd (PGL) in 2012 along Falcon Creek from on top of the Niagara Escarpment downstream to the outlet at Lake Ontario. A total of 9 reaches were delineated, with reach FC-6 corresponding to the portion of Falcon Creek that traverses 1200 King Rd. (**Figure 2.2**). This reach is bound by North Service Road at the upstream end and the CN Rail downstream, and flows through bedrock shale then the glacio-lacustrine sands, silts and gravels of the Glacial Lake Iroquois shoreline. The surrounding land use is primarily forest cover, from which channel

widening/slope failure has provided large woody debris (fallen trees). A historical analysis was completed by evaluating aerial photographs from 1954, 1978, and 2009, to identify historical watershed and channel change. Within reach FC-6, the area adjacent to Falcon Creek remained forested over the period of photo coverage. Because the creek is relatively small and lined with vegetation, it was difficult to delineate on the photographs. This concealment restricted the ability to accurately locate the channel banks and (or) centreline in order to perform more detailed measurement (e.g. erosion rates, changes in width, sinuosity, etc.)

Rapid field assessments (RGA and RSAT) were undertaken for the entire study area, and detailed reach surveys for reaches FC-2 and **FC-6** (congruent with the present study). These rapid assessments found that the channel is in a state of adjustment (unstable) with widening and planimetric adjustment being the primary forms of change (RGA Score = 0.41), and is of moderate stream health (RSAT Score = 24.5). Detailed fieldwork was also undertaken using a level survey, measuring cross-section dimensions, substrate materials, and the long profile. For this section, the energy gradient (bankfull slope) is 1.52%, with bankfull widths ranging from 5-6m, and depths from 0.67-0.78m. Valley wall contact resulted in bank heights being estimated as high as 5m in some locations. Substrate materials were primarily gravels with a median size of 2.77cm, and larger sizes in the large-cobble range.

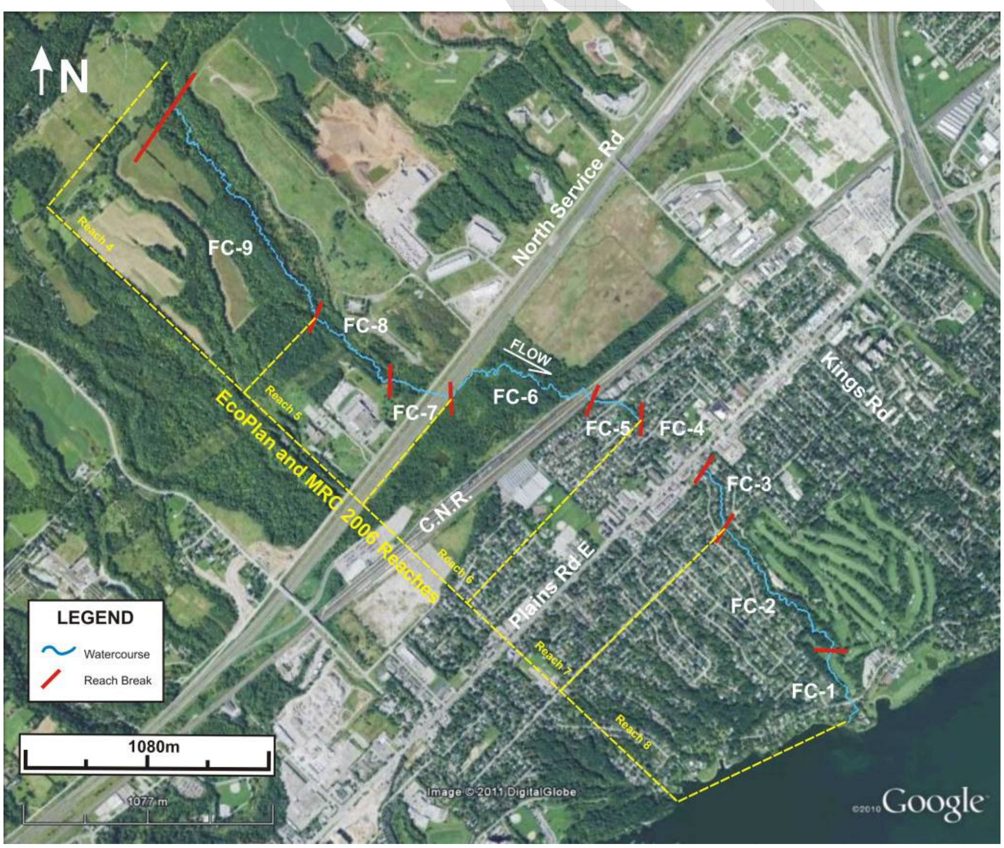


**Figure 2.2**: Falcon Creek reach delineation (PGL, May 2012).

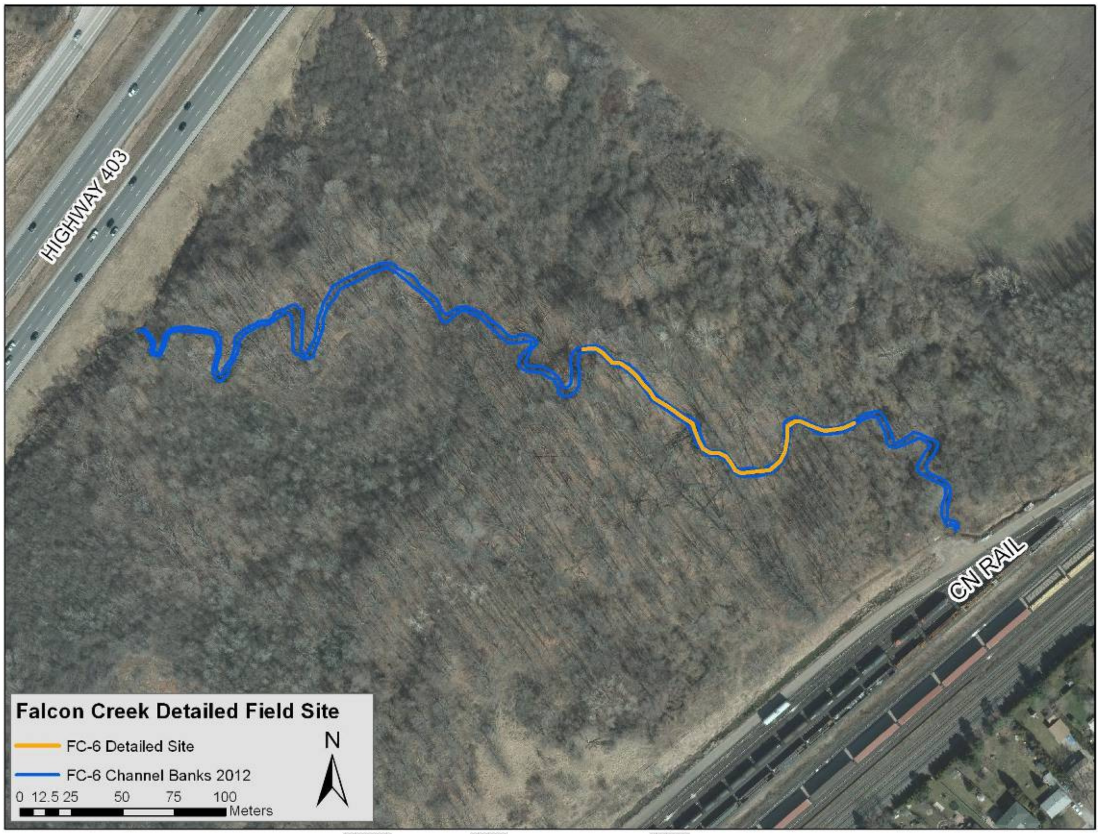


**Figure 2.3**: Falcon Creek RC-6 Detailed Site (PGL, May 2012).

## 2.3 Indian Creek Tributary Channel Design and Fluvial Geomorphologic Assessment (PARISH Geomorphic Ltd., June 2012)

A fluvial geomorphic assessment and channel design was completed by PARISH Geomorphic Ltd. for a tributary of Indian Creek just south of the 1200 King Road property. The design was completed to facilitate the transition of a CN Rail at-grade crossing to an elevated crossing at King Road. The grade separation involved excavation to create a tunnel for King Road beneath the existing CN Rail line. This required the removal of three culverts that conveyed flow of the tributary eastward across King Road. A bridge was proposed above the planned King Road tunnel to maintain conveyance of the tributary once the grade separation was completed. Additionally, a channel design was implemented up- and down- stream of the bridge to tie the channel into the new structure as well as enhance geomorphic and aquatic function.

The assessment revealed that the tributary was historically straightened for agricultural purposes and could be classified as in a state of transition (RGA Score=0.24). Channel adjustment was occurring through widening and aggradation as indicated by leaning trees, exposed tree roots, deposition in the

overbank zone, and accretion of fines on point bars. The channel was found to be in moderate stream health (RSAT Score=26.5) with poor riparian conditions due to the surrounding agricultural activities. Detailed fieldwork was also completed to determine the existing channel geometry, which could subsequently be used to ensure that calculated design dimensions were appropriate. Based on the 10 cross-sections completed in the study area the average bankfull width was 4.40m with a range of 3.40-6.12m. The average bankfull depth was 0.46m with a range of 0.38-0.52m.

The channel design was done as three segments; upstream of the grade separation, the creek bridge, and downstream of the bridge. This was done to accommodate significant changes in gradient which required different design strategies. A design discharge of 1.60m$^3$/s was based on hydraulics provided by AMEC (**Appendix B**) and was used to size the cross-sections (**Table 2.1**). Through hydraulic analysis and empirical meander belt width relations, the corridor width necessary for the channel design was determined to be 30m (top width) and 26m (bottom width). The upstream section was characterized by a gradient of 0.43% which allowed for the design to incorporate sinuousity and variability in the riffle-to-riffle spacing that was used. Three separate pool configurations were also designed for increased habitat diversity. As the design approached the creek bridge the cross section was designed wider (0.5m) to allow for fine sediments to settle and minimize accumulation on the bridge itself in order to maintain capacity. The fines would then be flushed out during flood events. For the creek bridge, it was proposed that two buried retaining walls fan out from the sides of the bridge inlet to ensure that the channel alignment at the inlet is maintained. On the surface of the bridge it was necessary to include a number of grade control structures to maintain a grade of 0.5% on the bridge as the structure would have no natural gradient. By creating some gradient on the surface of the bridge sediment transport would be maintained during low flow periods, again discouraging aggradation. The downstream section was the most complex to design due to the sediment starved conditions during low flow periods and the accommodation of a steep gradient (3.4%). A cascade-pool sequence was used with low sinuousity to accommodate the change in elevation while reducing flow speeds to allow for the safe passage of non-jumping species. The downstream section was anticipated to frequently be sediment starved when conditions were below the design discharge which would result in the channel using the banks as the primary sediment source. To mitigate this and ensure planform alignment is maintained bank protection throughout the downstream section was added to the design. This consisted of bioengineering along the pools where velocities are reduced and large stones keyed into the banks along the riffles where tractive forces are higher.

**Table 2.1: Typical riffle dimensions upstream and downstream of the creek bridge**

| Channel Characteristics | Upstream End | Downstream of Creek Bridge |
|---|---|---|
| Channel Slope (%) | 0.43 | 3.4 |
| Bankfull Width (m) | 3.5 | 4.0 |
| Average Depth (m) | 0.38 | 0.2 |
| Maximum Depth (m) | 0.45 | 0.25 |
| Width : Depth | 9.2 | 20.0 |
| Average Velocity (m/s) | 1.04 | 1.91 |
| Shear Stress ($N/m^2$) | 16.03 | 66.71 |

## 2.4 Historic Assessment

Aerial photographs from 1954, 1978, and 2013 were evaluated to identify historic land use and channel changes within the study area (**Figure 2.4 and 2.5**). There has been minimal land use change in the area over the period of photo coverage. In the 1954 photo, land use was primarily agricultural; in 1978 and 2013 some of the farming had been abandoned and replaced by deciduous scrub forest. Between 1954 and 1978, the area south of the C.N. Rail was converted into residential and commercial land use. Based on the vegetation, it appears that there has been little change in general planform alignment for the three watercourses over the period of record. It is clear that the Indian Creek tributary was straightened prior to the 1954 photo. Because the watercourses are relatively small and lined with vegetation, it was difficult to determine any small-scale changes in planform characteristics (e.g., erosion rates, changes in width, sinuousity).

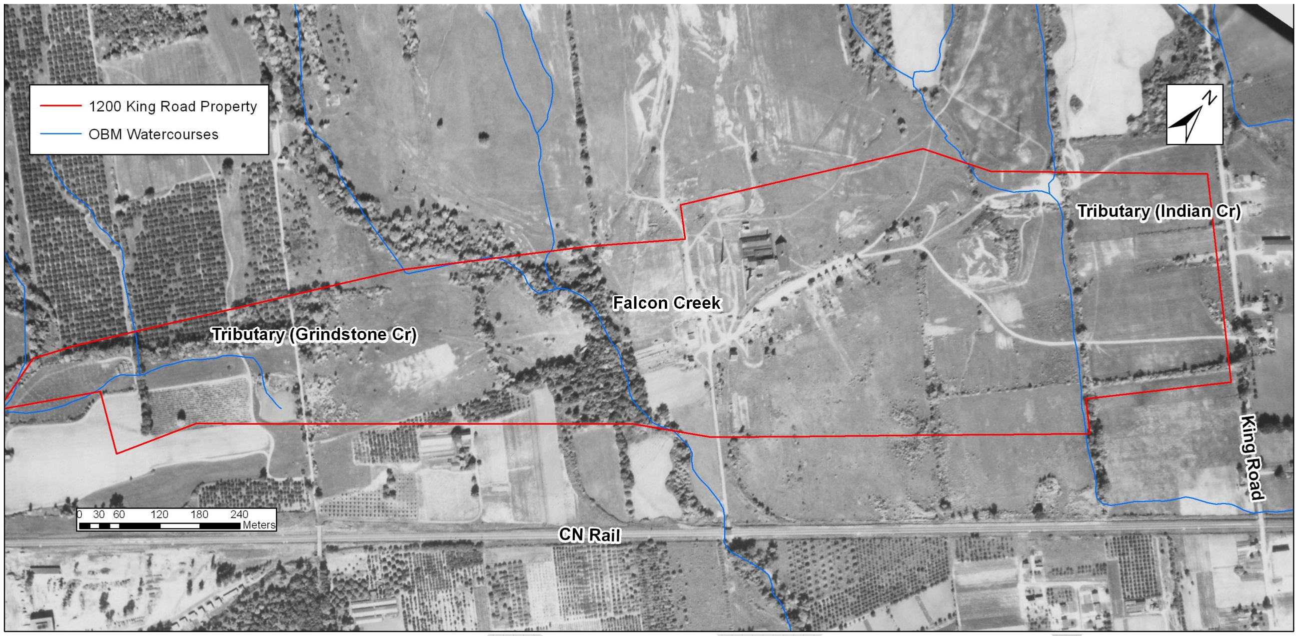


**Figure 2.4** 1954 aerial photograph of the study area.

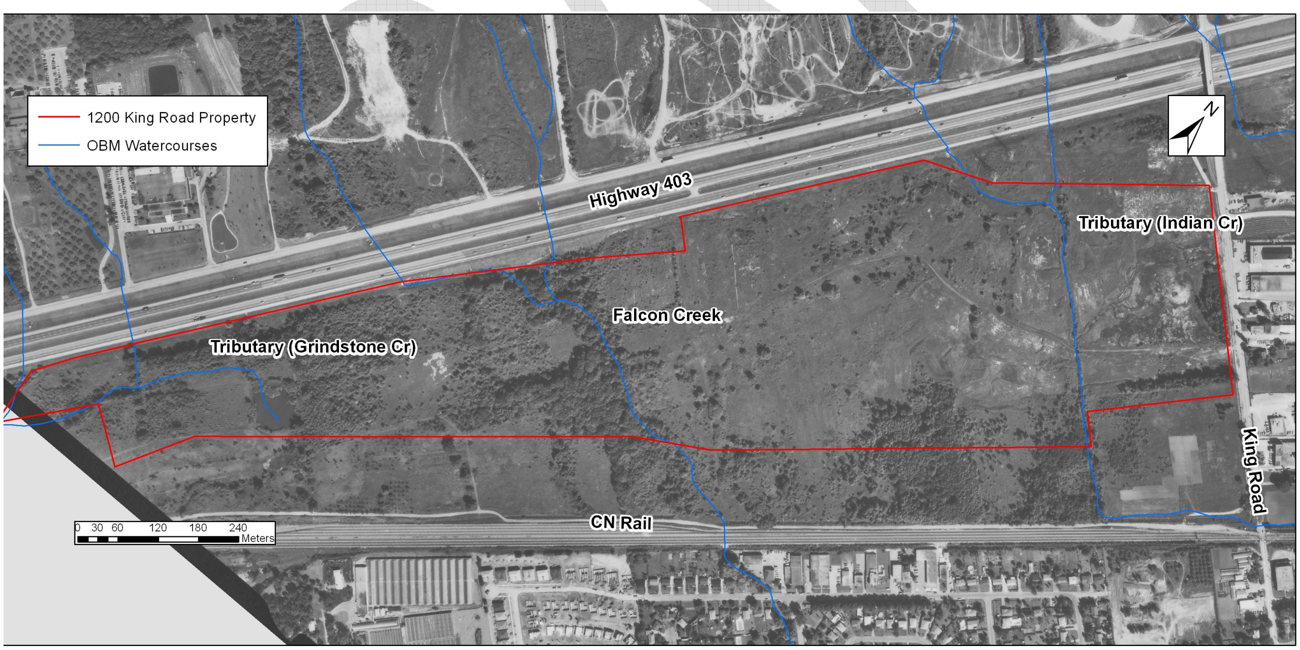


**Figure 2.5:** 1978 aerial photograph of the study area

# 3. Existing Conditions

Field reconnaissance was completed for the Grindstone Creek Tributary, Falcon Creek, and the Indian Creek Tributary by PARISH Geomorphic Ltd. This included an assessment of channel stability and health as well as the collection of detailed data through cross-sectional and longitudinal surveys. The field reconnaissance was scoped based on the data that was already available from the two previous studies. Two established reconnaissance techniques were applied to gather data on channel health and stability: the Rapid Geomorphic Assessment (RGA) and Rapid Stream Assessment Technique (RSAT).

## 3.1 Reach Delineation

Because channel materials, sediment inputs, valley types, and flow vary along a creek or stream, channels are often separated into segments, termed “reaches”. Reaches comprise stream segments of similar form and function, ranging from several hundred to several thousand meters in length. For this assessment, reach delineation incorporates sinuosity and gradient, local geology, valley confinement, human modification, and vegetative controls.

As discussed in the background review, the Falcon Creek Erosion Assessment refined previous reach delineations from the South Waterdown Subwatershed Study (EcoPlans and MRC, 2006). Based on a review of the surficial geology, and the valley channel character, further refinement of the Falcon Creek reaches was necessary for this study. Due to the transition from shale bedrock to glacio-lacustrine sands (**Section 2.1**), the valley changes from confined (with some semi-confined locations), and opens up into a wide floodplain. This allows for a corresponding change in meander configuration to a more regular form. Reach breaks have also been added at the upstream and downstream ends (**Figure 3.1**). Upstream there is a significant input from a tributary, and channel form is wider and more irregular downstream of this confluence. At the downstream end of the study area, the channel form becomes straight due to the alignment following the northern limit of the CN Rail yard.

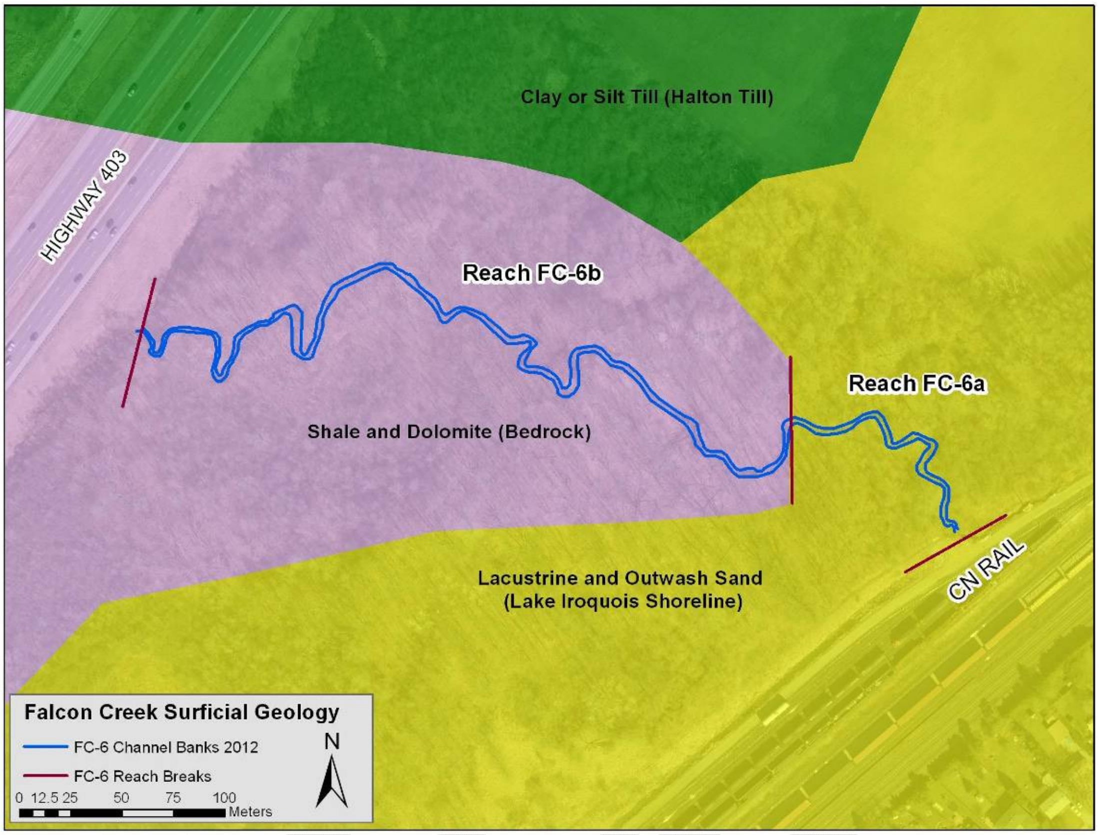

**Figure 3.1**: Surficial geology and reach delineation refinement for Falcon Creek.

The Grindstone Creek tributary flows onto the property from a culvert beneath Highway 403, north of the online pond. Before reaching the pond the flow splits, with one reach continuing westward towards the existing GO station (GC-T1) and the other becoming the inlet channel to the pond (GC-T2). The two reaches eventually converge again southwest of the GO Station and CN Rail line and continue to the main branch of Grindstone Creek. The third reach delineated was the outlet channel from the pond (GC-T3) (**Figure 3.2**). Three reaches were delineated for the Indian Creek tributary based on a confluence at the north end of the property (IC-T1 and IC-T2) and the tie-in for the designed channel near the southern boundary of the property (**Figure 3.2**).

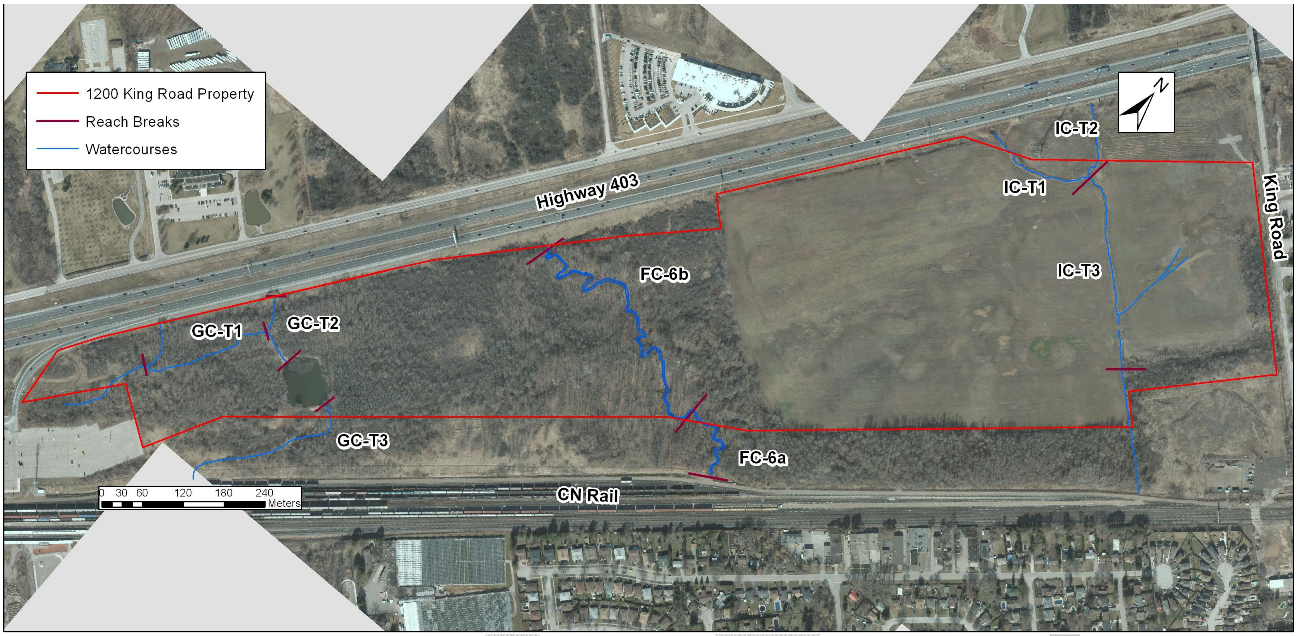


**Figure 3.2:** Reach break map for study area.



## 3.2 Rapid Assessment

Rapid assessments (RGA and RSAT) of the Grindstone Creek Tributary and the Indian Creek were completed in April 2014 while the Falcon Creek assessment was completed in December 2013. The assessments for the Indian Creek Tributary and Falcon Creek were updates to the previous assessments done in 2012 (Indian Creek Trib) and 2010 (Falcon Creek).

### 3.2.1 Rapid Geomorphic Assessment (RGA)

The RGA was designed by the Ontario Ministry of Environment (2003) to assess reaches in rural and urban channels. This qualitative technique documents indicators of channel instability. Observations are quantified using an index that identifies channel sensitivity based on the presence or absence of evidence of aggradation, degradation, channel widening, and planform adjustment. Overall the index produces values that indicate whether the channel is stable/ in regime (score $\leq$0.20), stressed/transitional (score 0.21-0.40), or adjusting (score $\geq$0.40) (**Table 3.1**)

**Table 3.1: RGA Classification**

| Factor Value | Classification | Interpretation |
|---|---|---|
| $\leq$0.20 | In Regime or Stable (Least Sensitive) | The channel morphology is within a range of variance for streams of similar hydrographic characteristics – evidence of instability is isolated or associated with normal river meander propagation processes |

| | | |
|---|---|---|
| 0.21-0.40 | Transitional or Stressed (Moderately Sensitive) | Channel morphology is within the range of variance for streams of similar hydrographic characteristics but the evidence of instability is frequent |
| ≥0.41 | In Adjustment (Most Sensitive) | Channel morphology is not within the range of variance and evidence of instability is wide spread |

### 3.2.2 Rapid Stream Assessment Technique (RSAT)

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

- Channel Stability
- Erosion and Deposition
- In-stream Habitat
- Water Quality
- Riparian Conditions
- Biological Indicators

Once a condition has been assigned a score, these scores are totaled to produce an overall rating that is based on a 50 point scoring system, divided into three classes:

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

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

### 3.2.3 Rapid Assessment Results

Rapid assessments were completed for three reaches of the Grindstone Creek tributary which takes a complicated flow path through the property. Reach GC-T2 begins where flow exits a culvert beneath the Highway 403 and continues downstream into the online pond. Channel dimensions were well-defined through this reach and characterized by low sinuousity. Dimensions ranged from 1.0-1.8m for bankfull width and 0.34-0.40m for bankfull depth. The channel was composed of soft, silt and clay material. A knickpoint was noted mid-reach (0.25m) which was resultant from tree roots crossing the bed of the channel. The reach was classified as In Regime with some evidence of degradation due to the knickpoint. Reach GC-T1 splits from Reach GC-T2 north of the pond and begins to flow westward. At the bifurcation, the channel was dry, with poorly defined dimensions; however a clear flow path was noted. The channel transitioned to undefined low bed relief through the middle of the reach. Channel form was not regained until the downstream end where the channel reached a confluence with another tributary. Beyond the confluence the channel form and geometry was well-defined. The reach was classified as In Regime as the channel had very little flow with which to modify its boundaries. Typical dimensions were 1.6-1.7m for bankfull width and 0.12-0.13m for bankfull depth. Reach GC-T3 begins as the southern outlet to the online pond. Flowing out of the pond the channel has a moderate gradient and is slightly entrenched. The channel then turns westward and gradient is reduced resulting in lower, less-defined banks. Throughout the reach, these transitions between steeper well-defined sections and low gradient sections persist. This resulted in flooding through the flatter sections, which was also due to the time of year the survey was completed (April). As the channel approaches the CN Rail yard, the channel is lined with rip-rap. Typical dimensions through this reach ranged from 1.32-1.60m for bankfull width and 0.20-0.34m for bankfull depth. Reach GC-T3 was classified as In Regime with some evidence of planimetric adjustment due to the transitions between well-defined and low bed relief form.

Reach FC-6b begins in the upstream at the culvert from Highway 403. The upstream section of this reach is characterized by highly sinuous tight meanders due to frequent valley wall contacts. The valley wall contacts continue throughout the length of the reach. Steep elevated banks were also common. Scour was prominent leading to leaning trees and exposed roots along the banks. Exposed clay was noted sporadically through the bed and banks. Channel dimensions ranged from 2.0-3.5m for bankfull width and 0.50-0.60m for bankfull depth. The reach was classified as Transitional with the widening and aggradation as the primary forms of adjustment. Reach FC-6a had a few valley wall contacts near the upstream end of the reach but was overall less confined than Reach FC-6b. Fallen trees and woody debris jams were indicative of widening. Scour was seen frequently throughout the reach, particularly in the bends. A number of small tributaries (3) were noted. The channel dimensions ranged from 4.5-5.5m for bankfull width and from 0.8-1.1m for bankfull depth. The channel was classified as Transitional with degradation and widening as the primary forms of adjustment. Degradation was indicated by elevated tree roots and incision into bedrock, while widening was indicated by steep bank angles, exposed tree roots, and extensive scour. These results were comparable to those from 2010 which indicated that the degree of adjustment was slightly more severe. When reaches FC-6a and FC-6b were considered as one in 2010

there would have been the potential to note more indicators of instability over the longer length which would have resulted in the higher score.

Reach IC-T3 flowed through two abandoned agricultural fields with very little geomorphic form. The channel showed some meander form immediately downstream of the confluence at the upstream end for approximately 30m, while the remainder of the reach was straightened. Cattail growth and tall herbs/grasses populated the banks and some sections of the channel itself. A small gully joined the channel mid-reach with minimal flow. The channel flowed through a culvert under an old farm lane crossing near the downstream end of the reach. Slumping was noted upstream of the culvert and pooling was noted downstream. Channel dimensions ranged from 3.20-4.00m for bankfull width and from 0.38-0.50m for bankfull depth. The reach was classified as In Regime with aggradation as the primary adjustment process. This differs from the 2012 result which classified the channel as Transitional. This can likely be attributed to the subjective nature of the assessment as it was clear from the more recent assessment that there was very little adjustment occurring.

**Table 3.2 – Summary of RGA results**

| Reach | Factor Value | | | | Stability Index | Condition |
|---|---|---|---|---|---|---|
| | Aggradation | Degradation | Widening | Planimetric Adjustment | | |
| **GC-T1** | 0.29 | 0.14 | 0.13 | 0.17 | 0.18 | In Regime |
| **GC-T2** | 0.29 | 0.33 | 0.00 | 0.00 | 0.15 | In Regime |
| **GC-T3** | 0.00 | 0.17 | 0.13 | 0.17 | 0.11 | In Regime |
| **FC-6a** | 0.11 | 0.29 | 0.63 | 0.00 | 0.26 | Transitional |
| **FC-6b** | 0.43 | 0.17 | 0.50 | 0.29 | 0.35 | Transitional |
| **FC-6 (2010)** | 0.14 | 0.33 | 0.75 | 0.43 | 0.41 | In Adjustment |
| **IC-T3** | 0.43 | 0.17 | 0.00 | 0.00 | 0.15 | In Regime |
| **Indian Cr. Trib (2012)** | 0.33 | 0 | 0.5 | 0.14 | 0.24 | Transitional/Stressed |

**Table 3.3 - Summary of RSAT results**

| Reach | Factor Value | | | | | | Overall Score | Condition |
|---|---|---|---|---|---|---|---|---|
| | Channel stability | Scour / deposition | Instream Habitat | Water Quality | Riparian Condition | Biological Indicators | | |
| Max. Score | 11 | 8 | 8 | 8 | 7 | 8 | 50 | |
| **GC-T1** | 5 | 4.5 | 2 | 6 | 5.5 | 2 | 25 | Moderate |
| **GC-T2** | 7 | 5 | 4 | 5 | 5 | 4 | 30 | Moderate |
| **GC-T3** | 5 | 4 | 4 | 4 | 5.5 | 4.5 | 27 | Moderate |
| **FC-6B** | 6 | 5 | 5 | 5 | 6 | 6 | 33 | Moderate |
| **FC-6C** | 5 | 4.5 | 4.5 | 4 | 3.5 | 4 | 25.5 | Moderate |
| **FC-6 (2010)** | 4 | 3 | 3 | 5 | 5.5 | 4 | 24.5 | Moderate |
| **IC-T3** | 5 | 4 | 3.5 | 5 | 2.5 | 3 | 23 | Moderate |
| **Indian Cr. Trib (2012)** | 6 | 4.5 | 5 | 3.5 | 4 | 3.5 | 26.5 | Moderate |



## 3.3 Detailed Field Data Collection

To supplement the rapid assessment data collection, a scoped detailed assessment was completed. This consisted of:

- 3 cross-sections on the Grindstone Creek tributary
- 4 cross-sections on the Indian Creek tributary
- 6 cross-sections and a longitudinal profile on Falcon Creek

The results of the cross-section measurements are shown below (**Table 3.4 – 3.6**). The cross-sections for the Grindstone Creek tributary were measured upstream of the pond; one on the inlet channel, and two on the westward flowing reach (GC-T1). The first cross-section (XS-1) was done in the middle of the reach while XS-2 was done near the confluence at the downstream end where the channel was more defined. The dimensions show that reach GC-T1 has smaller cross-sectional area than GC-T2 indicating that the majority of the flow coming from beneath Highway 403 is flowing into the online pond. The cross-sections measured for GC-T1 both have a high width:depth ratio which indicates that the cross-section is much wider than it is deep. This is a reflection of the poorly-defined geometry detailed in the rapid assessments.

**Table 3.4:** Cross-section dimensions for the Grindstone Creek tributary

| ***Cross-section Name:*** | ***GC-T1 (XS-1)*** | ***GC-T1 (XS-2)*** | ***GC-T2*** |
|---|---|---|---|
| Bankfull Width (m) | 1.77 | 1.48 | 1.77 |
| Average Bankfull Depth (m) | 0.06 | 0.10 | 0.13 |
| Maximum Bankfull Depth (m) | 0.10 | 0.19 | 0.29 |
| Bankfull Width:Depth | 27.47 | 14.46 | 13.22 |
| Cross-sectional Area ($m^2$) | 0.12 | 0.15 | 0.24 |

For the Indian Creek tributary, one cross-section was located on each of the upstream branches (IC-T1 and IC-T2) and two cross-sections were done on the main branch (IC-T3). One cross-section was located immediately downstream of the confluence (XS-1) while the second cross-section was located further downstream near the old farm crossing. The measurements indicate that the eastern tributary branch (IC-T2) has a larger cross-sectional area ($0.56m^2$) than the western tributary (IC-T1=$0.26m^2$). Therefore the eastern branch contributes the majority of the flow to the main tributary (IC-T3).

The results for the main branch of the tributary (IC-T3) are slightly smaller than the range of dimensions measured in 2005 for the Indian Creek Tributary Channel Design (**Section 2.3**). In 2005, the minimum bankfull width was 3.40m and the minimum bankfull depth was 0.38m, as compared to bankfull widths of 2.50m and 3.67m, and bankfull depths of 0.35m and 0.33m measured in 2014. It is expected that the 2014 dimensions would be slightly smaller because the measurements were taken further upstream. The 2014 cross-sections were done within the 1200 King Road property upstream of the old farm crossing, while the 2005 measurements were done downstream along the section of channel that runs parallel to the CN Rail line.

**Table 3.5:** Cross-section dimensions for the Indian Creek tributary

| ***Cross-section Name:*** | ***IC-T1*** | ***IC-T2*** | ***IC-T3 (XS-1)*** | ***IC-T3 (XS-2)*** |
|---|---|---|---|---|
| Bankfull Width (m) | 1.15 | 2.30 | 2.50 | 3.67 |
| Average Bankfull Depth (m) | 0.22 | 0.24 | 0.35 | 0.33 |
| Maximum Bankfull Depth (m) | 0.40 | 0.44 | 0.63 | 0.56 |
| Bankfull Width:Depth | 5.16 | 9.43 | 7.17 | 11.29 |
| Cross-sectional Area ($m^2$) | 0.26 | 0.56 | 0.87 | 1.20 |

The detailed assessment for Falcon Creek included six cross-sections and a longitudinal profile to provide additional detail as compared to the other watercourses. This is because it is the largest watercourse on the property and appears to be natural with minimal alteration. The measurement of a longitudinal profile allowed for the calculation of bankfull hydraulics (**Table 3.7**). For cross-section dimensions, bankfull

width had a range of 5.25-8.30m with an average of 6.47m; bankfull depth had a range of 0.67-0.91m with an average of 0.77m. These dimensions are comparable to those measured in 2010 for the Falcon Creek Erosion Assessment (**Section 2.2**); the average bankfull width was 5.69m and the average bankfull depth was 0.75m. Based on the 2014 measurements, bankfull discharge ranged from 8.96-16.52$m^3$/s with an average of 11.66$m^3$/s. The resultant velocities ranged from 1.92-2.67m/s with an average of 2.29m/s. These results fall in a similar range to those calculated in 2010 in which the average bankfull discharge was 13.35$m^3$/s and the average bankfull velocity was 2.67m/s.



**Table 3.6:** Cross-section dimensions for Falcon Creek

| ***Cross-section Name:*** | ***XS-1*** | ***XS-2*** | ***XS-3*** | ***XS-4*** | ***XS-5*** | ***XS-6*** | ***Average*** |
|---|---|---|---|---|---|---|---|
| Bankfull Width (m) | 6.00 | 5.50 | 8.30 | 8.00 | 5.75 | 5.25 | **6.47** |
| Average Bankfull Depth (m) | 0.67 | 0.70 | 0.74 | 0.91 | 0.90 | 0.73 | **0.77** |
| Maximum Bankfull Depth (m) | 1.13 | 0.95 | 1.02 | 1.59 | 1.20 | 1.16 | **1.17** |
| Bankfull Width:Depth | 8.97 | 7.88 | 11.21 | 8.79 | 6.42 | 7.24 | **8.42** |
| Cross-sectional Area ($m^2$) | 3.78 | 3.75 | 4.47 | 6.57 | 5.28 | 4.10 | **4.66** |

**Table 3.7:** Bankfull hydraulics for Falcon Creek

| ***Cross-section Name:*** | ***XS-1*** | ***XS-2*** | ***XS-3*** | ***XS-4*** | ***XS-5*** | ***XS-6*** | ***Average*** |
|---|---|---|---|---|---|---|---|
| Bankfull Discharge ($m^3$/s) | 8.96 | 9.75 | 11.87 | 10.69 | 16.52 | 12.19 | **11.66** |
| Average Bankfull Velocity (m/s) | 1.92 | 2.40 | 2.29 | 2.16 | 2.67 | 2.33 | **2.29** |
| Maximum Bankfull Velocity (m/s) | 3.09 | 3.12 | 3.24 | 3.76 | 3.55 | 3.56 | **3.38** |
| Average Shear Velocity [u*] (m/s) | 0.27 | 0.28 | 0.25 | 0.27 | 0.31 | 0.29 | **0.28** |
| Stream Power (W/m) | 1142.92 | 1243.43 | 1513.20 | 1363.92 | 2106.71 | 1554.25 | **1487.41** |
| Stream Power per unit Width (W/$m^2$) | 190.49 | 226.08 | 182.31 | 203.27 | 366.70 | 296.05 | **244.15** |
| Average Shear Stress (N/$m^2$) | 70.42 | 76.05 | 60.39 | 71.48 | 97.08 | 85.70 | **76.85** |
| Maximum Shear Stress (N/$m^2$) | 137.98 | 118.85 | 126.63 | 147.80 | 144.10 | 145.35 | **136.78** |

## 3.4 Meander Belt Width Delineation

Streams and rivers are dynamic features that change their configuration and position within a floodplain by means of meander evolution, development, and migration processes. When meanders change shape and position, the associated erosion and depositional processes that occur can cause loss or damage to private property and infrastructure. For this reason, when development or other activities are proposed

near a watercourse, it is desirable to designate a corridor that is projected to contain all of the natural meander and migration tendencies of the channel. Outside of this corridor, it is assumed that private property and structures will be safe from the erosion potential of the watercourse. The space that a meandering watercourse occupies on its floodplain, within which all associated natural channel processes occur, is commonly referred to as the meander belt.

In order to establish an erosion hazard corridor, a process-based methodology for determining meander belt widths for watercourses is followed. This methodology is provided within a detailed document which outlines Belt Width Delineation Procedures for confined and unconfined systems based on background information, historic data (including aerial photography), degree of valley confinement and channel planform (Parish Geomorphic Ltd., 2004). A meander belt is typically identified by drawing lines parallel to the governing outermost meanders of the existing channel planform and following the meander axis.

This method was used for the two Falcon Creek reaches which maintain a natural, well-developed planform. The preliminary meander belt width was delineated for each reach (18m for FC-6a, and 33m for FC-6b), and then a factor of safety was determined to create a final corridor. Based on the rapid assessments, the channel was identified as being in adjustment (2010) and in transition (2013). This resulted in a factor of safety of 30% of the preliminary MBW being added (15% to either side). The resultant final MBW corridor widths were 23.4m for FC-6aa and 42.9m for FC-6b.

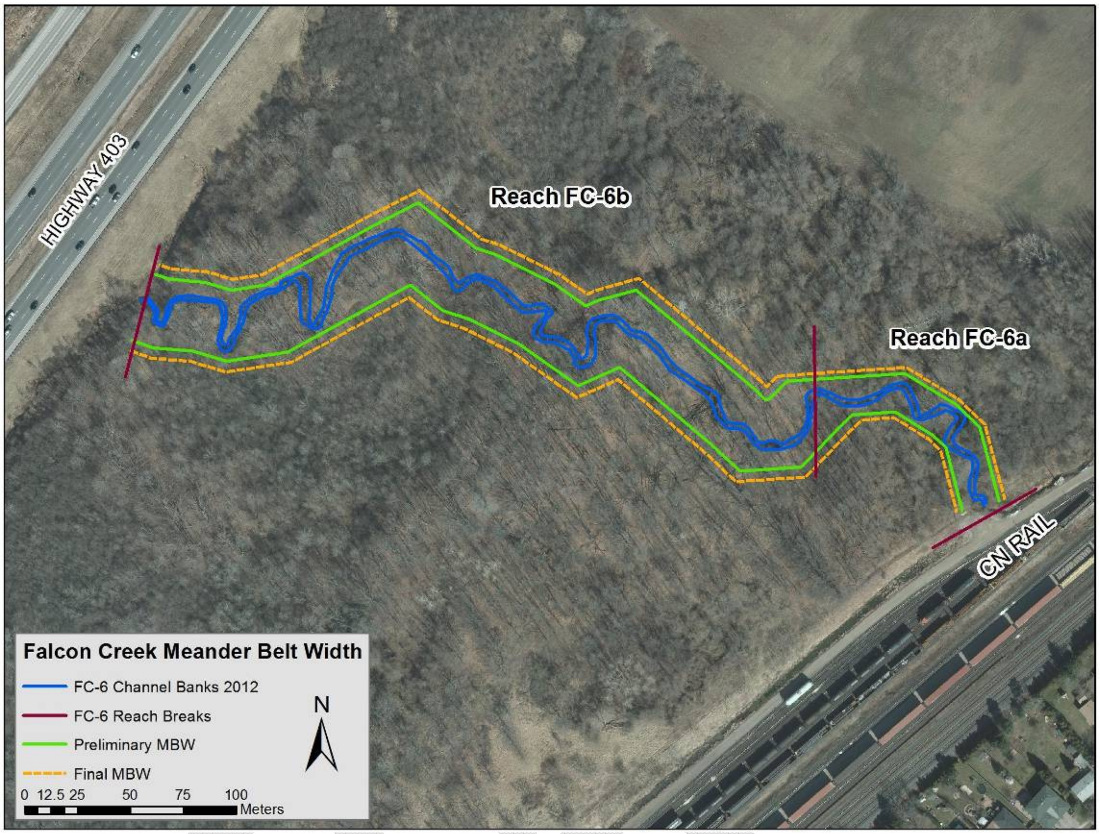


**Figure 3.3**: Meander Belt Widths for Reaches FC-6a and FC-6b.

It was not feasible or appropriate to apply the traditional methodology for meander belt width delineation to the Grindstone Creek and Indian Creek tributaries due to historic alteration and straightening. There was also difficulty in accurately delineating the planform alignments due to the small size of the channels and dense vegetation. In the event that a watercourse has been altered and/or necessary data is insufficient, a meander belt width can be derived by means of an empirical analysis based on channel parameters (width, depth, cross-sectional area). The following equations (**Table 3.4**) provide an estimate of meander belt width dimensions according to bankfull channel dimensions. These relations are based on measurements of real watercourses, however; the transferability to watercourses that are situated within southern Ontario is limited due to differences in hydrologic regime, drainage area, and general controlling factors. Reviewed collectively, they do provide a data set from which to corroborate results attained through use of the standard belt width delineation procedure and help to ensure that results are conservative.

**Table 3.4:** Empirical formulas for estimating meander belt width dimensions

| Meander Belt Empirical Analysis | | | |
|---|---|---|---|
| **Source** | **Equation** | | **Meander Belt Width (m)** |
| Williams (1986) – channel area (m$^2$) | $18Ac^{0.65}$ | = | 9.92 |
| Williams (1986) – width (m) | $4.3W^{1.12}$ | = | 6.57 |
| Ward (2002) - width (ft) - no factor of safety | $4.8W^{1.08}$ | = | 7.94 |
| Lorenz et al. (1985) - width (m) | $7.53W^{1.01}$ | = | 11.01 |
| AVERAGE | | = | 8.89 |
| STANDARD DEVIATION | | = | 2.00 |

Bankfull channel dimensions measured during field reconnaissance were used as input parameters for the empirical analysis and are presented in **Table 3.5**. Due to the small channel dimensions, the belt widths produced by the different equations were relatively similar. The calculated average was selected as the preliminary meander belt width. A factor of safety of 10% of the preliminary belt width was added to both sides. The meander belt width delineation for reach IC-T3 was done as part of the Indian Creek Tributary Design study (PGL, 2012). A memo discussing the methods used is appended to this report (**Appendix B**). The dimensions used for the previous analysis were checked with those collected for the current study to ensure the meander belt width remained appropriate. The meander belt widths are shown below (**Figure 3.4 and 3.5**).

**Table 3.5:** Results of empirical meander belt width analysis

| Reach | Preliminary MBW | Final MBW |
|---|---|---|
| GC-T1 | 8 | 9.6 |
| GC-T2 | 10 | 12 |
| GC-T3 | 9 | 10.8 |
| IC-T1 | 8 | 9.6 |
| IC-T2 | 13 | 15.6 |
| IC-T3* | 23 | 28 |

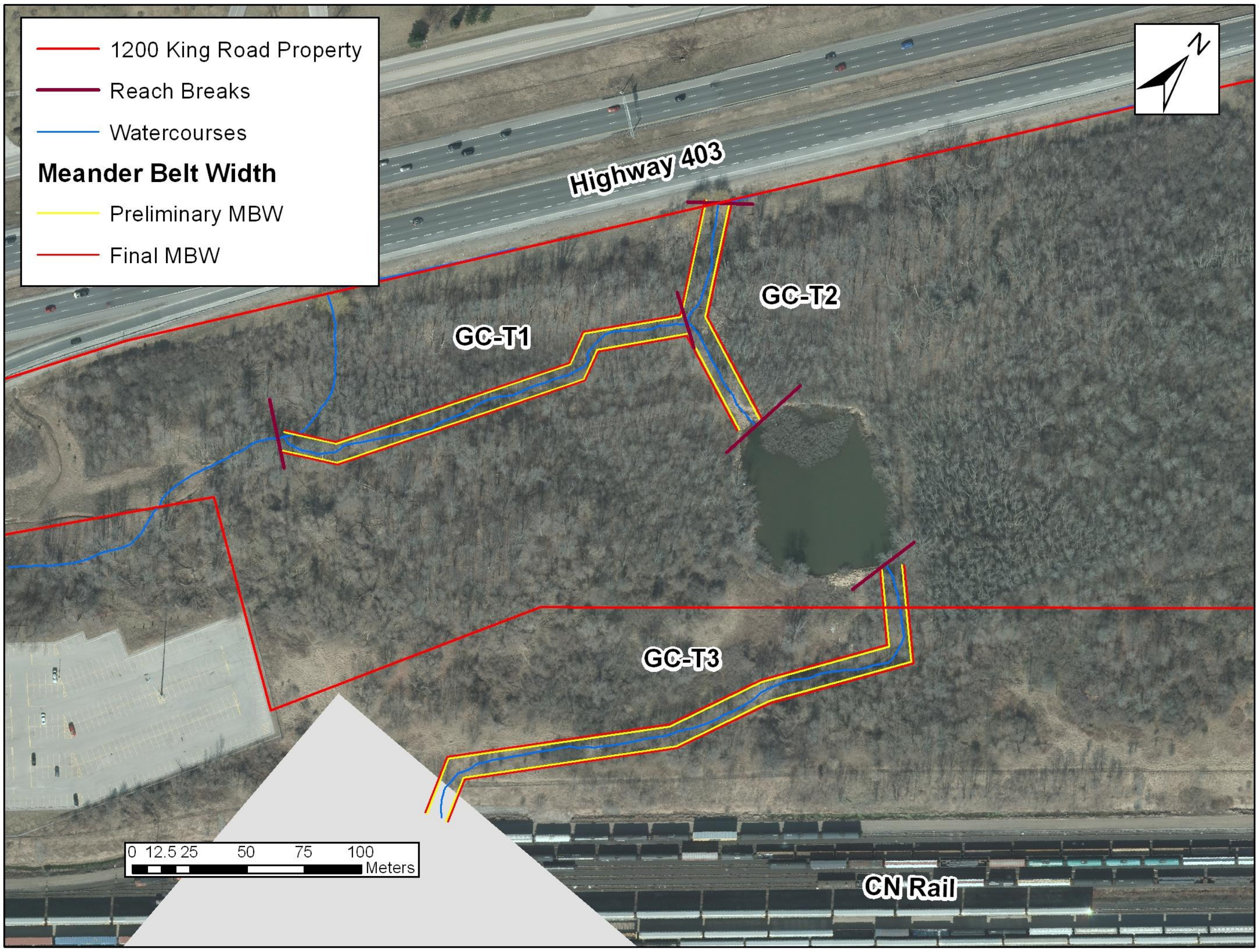


**Figure 3.4:** Meander belt widths for the Grindstone Creek tributary

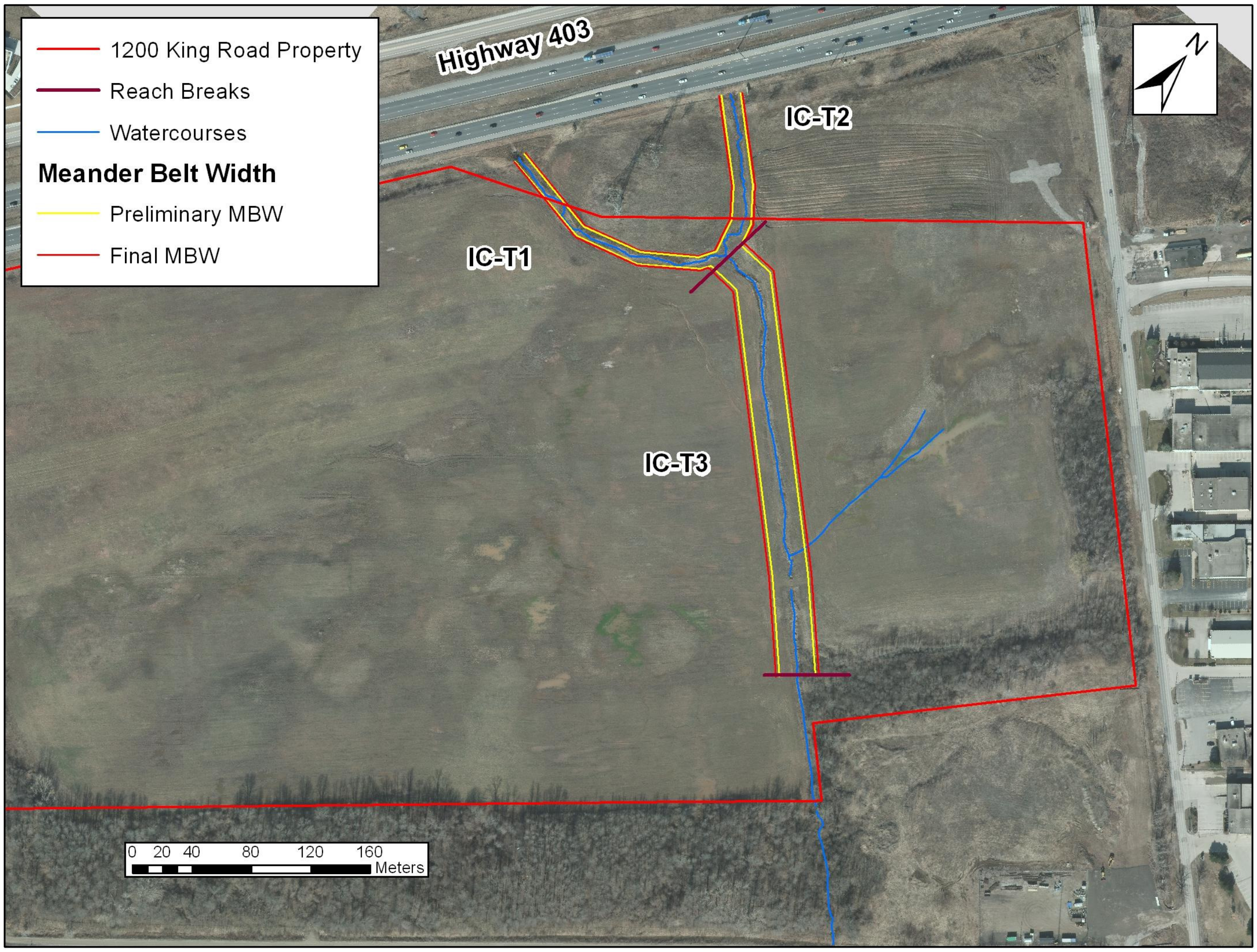


**Figure 3.5:** Meander belt widths for the Indian Creek tributary

# 4. Recommendations

Based on the existing conditions assessment and proposed development plan (**Figure 4.1**) for the property recommendations for each watercourse have been prepared and will be discussed in this section. The recommendations relate primarily to the proposed road alignment which will cross all three watercourses. Future development is anticipated in the area surrounding Falcon Creek and the Grindstone creek tributaries but is not included as part of this development phase. The proposed development is mainly focused around the Indian Creek tributary.

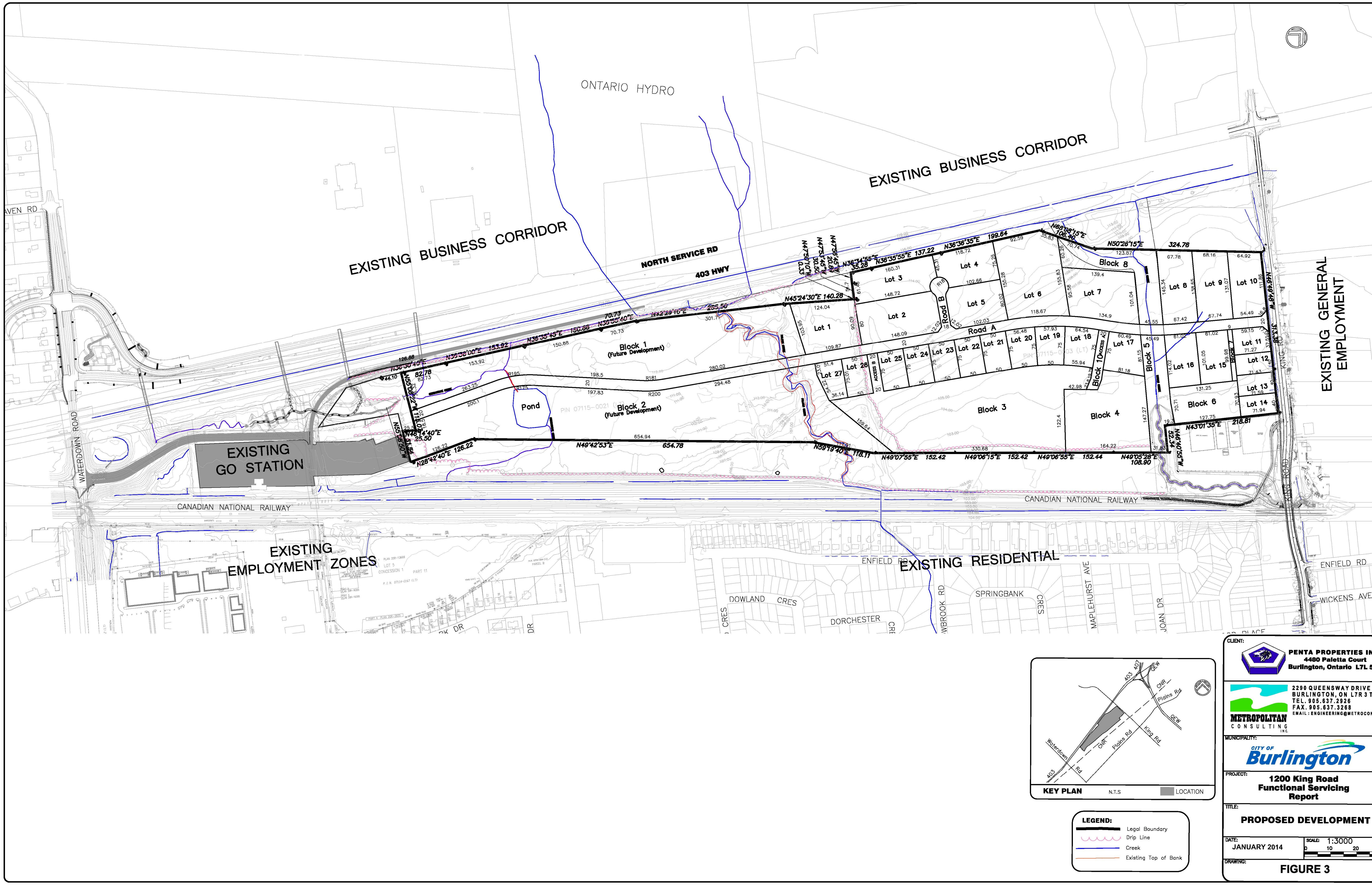


**Figure 4.1:** 1200 King Road proposed development plan (provided by Metropolitan Consulting)

## 4.1 Grindstone Creek Tributary

The proposed road alignment will cross the Grindstone Creek tributary in reach GC-T2, the pond inlet channel. Based on the size of the channel and the lack of a natural planform alignment no formal crossing assessment is required. It is recommended that the crossing size accommodate additional width beyond the bankfull width to maintain channel banks within the structure. A minimum size of approximately 5m is recommended as this would accommodate three times the measured bankfull (1.70m). While the channel is low sinuousity and minimal migration is anticipated providing the additional width will ensure that channel form is maintained through the structure.

## 4.2 Falcon Creek

Falcon Creek is the largest, most active stream in the study area with a well-defined valley, therefore an assessment to determine the preferred location and recommended structure size was required. This assessment was completed previously to support the selection of the proposed road alignment. A memo discussing the assessment is appended to this report (**Appendix C**). The crossing assessment determined that based on the bankfull width and meander amplitude, the crossing span should be 17m. This span accounts for the channel widening and the possibility that an upstream meander may migrate towards the crossing. A slight skew was also recommended to ensure that the crossing was properly aligned with the channel planform.

## 4.3 Indian Creek Tributary

It is understood that as part of the development of the 1200 King Road property a channel design will be implemented for the Indian Creek tributary. The channel design will improve channel form and function by adding sinuousity to the planform and creating a more natural cross-sectional shape. The design will be based on those completed for the 2012 Indian Creek Tributary Design for the King Road CN grade separation. When the original designs were completed a preliminary conceptual design was also completed for the 1200 King Road property (**Figure 4.2**). This design extended the design dimensions and parameters calculated for the section upstream of the creek bridge further upstream. The design was not specific to the 1200 King Road property. The 2014 measured cross-sections were used to verify the appropriateness of the original 2012 channel design for the property. These sections were measured upstream of the confluence found mid-reach with an eastern tributary. Because there is not a substantial difference in cross-sectional dimensions between the 2014 sections and those measured downstream of the property it can be assumed that this confluence does not denote a significant change in channel hydraulics. The original design is therefore appropriate for reach IC-T3. Cross-sectional dimensions for the preliminary design would then be 3.5m for average bankfull width and 0.38m for average bankfull depth. This preliminary design is not suitable for to the two upstream branches IC-T1 and IC-T2 because channel dimensions and hydraulics would be entirely different. At a detailed design stage it will be necessary to determine appropriate dimensions for these reaches to ensure the channel is not

overdesigned as the two reaches carry less flow than the combined reach downstream. Within the preliminary design, the crossing span is shown to be 9m. Based on a channel design width of 3.5m this would be inadequate. The crossing should be a minimum of 11.0m to accommodate three times the new bankfull width. This should not cause any issue as the corridor width of 30.0m is large enough to incorporate a wider crossing structure.

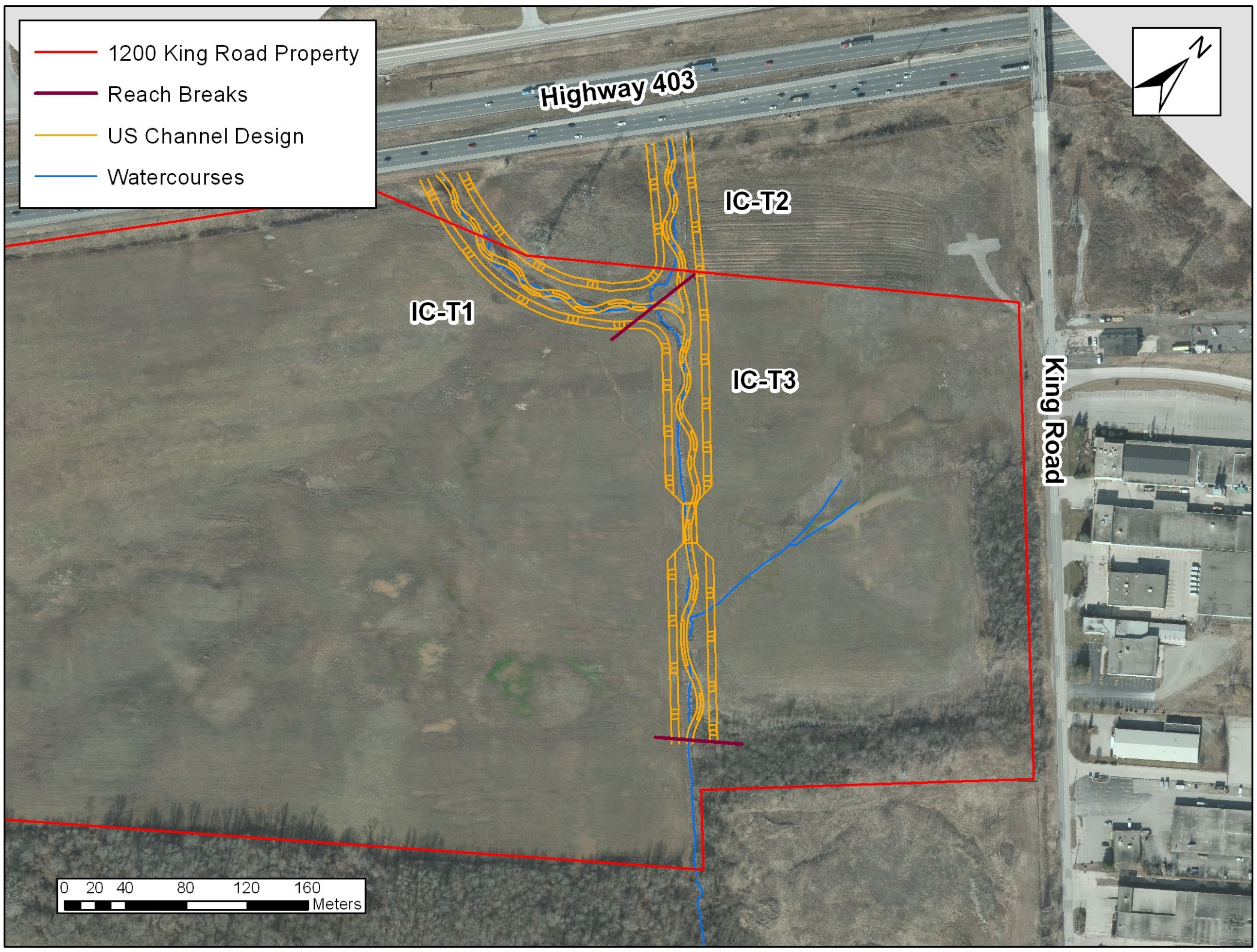


**Figure 4.2:** Preliminary channel design for Indian Creek tributary (as done in 2012)

# 5. Summary

A fluvial geomorphic assessment was undertaken for the 1200 King Road property in advance of proposed development to characterize the existing conditions and provide recommendations. The study focused on three separate watercourses; a tributary of Grindstone creek, Falcon Creek, and a tributary of Indian Creek. Due to extensive background information from two previous studies (PGL, May 2012 & PGL, June 2012) field data collection was scoped to avoid unnecessary duplication and focused on verification of previous results. The field data and desktop assessments indicated that the Grindstone Creek tributary was a small ill-defined channel which split flow between a reach flowing westward off the property and a reach that flowed into an online pond. A minimum crossing span of 5m was recommended for the Grindstone Creek tributary based on the bankfull width.

Falcon Creek was the most substantial watercourse within the property maintaining a well-developed planform and channel dimensions with what appears to be no historic alterations. It was found to be In Transition based on the 2014 rapid assessments with widening and as the primary form of adjustment. Due to the active nature of the channel a detailed crossing assessment was required that accounted for channel dimensions, potential migration, and current planform alignment. Based on the amplitude of an upstream meander and the existing bankfull width a span of 17m was recommended. A slight skew was also recommended to properly align the crossing with the channel planform to reduce the potential for future erosion.

The Indian Creek tributary was historically straightened prior to 1954 for agricultural purposes based on historic aerial photos. As a result of this the channel was degraded, with a U-shaped cross-section, no sinuousity, and no defined bed structure. To improve channel form and function it is proposed to extend the previous channel design (PGL, 2012) upstream through the property to the confluence of IC-T1 and IC-T2. Based on updated field measurements of channel geometry it was determined that the previous design remains applicable to IC-T3 as it exists currently. However, the original crossing span (9m) should be increased to a minimum of 11m to accommodate three times the designed bankfull width (3.5m). The 2014 measurements indicated that upstream of IC-T3 the flow is split between IC-T1 and IC-T2. The 2012 design is not suitable for these two reaches which are smaller than the main branch of the tributary. During detailed design, it will be necessary to develop new design dimensions for these two reaches which are more appropriate for the existing hydraulics to ensure that they are not overdesigned.

# 6. References


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# Appendix A: Field Photos

**Photo 1**: GC-T1 lack of channel definition.

**Photo 2**: GC-T1 area where channel is defined.

**Photo 3**: Cross-section at GC-T2.

**Photo 4**: Typical conditions for reach GC-T2.

**Photo 5:** Channel outletting from online pond GC-T3.

**Photo 6:** Downstream in GC-T3 channel gradient reduced.

**Photo 7:** GC-T3 Channel rip-rap lined approaching CN Rail yard.

**Photo 8:** IC-T3 main branch of Indian Creek tributary, straightened channel flowing through abandoned agricultural fields

**Photo 9:** IC-T3 further downstream approaching old farm lane crossing.

**Photo 10:** IC-T2 Eastern branch of tributary to Indian Creek, measured cross section

**Photo 11:** IC-T1 Western branch of tributary to Indian Creek, measured cross section.

**Photo 12:** FC-6A channel bend along valley wall contact

**Photo 13:** FC-6A erosion and undercutting along bank.

**Photo 14:** FC-6A woody debris in channel and erosion along banks.

**Photo 15:** FC-6A channel at downstream end of reach approaching CN Rail yard

**Photo 16:** FC-6A typical channel conditions

**Photo 17:** FC-6B box culvert where flow originates from beneath Highway 403

**Photo 18:** FC-6B erosion along bank

**Photo 19:** FC-6B confinement by valley wall contact.

**Photo 20:** FC-6B tight meander bend illustrating high sinuousity

**Photo 21:** FC-6B active erosion and channel adjustment

# Appendix B: Meander Belt Width Memo

Memorandum

| | | | |
|---|---|---|---|
| **TO:** | Ron Scheckenberger – AMEC<br>Amy Mayes – Conservation Halton | **DATE**: | December 23, 2011 |
| **FROM:** | John Parish, P.Geo. | | |
| **SUBJECT:** | Indian Creek Tributary – Meander Belt Width/Corridor Size | | |

Please accept this memo as a summary of a new, proposed channel design and corridor size assessment, based on the revised hydrology and resulting hydraulics, recently completed by AMEC. This work is presented as a first step towards accepting the corridor, based on the fluvial geomorphology. Specifically, the first component is the updated channel design, which is then used to determine whether the proposed corridor block (~30m top width) would be sufficient. Also, included in this memo is presentation of the various empirical methods used to evaluate the corridor size, based on the new channel design dimension and metrics.

Channel Design

As you are aware, the revised hydrology has resulted in a lower discharge, specifically values of 1.95 m3/s at King Road and 1.58 m3/s at the confluence. Accordingly, we have chosen a design discharge of 1.60 m3/s, for the reach upstream of the King Road grade separation. This discharge, while matching the 2-year flow from the upstream section is slightly below the 2-year in this reach, thus is a conservative surrogate for a bankfull flow, and will enable the channel to be effectively tied into both the upstream and downstream channel reaches.

An updated channel planform and revised design typical sections are attached to this memo. The design sections have resulted in a channel width of 3.5m, which is approximately 1m smaller than the previous design. This narrower channel has enabled a planform to be developed that has both a primary and secondary meander pattern. The broader secondary pattern has the channel moving across the bottom of the corridor, mimicking what a natural tendency. The energy gradient is slightly lower (0.34% as oppose to 0.35%), with a sinuosity of 1.21. The channel depth is 0.35m for the riffles and 0.5m in pools, resulting in width to depth ratios of 10 or lower, again reflecting a range found in natural, stable channel systems.

Channel Corridor

As we are all aware, the size of the corridor has been a concern. The corridor was initially sized based on hydraulic capacity, with a top width of 30m. Depending upon the top-of-bank elevations and desired side slopes, this can leave approximately 26m on the bottom to place the new channel. Given that this reach of Indian Creek has been altered (straightened), and that there have been no historic pattern detected nor any suitable surrogates either upstream or downstream, the use of empirical relations to determine the meander belt width was warranted. Shown below in the table is a summary of the various relations that were calculated.

| **Channel Parameters (Inputs)** | |
|---|---|
| *Parameter* | *Value* |
| Bankfull Cross-Sectional Area ($m^2$) | 1.4 |
| Watershed Area ($km^2$) | 1.54 |
| Bankfull Discharge ($m^3/s$) | 1.6 |
| Slope (%) | 0.0034 |
| Bankfull Width (m) | 3.5 |
| Bankfull Mean Depth (m) | 0.4 |
| bankfull maximum depth (m) | 0.5 |

| **Meander Belt Calculations** | | | |
|---|---|---|---|
| *Source* | *Equation* | *Preliminary Meander Belt Width (m)* | *Final Meander Belt Width (m)* |
| Collinson (1978) - maximum depth (m) | $65.6D_{max}^{1.57}$ | 22.1 | 26.5 |
| Dunne (1978) - drainage area (mi2) | $120A_w^{0.43}$ | 29.2 | 35.0 |
| Lorenz et al. (1985) - width (m) | $7.53W^{1.01}$ | 26.7 | 32.0 |
| Williams (1986)- width (m) | $4.3W^{1.12}$ | 17.5 | 21.0 |
| Williams (1986)- channel area (m) | $18A_c^{0.65}$ | 22.4 | 26.9 |
| Williams(1986) - hydraulic depth (m) | $148D^{1.52}$ | 36.8 | 44.2 |
| Bridge and Mackey (1993) - hydraulic depth (m) | $59.9D^{1.8}$ | 11.5 | 13.8 |
| Parish/TRCA (2001) - discharge and drainage area | $8.32*ln(A_w*9806*Q_{bf}*S)-14.83$ | 21.8 | 30.4 |
| Ward (2002)- width (ft) - no factor of safety | $4.8W^{1.08}$ | 20.4 | ---- |
| Ward (2002)- width (ft) - w/ factor of safety | $6W^{1.12}$ | ---- | 28.1 |

As Table 1 indicates, the results were divided into a preliminary belt width (which is the result from the empirical relation) and the final belt width that adds 20% (10% to each side of the corridor) or has a pre-established factor of safety from the original equation (e.g., TRCA and Ward). The mean for the preliminary belt width is 23.2m. If the outliers (11.5 and 36.8) were removed the mean drops to 22.9m. These represent a good starting point for the corridor as the preliminary belt width.

The Parish/TRCA method was purposely developed to be overly conservative. The method developed by Ward builds upon the Williams method and was developed in part to better fit smaller systems. The Ward study (paper attached) attempted to develop a better fit and for streams, including 'set backs' for riparian systems in agricultural land. The research involved increasing to coefficient to '6', which gave a better fit for more meandering systems and provided a defensible result that enable more 'set backs'. The term 'set back' could be also described as a factor of safety as it is known that a meander belt width is not a static value.

<u>Factor of Safety</u>

In our correspondence and meeting discussions regarding the corridor at this site, one of the primary topics has been the factor of safety in sizing the corridor. It is known that Conservation Halton would like to have the meander belt width and a factor safety accommodated within the bottom width of the corridor; which would represent the final meander belt width (see Table 1). They would be willing to have a flatter side slope within the corridor to enable some channel migration and cutting of these flatter side slopes as long as the ultimate migration would not jeopardize the corridor width. For instance, if we chose the Ward value with the factor of safety built in (result is 28.1m), provided we could demonstrate that a 2:1 side slope was feasible for the 1m deep corridor, then a 32.1m top width would be the result. The sensitivity of these relations and the end result should be noted. If the design width was reduced from 3.5m to 3.3m, the resulting value for the Ward equation, with the factor of safety is 26.3m, which would enable the proposed corridor to work. Thus, a 20cm reduction in the channel design width can reduce the corridor width by 2m. This change in the channel design is relatively minor and could easily be accomplished without jeopardizing the stability and function of the channel.

The actual amount of change of the meander belt width is often less than 10%, when the actual measurements of the migration of the bends that define the belt are determined. When the channel is being designed in a corridor, the amount of change is completely within the control of the designer and thus could be even less. The 10% value also provides a scalar approach to the sizing the setback, where as the meander belt width increases, so to does the factor of safety. This scalar approach has been applied to a variety of projects within the Conservation Halton jurisdiction, including secondary planning areas in Oakville and Milton.

It is felt that a strong argument can be made, that we could use the result from Williams (based on channel area) of 22.4m as the preliminary meander belt width. We could then add 10% for both sides of the corridor and result in a bottom width of 26.8m; which will fit within the bottom of the proposed corridor. The fact that this value is close to the Ward value with a factor of safety built in is comforting. In addition, the mean value of the final meander belt width values from Table 1 is 28.6m (interestingly, the mean value does not change whether the outliers are included or not). Thus, the mean value (28.6m), the Ward value (28.1m) and the TRCA value (30.4m) are all in the ballpark, thereby providing confidence that the corridor dimensions are appropriately sized. Further, it should be emphasized that the channel within this corridor is being designed and the rate and direction of any future channel migration can be controlled through altering bend shape alone; without needing to reinforce the banks with stone or excessive bio-engineering methods.

Conclusions

With the updated hydrology, a revised channel design was completed. The resulting design had channel dimensions that were slightly narrower and shallower. The new channel has a more varied planform pattern, which is easily accommodated within the proposed bottom width of the corridor. It is felt that the corridor, as proposed (30m top width) could be accommodated, which would have a 26m wide final belt width. The channel dimensions could be kept the same as proposed ro slightly reduced to ensure the empirical relations should be proposed corridor size. If an additional 2m could be found (corridor top-width of 32m), then the final belt width of 28.1m (Ward) could be applied.

# Appendix C: Falcon Creek Crossing Recommendation Memo

# Falcon Creek Crossing Recommendation

PARISH geomorphic

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Canada
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(905) 877-4143 Fax
www.parishgeomorphic.com Internet

**To:** Ashley Walker
Metropolitan Consulting

**Date:** October 2, 2013
**Ref:** 01-13-44

**CC:** Karl Gonnsen, Peter Scott – Metropolitan Consulting

**From:** John McDonald

**Subject:** 1200 King Rd Property – Falcon Creek Crossing Recommendation for South Service Road

Memorandum

**Introduction**

As a part of the development plans for the 1200 King Rd property in Burlington, Ontario, the construction of a portion of South Service Road has been proposed from King Road to the Eastbound Highway 403 onramp located along the north side of the Aldershot GO Station parking lot. To complete this, the road will have to cross three streams: Indian Creek, Falcon Creek, and a small tributary of Grindstone Creek. Of these three, Falcon Creek is the largest and most active stream with a well defined valley, therefore a preferred location and recommended structure size is required. The location of the crossing of Falcon Creek is less straight-forward than that of the Indian Creek (which is the next largest watercourse to be crossed). The land use and morphology of Falcon Creek is more complex than the previously straightened Indian Creek which flows through an agricultural field/open space. Utilizing previous fieldwork data (2010), surficial geology, topography, and recent site visits, a risk based approach can be used to determine a suitable location and span for the crossing.

**Background Review – Falcon Creek Erosion Assessment (PARISH Geomorphic Ltd, 2012; prepared for Valdor Engineering Inc.)**

A detailed erosion assessment was completed by PARISH Geomorpic Ltd (PGL) in 2012 along Falcon Creek from on top of the Niagara Escarpment downstream to the outlet at Lake Ontario. A total of 9 reaches were delineated, with reach FC-6 corresponding to the portion of Falcon Creek that traverses 1200 King Rd (**Figure 1**). This reach is bound by North Service Road at the upstream end and the CN Rail downstream, and flows through bedrock shale then the glacio-lacustrine sands, silts and gravels of the Glacial Lake Iroquois shoreline. The surrounding land use is primarily forest cover, from which channel widening/slope failure has provided large woody debris (fallen trees). A historical analysis was completed by evaluating aerial photographs from 1954, 1978, and 2009, to identify historical watershed and channel change. Within reach FC-6, the area adjacent to Falcon Creek remained forested over the period of photo coverage. Because the creek is relatively small and lined with vegetation, it was difficult to delineate on the photographs. This concealment restricted the ability to accurately locate the channel banks and (or) centreline in order to perform more detailed measurement (e.g. erosion rates, changes in width, sinuosity, etc.)

Rapid field assessments (RGA and RSAT) were undertaken for the entire study area, and detailed reach surveys for reaches FC-2 and **FC-6** (congruent with the present study).

### *Rapid Assessments*

The Rapid Geomorphic Assessment (RGA) survey documents observed indicators of channel instability (MOE, 1999). Observations are quantified using an index that identifies channel sensitivity based on evidence of aggradation, degradation, channel-widening and planimetric adjustment. The index produces values that indicate whether the channel is stable/in regime (score <0.20), stressed/transitional (score 0.21-0.40) or adjusting (score >0.40).

A Rapid Stream Assessment Technique (RSAT) survey provides a broader view of the system by also considering the ecological functioning of the stream (Galli, 1996). Observations include in-stream habitat, water quality, riparian conditions, and biological indicators. Additionally, the RSAT approach includes semi-quantitative measures of bankfull channel dimensions, type of substrate, vegetative cover, and channel disturbances. RSAT scores rank the channel as maintaining a low (<20), moderate (20-35) or high (>35) degree of stream health.

These rapid assessments found that the channel is in a state of adjustment (unstable) with widening and planimetric adjustment being the primary forms of change (RGA Score = 0.41), and is of moderate stream health (RSAT Score = 24.5). Detailed fieldwork was also undertaken using a level survey, measuring cross-section dimensions, substrate materials, and the long profile. For this section, the energy gradient (bankfull slope) is 1.52%, with bank widths ranging from 5-6m, and depths from 0.67-0.78m. Valley wall contact resulted in bank heights being estimated as high as 5m in some locations. Substrate materials were primarily gravels with a median size of 2.77cm, and larger sizes in the large-cobble range.

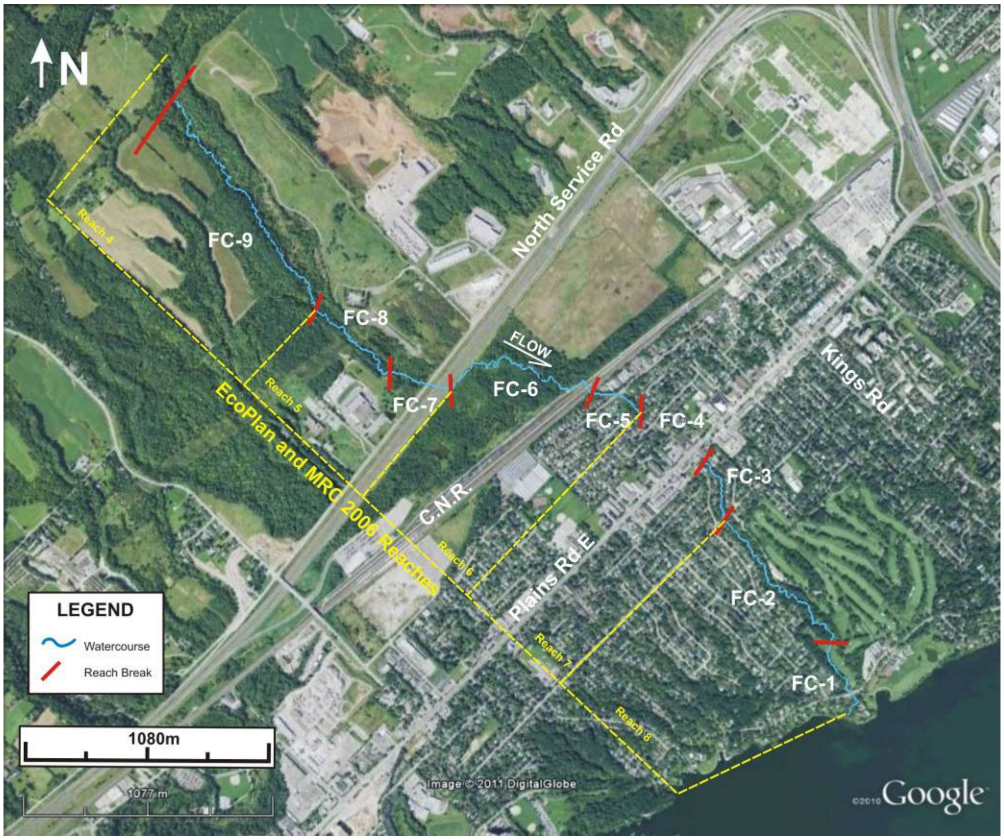

**Figure 1**: Falcon Creek reach delineation (PGL, 2012).

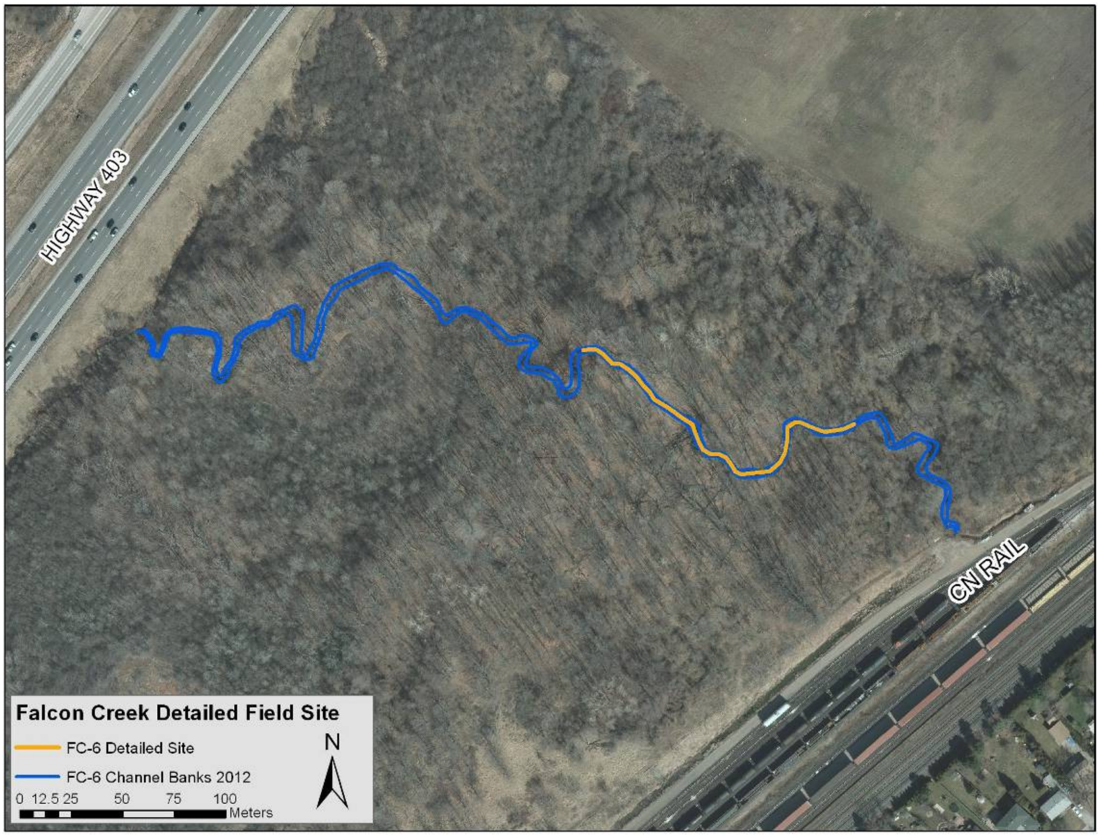

**Figure 2**: Falcon Creek RC-6 Detailed Site (PGL, 2012).

**Reach Delineation - Revisited**

Reaches are lengths of channel (typically 200m to 2km in length) 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 smaller distance than those of higher-order watercourses. At the reach scale, characteristics of the stream corridor exert a direct influence on channel form, function and processes.

The Falcon Creek Erosion Assessment had refined previous work done for the South Waterdown Subwatershed Study (EcoPlans and MRC, 2006), and upon review of the surficial geology, and the valley and channel character, further modification has been applied to the previous reach identification. Within this reach, there is a distinct change in surficial geology, which inherently affects valley and channel form. Falcon creek flows through bedrock (shale) then glacio-lacustrine sands. As it enters the sandy region, the valley changes from a confined system (with some semi-confined locations), and opens up into a wide floodplain (**Figure 3**). This change allowed the channel to change its meander configuration to a more regular form. Reach breaks have also been added at the upstream and downstream ends. Upstream there is a significant input from a tributary, and channel form is wider and more irregular downstream of this confluence. At the downstream end of the study area, the channel form becomes straight due to the alignment following the northern limit of the CN Rail yard.

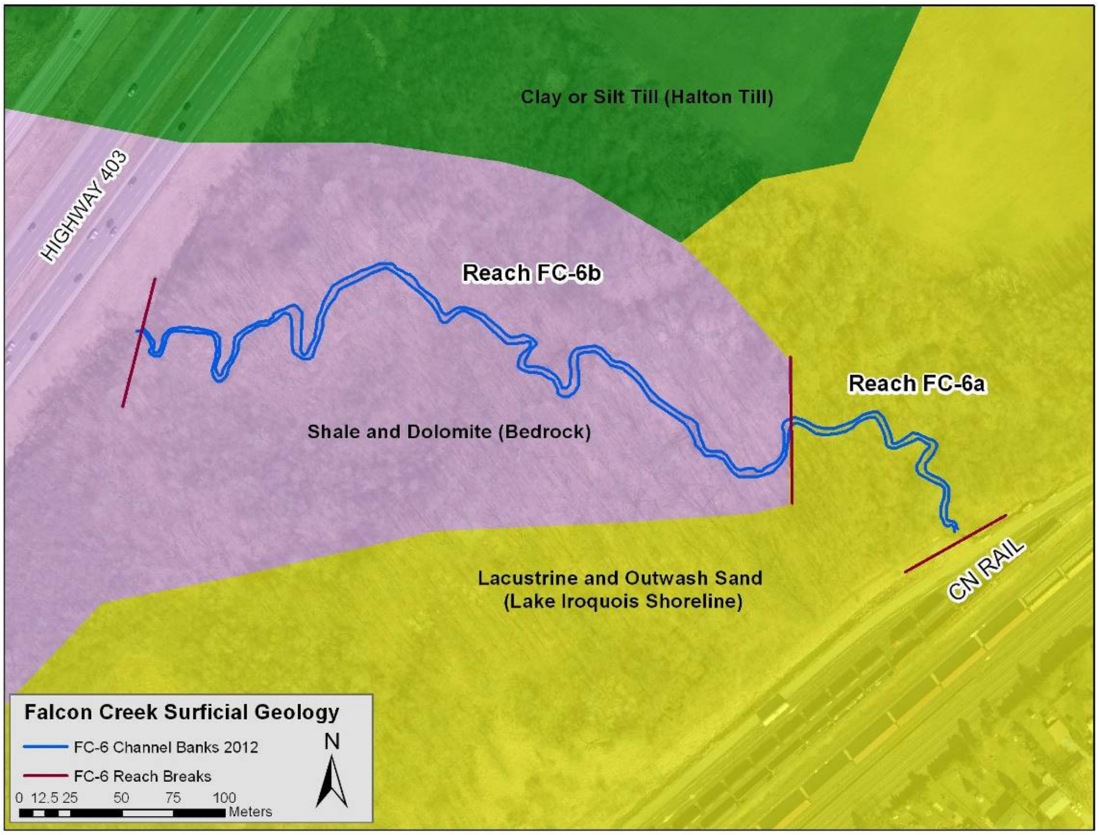


**Figure 3**: Surficial geology and reach delineation.

**Desktop Assessment – Meander Belt Width**

Streams and rivers are dynamic features that change their configuration and position within a floodplain by means of meander evolution, development, and migration processes. When meanders change shape and position, the associated erosion and depositional processes that occur can cause loss or damage to private property and infrastructure. For this reason, when development or other activities are proposed near a watercourse, it is desirable to designate a corridor that is projected to contain all of the natural meander and migration tendencies of the channel. Outside of this corridor, it is assumed that private property and structures will be safe from the erosion potential of the watercourse. The space that a meandering watercourse occupies on its floodplain, within which all associated natural channel processes occur, is commonly referred to as the meander belt.

In order to establish an erosion hazard corridor, a process-based methodology for determining meander belt widths for watercourses is followed. This methodology is provided within a detailed document which outlines Belt Width Delineation Procedures for confined and unconfined systems based on background information, historic data (including aerial photography), degree of valley confinement and channel planform (Parish Geomorphic Ltd., 2004). A meander belt is typically identified by drawing lines parallel to the governing outermost meanders of the existing channel planform and following the meander axis.

A preliminary meander belt width was delineated for each reach (18m for FC-6a, and 33m for FC-6b), and then a factor of safety was determined to create a final corridor. Based on the rapid assessment from the previous work on this reach, the channel was identified as being in adjustment. This resulted in a factor of safety of 30% of the preliminary MBW width being added (15% to either side). The resultant final MBW corridor widths were 23.4 for FC-6a and 42.9m for FC-6b.

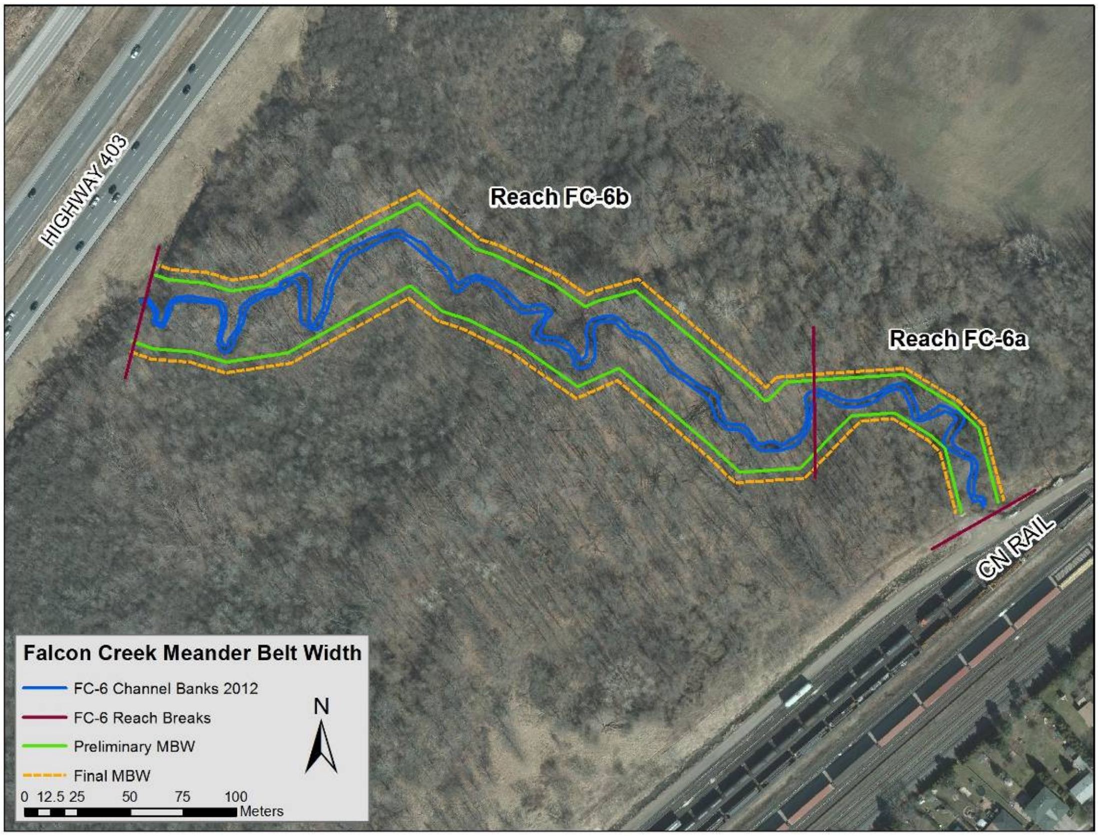


**Figure 4**: Meander Belt Widths for Reaches FC-6a and FC-6b.

*Meander Belt Width - Empirical Analysis*

Meander belt widths can be further verified using empirical relations based on channel parameters. The following equations (**Table 2**) provide an estimate of the meander belt width according to bankfull channel dimensions. These relations are based on measurements of real watercourses, however; the transferability to watercourses that are situated within southern Ontario is limited due to differences in hydrologic regime, drainage area, and general controlling factors. Reviewed collectively, they do provide a data set from which to corroborate results attained through use of the standard belt width delineation procedure and help to ensure that results are conservative.

**Table 1:** Empirical relation parameters for reach FC-6b.

| Parameter | Symbol | Measure |
|---|---|---|
| Width (average bankfull) | W | 5.5 m |
| Hydraulic Depth (average bankfull) | D | 0.73 m |
| Maximum Depth (bankfull) | $D_{max}$ | 0.78 m |

**Table 2:** Empirical formulas for estimating meander belt width dimensions.

| Meander Belt Empirical Analysis | | | |
|---|---|---|---|
| **Source** | **Equation** | | **Meander Belt Width (m)** |
| Williams (1986) - width (m) | $4.3W^{1.12}$ | = | 29.02 |
| Ward (2002) - width (ft) - no factor of safety | $4.8W^{1.08}$ | = | 33.27 |
| Ward (2002) – width (ft) – w/ factor of safety | $6W^{1.12}$ | = | 46.69 |
| Lorenz et al. (1985) - width (m) | $7.53W^{1.01}$ | = | 42.13 |
| Bridge and Mackey (1993) – hydraulic depth (m) | $59.9D^{1.8}$ | = | 33.97 |
| Collinson (1978) – maximum depth (m) | $65.6D_{max}^{1.57}$ | = | 44.41 |
| **AVERAGE** | | = | 36.56* |
| **STANDARD DEVIATION** | | = | 6.46* |

*Average and standard deviation exclude the result from the Ward (2002) equation that includes a factor of safety.

Bankfull channel dimensions measured during the 2010 field assessment were used as input parameters for the empirical analyses and are presented in **Table 1**. These are representative of reach FC-6b, field parameters were not collected for reach FC-6a (Rapid Assessments can provide the required inputs, and confirm those for FC-6b—to be completed). The resulting belt width estimates ranged from 29.02 to 46.69m, with an average of 36.56m. The preliminary belt width of 33.0m is comparable to the empirical results average of 36.56m and those predictions derived by Ward (2002), and Bridge and Mackey (1993) (**Table 2**). The final belt width of 42.9m is conservative, but necessary to accommodate the observed site conditions which include a high degree widening. It is also within the range of the higher predicted belt width dimensions in **Table 2**.

**Crossing Recommendation – Location and Span**

To provide insight towards the structure location and sizing for watercourse crossings, a risk-based procedure is typically applied. This procedure takes into account six main parameters, including channel size, valley setting, meander belt width, meander amplitude, channel stability and the 100-year migration rate. All of these risk factors encompass a wide range of data sources at a variety of spatial and temporal sales in order to evaluate and determine whether a crossing structure size is appropriate from a geomorphic perspective. Each risk factor is described below,

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

- *Valley Setting*: Watercourses with wide, flat floodplains and low valley and channel slopes tend to migrate laterally across the floodplain over time. Watercourses that are confined in narrow, well drained valleys are less likely to erode laterally but are more susceptible to down-cutting and channel widening, particularly where there are changes in upstream land use. Typically the classification of the valley will fall into one of three categories: confined, partially confined, and unconfined.

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

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

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

- *100-year Migration Rates*: Using historical aerial photographs, migration rates may be quantified (where possible) for each crossing location. A higher migration rate indicates a more unstable system and higher geomorphic risk. Ideally, watercourse crossing structures should be aligned perpendicular to and centered on a straight section of channel, or at an appropriate skew that would not affect channel processes. In terms of sizing, the structure would ideally span the meander belt width in order to accommodate the downstream migration of meander features. In many cases, however, the costs prohibit such structure sizes. From a geomorphic perspective, larger structures are favored to minimize the long-term risk and maintenance associated with natural channel adjustment.

Suitable locations for watercourse crossings as identified from a geomorphic perspective are primarily evaluated using the *valley setting* criteria, with added consideration of the existing channel planform configuration. All criteria (risk factors) are employed in the determination of the structure size.

Following a recent site visit in May of 2013, two locations were identified due to the relatively straight section of channel, and confined valley setting (**Figure 5**). Each site is suitable from a geomorphic perspective, but due to Option 1 being slightly more confined it may be less susceptible to channel migration, while Option 2 is semi-confined and possibly more likely to endure migration. Furthermore Option 2 has a higher ecological constraint, therefore Option 1 was selected as the preferred crossing location.

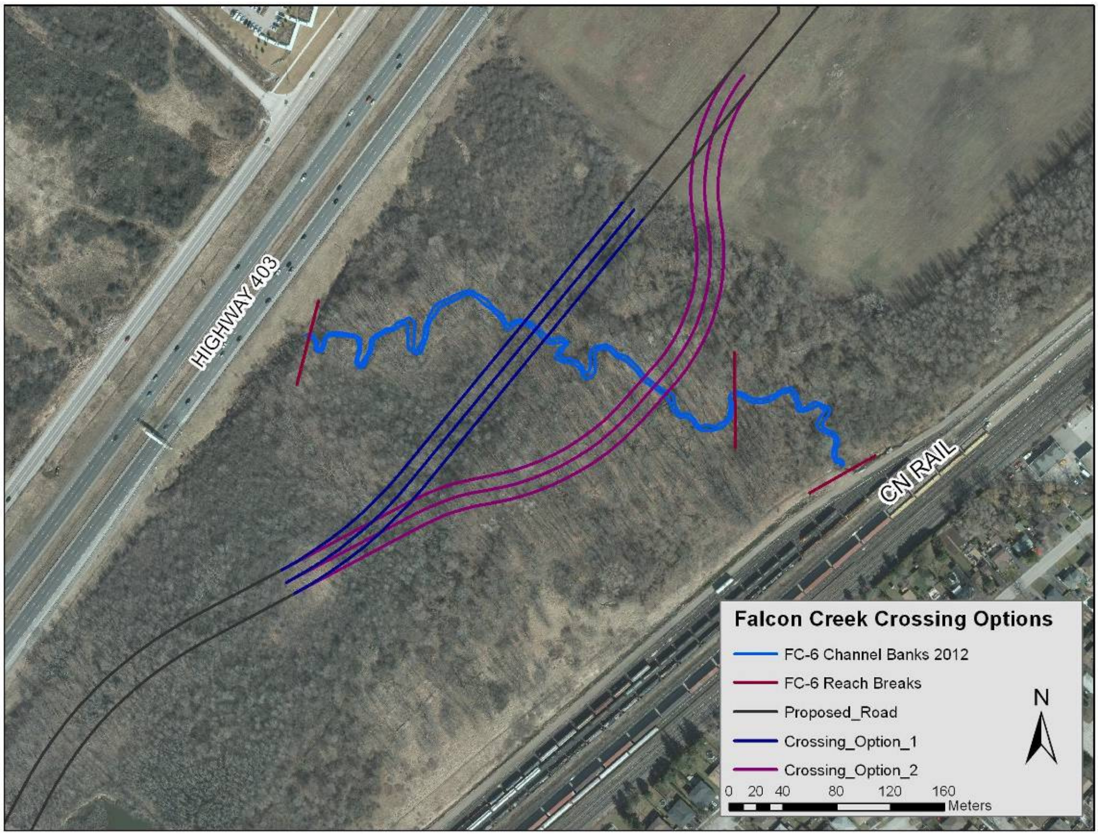


**Figure 5**: Crossing options for the proposed South Service Road over Falcon Creek.

**Table 3** presents the resulting data using each risk factor. Much of the risk associated with Option 1 on Falcon Creek is attributed to channel widening, and secondarily, planimetric adjustmet (formation of chutes and islands). The watercourse is situated within forested, confined to partially confined valley with a bedrock substrate with a veneer of alluvium (mostly gravels). These conditions contribute to the high degree of widening adjustment that was observed through the rapid geomorphic assessment. The existing channel width is 5m through this section, and can be expected to enlarge due to widening being the main process of adjustment. The governing meander amplitude measures approximately 10m, and is located upstream of the proposed crossing, therefore presenting a risk factor in the case that it may migrate downstream, regardless of this being a confined system. As a result of the confined nature, the meander belt width is also less influential in gauging risk to the crossing.

**Table 3:** Summary of risk assessment parameters for Falcon Creek at Crossing Location 1

| Bankfull Width (m) | Valley Setting | Meander Belt Width (m) | Meander Amplitude (m) | RGA stability index | 100-year Migration Rate (m/yr) |
|---|---|---|---|---|---|
| 5 | Confined | 42.9 | 9.5 | 0.41 | N/A |

The structure size was determined using the meander amplitude and existing bankfull channel width. To accommodate the existing channel planform, a slight skew has been proposed, with an opening width of at least 17m. This width would allow passage of the existing upstream meander with an additional factor of safety. Furthermore, it can account for expected widening from the existing bankfull width as it is more than three times the bankfull width of 5m. The proposed crossing location and span for Option 1 can be seen in **Figure 6**.

Natural channel design can also be applied in the construction of this crossing. By adjusting the cross-section to improve capacity, further widening and planimetric adjustment (chutes and island formations, etc) can be mitigated. If required, bank stabilization can be imposed through bioengineering techniques or the placement of stone treatments.

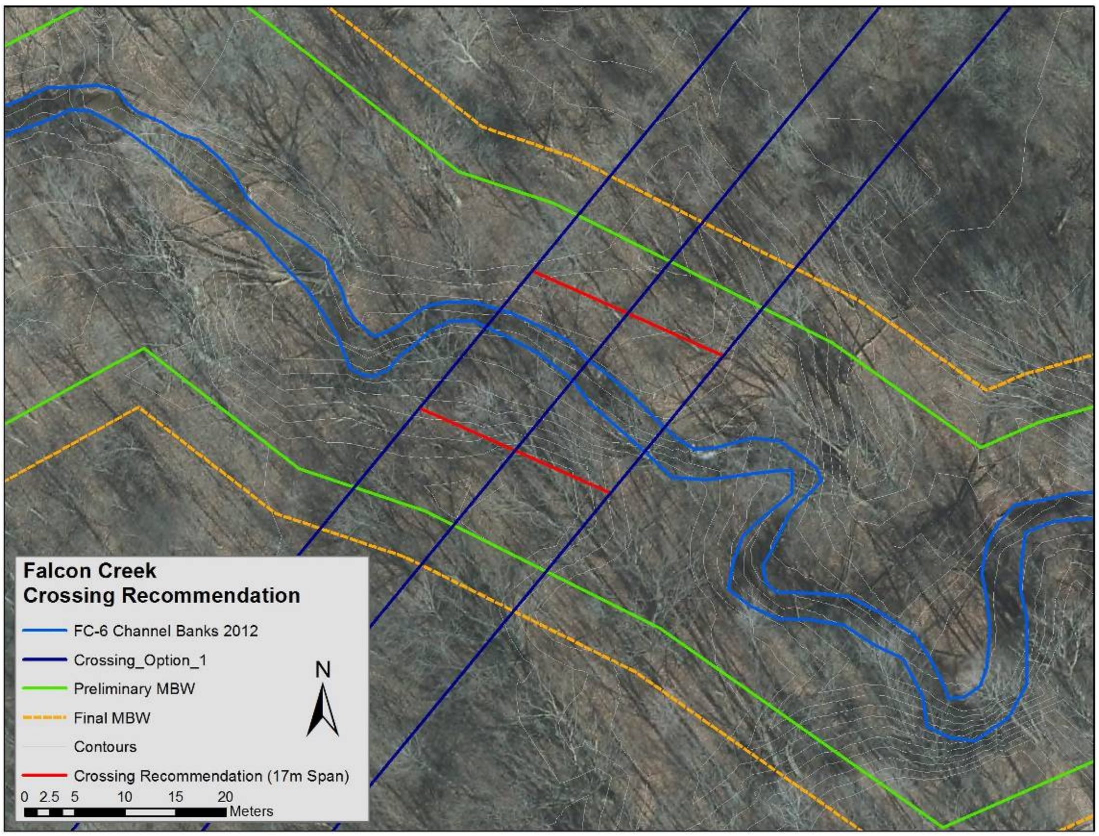


**Figure 6**: Recommended crossing span and orientation for Option 1 over Falcon Creek.

**Summary**

A meander belt width and crossing risk assessment was undertaken for a section of Falcon Creek within the 1200 King Rd property in Burlington, Ontario. The purpose of this report was to establish hazard limits and provide a preferred location for a watercourse crossing, with a recommended size and skew from a geomorphic perspective. This included a background review of a recent geomorphic study on Falcon Creek (which included field data), and desktop analyses to characterize the channel morphology and catchment conditions.

Based on a review of available mapping (surficial geology and topography), and aerial imagery, an adjustment to the reach boundaries and sub-division of the existing reach from the Falcon Creek Erosion Assessment (PGL, 2012) was completed. A preliminary belt width was governed by the lateral extent of the meander form and was determined to be 33m. Due to the high RGA score indicating that the channel is in a state of adjustment, a 30% factor of safety was applied (15% to each side of the preliminary belt width), resulting in a final belt width of 42.9m. These meander belt width results were comparable to those predicted using empirical formulas. The meander belt width was then reviewed collectively with other risk factors to determine an appropriate size and location for a crossing structure.

Much of the risk surrounding Falcon Creek in the vicinity of the proposed crossing is due to channel widening and planimetric adjustment (formation of chutes and islands) in a confined valley setting. Based on site observations, channel configuration (straighter planform), and valley confinement, Option 1 was selected as a preferred site. This also coincides with the preference from an ecological standpoint based on Option 2 having a higher ecological constraint. The lateral extent of channel adjustment is ultimately controlled by the degree of confinement, which, for Option 1 is confined. Crossing recommendations primarily accounted for channel widening and the possibility that an upstream meander might migrate towards the crossing. Therefore, the proposed 17m crossing is rather conservative in this straight and confined section with a relatively small bankfull width. While larger structures like those that may span the entire meander belt width are most favourable from a geomorphic perspective, the provided span recommendation should support the long term form and function of Falcon Creek and limit risk to the proposed infrastructure.

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