GUIDING SOLUTIONS IN THE
NATURAL ENVIRONMENT

Fluvial Geomorphology Report

in support of a
Master Environmental Servicing Plan
4134 16th Avenue, City of Markham

Prepared For:

Sixteenth Land Holdings Inc.

Prepared By:

Beacon Environmental Limited

Date: *Project:*

November 2017 **215200.1**

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1. Introduction

Sixteenth Land Holdings Inc. has retained Beacon Environmental Limited (Beacon) to prepare this Fluvial Geomorphology Report in support of an Official Plan Amendment ("OPA") application to permit the development of a residential community on the property that is municipally known as 4134 16th Avenue, in the City of Markham, Region of York ('subject property'). The subject property is located in Part lots 16, 17 and 18, Concession 5 (**Figure 1**). Except for an area adjacent to Kennedy Road, the balance of the property is currently used by its former owner York Downs Golf & Country Club for a golf course.

The subject property has a total of area of approximately 168 hectares (ha), and is located on the north side of 16th Avenue, west of Kennedy Road, and has a small frontage on the east side of Warden Avenue. There is existing residential development surrounding the property on all sides. Berczy Creek crosses the western portion of the property, and the Bruce Creek traverses the property in a north / south direction, bisecting the property into west and east tableland areas.

The current golf course use has been in operation since York Downs Golf & Country Club opened in the early 1970's. The current Official Plan designation of 'Private Open Space' for the areas outside of the valleylands reflects this historic golf course use.

Sixteenth Land Holdings Inc. intends to develop the property for a residential community and is submitting an OPA to re-designate the developable portion of the property from 'Private Open Space' to appropriate urban residential designations to permit the development of residential uses.

This report has been prepared in conjunction with the OPA application in support of the redesignation as proposed in the draft OPA and in the Planning Report (Gatzios Planning August 2016 and revised on September 15, 2017). Please refer to the draft OPA and to the Planning Report for a description of the proposed Official Plan land use designations proposed for the property.

The proposed residential development is detailed in the two draft plan of subdivision applications that accompany this OPA application. There is one draft plan of subdivision for the east portion of the property and one for the west portion of the property. The west draft plan of subdivision also contains the valleylands associated with both the Berczy Creek and the Bruce Creek. References in this report to the two draft plans or to specific lots / blocks will include 'East' or 'West' to denote the appropriate area.

The East draft plan of subdivision contains a mix of residential, open space blocks, an elementary school block and SWM ponds.

The West draft plan of subdivision contains a mix of residential, mixed use, open space blocks, parks and SWM ponds.

The purpose of this Fluvial Geomorphology Report is to summarize the existing conditions, contribute to the determination of development constraints, and provide input to stormwater servicing plans for the subject property. This report has been updated to reflect the revised draft plans and to address approval agency comments issued for the 2016 report submission.

In accordance with the approved Terms of Reference for the overall MESP report, the following tasks were undertaken in support of this study:

- Background review of available materials (topographic mapping, aerial photography, watershed reports, relevant studies, site plan);
- Desktop assessment to delineate reaches based on underlying geomorphic controls and establish changes in land use and channel planform over time (referencing available history aerial imagery);
- Mapping analysis to delineate the meander belt width for stream corridors (unconfined watercourses) in accordance with relevant policies and guidelines to aid in the determination of erosion hazard limits;
- Delineation of occupied Redside Dace regulated habitat in conformance with Ontario Regulation 242/08 (meander belt width plus 30 m) for stream and valley corridors to aid in the determination of development limits;
- Field investigations including:
    - Rapid field assessment on a reach basis to characterize existing geomorphic conditions and document evidence of active channel processes; and
    - Detailed field assessments of two (2) sites for the purpose of determining erosion thresholds;
- Analysis of detailed geomorphic field data to determine erosion thresholds;
- Impact assessment of proposed development plan to evaluate potential impacts on channel morphology; and
- Analysis of fluvial geomorphology requirements for Natural Heritage System (NHS) crossings.

2. Background Review

2.1 Watershed Conditions

2.1.1 Climate

Climate provides the driving energy for a fluvial system and directly influences basin hydrology and rates of channel erosion, particularly through precipitation. Precipitation records obtained from climate normals (1981-2010) recorded at Richmond Hill Station, located northwest of the subject property, averaged 69 mm per month in winter (November through February), and 86 mm in summer (July and August; Environment Canada 2015). This increase over the summer months is likely a result of convective thunderstorms. While total precipitation amounts are greater during the summer months, snowmelt and rain-on-snow events tend to produce the highest flows within a watershed.

1:17,000

0 75 150 300 450 600

Legend

- 🟥 Subject Property
- — Draft Plan Boundary
- — Watercourse

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4134 16TH AVE

FIGURE 1 Site Location

First Base Solutions Web Mapping Service 2015
UTM Zone 17 N, NAD 83

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2.1.2 Geology

The planimetric form of a watercourse is fundamentally a product of the channel flow regime and the availability of sediments (i.e., surficial geology) within the stream corridor. The 'dynamic equilibrium' of these inputs governs channel planform. These factors are influenced in smaller systems by physiography, riparian vegetation and land use. The subject property is located within the Peel Plain physiographic region (Chapman and Putnam 1984); a thin veneer of silt and clay glaciolacustrine deposits that were deposited over the underlying Halton Till. This region is predominantly comprised of clay, with localized clay loam and loam deposits. Although the topography is relatively flat, infiltration is limited by the clay content of the soils. Surficial geology within the property is dominated by the Halton Till formation, a sandy silt to clayey silt till interbedded with silt, clay, sand and gravel. Locally, within the stream corridor, both Berczy and Bruce Creeks rework a veneer of modern alluvial sand and gravel deposits (TRCA 2007a).

2.1.3 Rouge River State of the Watershed Report (2007)

The Toronto and Region Conservation Authority (TRCA) and Rouge Park Alliance, in cooperation with the multi-stakeholder Rouge Watershed Task Force, undertook the development of an integrated watershed plan for the Rouge River watershed. This report provided the basis for the updated Rouge River Watershed Plan, and provided an overview of existing environmental conditions within the watershed. Berczy Creek and Bruce Creek represent two of the five tributaries that make up the Middle Rouge tributaries within the Rouge River watershed.

The Rouge River and its tributaries are referred to as 'semi-alluvial' in nature meaning these systems flow through both older glacial deposits as well as their own eroded deposits (alluvium) (TRCA 2007a). The morphology of semi-alluvial channels is partially controlled by the properties of the glacial deposits through which they flow, as well as by the characteristics of alluvium transported from upstream. In the Rouge River watershed, glacial lacustrine (till) deposits and glacial outwash material represent the primary underlying controls on morphology (TRCA 2007a).

As with the majority of watersheds in southern Ontario, the Rouge River watershed has been altered by human activity (TRCA 2007a). The influence of uncontrolled stormwater inputs to the downstream watershed from older development areas have resulted in notable changes to the hydrologic regime, and subsequently channel morphology and stability (TRCA 2007a).

2.1.3.1 Fluvial Geomorphology

Berczy Creek

The portion of Berczy Creek flowing through the subject property was characterized as a third order stream through the watershed report (TRCA 2007b). The report also noted that, through their Regional Watershed Monitoring Network, TRCA established a long-term geomorphic monitoring station (GR-12) downstream of the subject property in 2002. Morphologic characteristics reported for station GR-12 indicated an average bankfull width of 5.33 m, average bankfull depth of 0.71 m and bankfull gradient of 0.23%. Bank heights averaged 1.1 m in height, while the median grain size for the site fell within the small gravel size class.

Bruce Creek

The portion of Bruce Creek flowing through the property was characterized as a third order stream through the watershed report (TRCA 2007b). The report also noted that, through their Regional Watershed Monitoring Network, TRCA established a long-term geomorphic monitoring station (GR-17) downstream of the subject property in 2002. Morphologic characteristics reported for station GR-17 indicated an average bankfull width of 5.66 m, average bankfull depth of 0.55 m and bankfull gradient of 0.41%. Bank heights averaged 1.1 m in height, while the median grain size for the site fell within the small gravel size class.

2.1.4 Aquatic Habitat

The watershed report identifies the portion of Bruce Creek within the subject property as falling within Fishery Management Zone (FMZ) 3, while the portion of Berczy Creek within the subject property falls within FMZ 2, as documented in the Rouge River State of the Watershed Report (TRCA 2007c). These zones delineate areas within which fish communities, thermal regimes and underlying environmental controls remain relatively consistent.

The report classifies Berczy Creek as a riverine cool water system based on the known groundwater discharge areas upstream of the subject property. FMZ 2 is managed for the following key target species:

- Redside dace (*Clinostomus elongatus*);
- Brassy minnow *(Hybognathus hankinsoni);*
- Rainbow darter (*Etheostoma caeruleum*); and
- American Brook Lamprey (*Lethenteron appendix*).

Occurrences of migratory salmonids have been recently documented and much of Berczy Creek is also known habitat for Redside Dace. In addition to its Provincially Endangered status, it is also listed on the federal Species at Risk Act as Special Concern. Records as recent have 2005 have been documented for reaches just downstream of the golf course lands and existing populations are known in other nearby reaches.

The report classifies Bruce Creek as a riverine warm water system. Groundwater discharge areas are present just upstream of the subject property but the influence of several golf courses and urbanization cause a warming effect, which results in the warm water designation. FMZ 3 is managed for the following key target species:

- Redside dace (*Clinostomus elongatus*);
- Brook trout (*Salvelinus fontinalis*);
- Rainbow darter (*Etheostoma caeruleum*);
- Mottled sculpin *(Cottus bairdi)*; and
- American Brook Lamprey (*Lethenteron appendix*).

According to the report, Bruce Creek provides very high quality fish habitat that supports Brook Trout (*Salvelinus fontinalis*) in the upper reaches (upstream of the subject property), and an abundant Redside Dace population through the mid-lower reaches (including through the subject property). Similar to Berczy Creek, records as recent as 2005 have been documented at a sampling site immediately downstream of 16th Avenue. The reaches that flow through the subject property also have documented occurrences of migratory salmonids. The overall species profile for Bruce Creek is primarily warmwater with at least 26 species identified in recent years. Water quality is considered 'very good' in the mid to lower reaches of the subwatershed. Bruce Creek is the only watercourse with such a rating in the entire Rouge River watershed. The thermal rating was classified as unstable.

2.2 City-Wide Stream Erosion Master Study Update (AECOM, 2014)

As an update to the 2007 Erosion Restoration Implementation Plan, the City of Markham completed a City-Wide Stream Erosion Study Update (AECOM 2014) to re-examine previously identified erosion concerns and document new sites. Of the watercourse reaches delineated within the City's municipal boundary, three were relevant to the subject property: Reaches BRU-3 and BRU-2 of Bruce Creek and Reach BZ-2 of Berczy Creek. Reach BRU-3 captures almost the entire length of the Bruce Creek within the subject property, with the exception of the portion of Bruce Creek just upstream of 16th Avenue. Reach BRU-2 then extends downstream from this point to the Carlton Road crossing of Bruce Creek in Unionville. Reach BZ-2 begins at the southwest property boundary and extends just south of 16th Avenue.

Within these reaches, the study identified two priority erosion sites relevant to the subject property:

- BZ-ES-12 (Berczy Creek) – Undercutting and scouring on the outer meander, upstream of a golf course crossing.
- BZ-ES-14 (Berczy Creek) – Undercutting and scouring adjacent to York Downs Golf and Country Club. Corrugated steel drainage pipe exposed at midpoint of site. Failing trees at downstream limit.

BZ-ES-12
While this site was identified as an area of erosion, the report also noted that the observed erosion was occurring at a site where erosion could be expected to occur under natural conditions. A conceptual restoration design in the form of minor grading and the installation of rock toe protection was proposed through the report to address the observed area of erosion.

BZ-ES-14
At this site an existing drainage pipe extends into the active channel. The report proposed a conceptual design solution that involved trimming the pipe, grading the bank and installing stone protection around the pipe.

3. Planning and Environmental Policy Context

The following Federal, Provincial, Regional, TRCA and Municipal planning and environmental policies are applicable to this report:

3.1 Provincial Policy Statement (2014)

The Provincial Policy Statement (MNRF 2014) issued under the Planning Act (1990) outlines areas of provincial interest with respect to natural hazards. In support of the Policy Statement, a Technical Guide - Rivers and Streams: Erosion Hazard Limit document was prepared (MNR 2002) to outline standardized procedures for the delineation and management of riverine erosion hazards in the Province of Ontario. The guide presents erosion hazard protocols based on two generalized landform systems through which watercourses flow: confined and unconfined valley systems. Through this approach, the meander belt width plus an erosion access allowance is defined to determine the erosion hazard limit of an unconfined valley system. For confined valley systems, the erosion hazard limit is governed by geotechnical considerations, including the stable slope allowance and an applicable toe erosion allowance (i.e., channel migration component).

3.2 Region of York Official Plan (2009)

The Region of York Official Plan was adopted in 2009 and approved by the Ministry of Municipal Affairs and Housing in September 2010 incorporating several modifications. The OP identifies a Regional Greenlands System. The policies detailed in the plan are intended to identify, protect and restore the Greenlands System as a permanent resource for the Region. Lands designated Greenlands in the Region of York Official Plan are subject to development constraints.

The boundaries and extent of the Greenlands System identified on Map 2 of the Official Plan are approximate. Specific delineation or clarification of greenland boundaries may be undertaken when applications for development are received. Refinements to the boundaries may occur through environmental evaluation, and do not require an amendment to the plan.

Development applications within or on lands close to the Greenlands System must be accompanied by an environmental evaluation of impacts the development will have or is expected to have on the environmental functions, attributes, or linkages of the Greenlands System. The evaluation must also provide the details of any mitigation measures that will ensure that the Greenlands features will not be adversely impacted.

3.3 Town of Markham Official Plan (1987)

Markham's new Official Plan was adopted by Council on December 10, 2013, and approved by York Region on June 12, 2014. The new Official Plan has been appealed to the Ontario Municipal Board and is not yet in force. Until an Ontario Municipal Board decision to approve all or part of the new Official Plan has been made, the current Official Plan (Revised 1987), as amended, continues to remain in force and hence has been reviewed and applied to the subject property.

Schedule A (Land Use) identifies the subject property as Open Space, Hazard Land and the north east corner as Future Urban Area. Schedule I (Environmental Protection Areas) of the Markham Official Plan identifies Valleylands on the subject property which includes the Hazard Lands depicted on Schedule A. As outlined in the Markham OP:

> ‘*Environmental Protection Area identifies lands and water bodies containing natural features and/or ecological functions of such significance to the Town or sensitivity to disturbance as to warrant long term protection. Corresponding objectives for their preservation will be implemented through detailed policies which address specific subcategories as follows:*
>
> - *Locally Significant Area Complexes;*
> - *Valleylands including HAZARD LANDS designated on Schedule ‘A’ - LAND USE; and*
> - *Woodlots and other Significant Vegetation Communities.’*

Section 2.2.2.9 c) and f) of the Official Plan speaks to Environmental Buffers, which calls for the minimum width of an environmental buffer to be 10 m from the stable top of bank or predicted stable top of bank or the Regulatory Flood Line, drip line of the trees at the edge of the woodlot, or as defined by an Environmental Impact Study.

3.3.1 Greenway System

Appendix Map 1 of the Town of Markham OP identifies Bruce Creek, Berczy Creek, the eastern woodlot and a Bruce Creek Tributary as part of the Greenway System (Beacon 2017).

The purpose of the Greenway System was to:

- Support ecological functions;
- Provide access to natural areas; and,
- Provide continuous trails linking the Town’s Greenway System with the Rouge Park, the Oak Ridges Moraine and the Don River Valley south of Steeles Avenue.

The Greenway System as shown on Map 4 in the City of Markham 2014 OP incorporates the same areas/features as the 1987 Greenway System, with one exception, the 2014 Greenway System does not include the Bruce Creek tributary.

3.4 Endangered Species Act (2007)

The reaches of Bruce and Berczy Creeks within and adjacent to the subject property have been classified by the Ontario Ministry of Natural Resources and Forestry (MNRF) as watercourses that are being used, or were used at any time during the previous 20 years, by a Redside Dace, and that provide suitable conditions for a Redside Dace to carry out its life processes. This minnow species and its habitat receive protection under the *Ontario Endangered Species Act* (*ESA* 2007). Redside Dace occupied habitat is defined under Ontario Regulation 242/08 as any part of a stream or other watercourse, the area encompassing the meander belt width of said watercourse, and the vegetated area or agricultural lands that are within 30 metres of the meander belt width.

3.5 Toronto and Region Conservation Authority Regulations and Guidelines

3.5.1 Conservation Authorities Act (Ontario Regulation 166/06)

The Toronto and Region Conservation Authority (TRCA) regulates land use activities in and adjacent to wetlands, watercourses and valleylands under Ontario Regulation 166/06 (*Regulation for Development, Interference with Wetlands and Alterations to Shorelines and Watercourses*) made under the *Conservation Authorities Act.*

Subject to conformity with the municipality's Official Plan, the completion of appropriate studies and application for Conservation Authority permits, The Authority may grant permission for development within these areas if it can be proven that control of flooding, erosion, pollution or the conservation of land will not be affected by the development.

3.5.2 The Living City Policies (2014)

The TRCA's Living City Policy was approved in November 2014 and replaces the Valley and Stream Corridor Management Program (1994). The Living City Policy document, among other matters, implements current federal, provincial and municipal legislation, policies and agreements affecting conservation authorities; and implements the policies for TRCA's updated section 28 of Ontario Regulation 166/06. For purposes of implementing TRCA's Environmental Management Policies:

a) Confined River or Stream Valleys are considered **Valley Corridors**; and
b) Unconfined River or Stream Valleys are considered **Stream Corridors**.

According to the Living City Policy, the boundaries of a valley or stream corridor generally require a minimum 10 m setback from the greater of:

- Physical top of the valley feature;
- Long term stable top of slope, where geotechnical concerns exist (which must be confirmed through an appropriate geotechnical analysis);
- Regulatory floodplain;
- Meander belt; and
- Limits of significant vegetation which is contiguous with the valley corridor.

It is the policy of TRCA:

> *"That erosion hazard limits will be determined through site specific field investigations and technical reports where required, in accordance with the text of TRCA's Regulation and Provincial and TRCA standards. Where erosion hazard limits are required and not available, or where existing erosion hazard information does not meet current Provincial or TRCA standards, TRCA may require the erosion hazard to be determined by a qualified professional, at the expense of the proponent, to the satisfaction of TRCA."*

The Belt Width Delineation Procedures (Parish Geomorphic Ltd. 2004) document outlines standards for delineating the meander belt width in TRCA jurisdiction.

4. Characterization of Existing Conditions

4.1 Reach Delineation

To facilitate a systematic evaluation of the portions of Bruce Creek and Berczy Creek within the subject property, the watercourses were delineated into reaches (**Figure 2**). Reaches are homogenous sections of channel with regard to form and function and can, therefore, be expected to behave consistently along their length to changes in hydrology and sediment inputs, as well as to other modifying factors (Montgomery and Buffington, 1997; Richards et al. 1997).

The determination of reach extents was initially based on a desktop evaluation of degree of valley confinement, sinuosity, and transitions in riparian vegetation. Verification of reach limits was undertaken in the field to confirm that the extent of mapped features accurately reflected existing conditions and underlying geomorphic controls. It should be noted that, where appropriate, reach delineation extended beyond the property limits to capture portions of reach that were relevant to the subject property. Field confirmation of reach extents and existing conditions was limited to mapped features within the property boundary, and those lands beyond the subject property that are in public ownership.

4.2 Meander Belt Width

The meander belt width is generally defined as the lateral extent that a meandering channel has historically occupied and will likely occupy in the future. Following the TRCA (2004) guidelines, for the unconfined portions of the watercourses, the meander belt width is generally defined as the lateral extent that a meandering channel has historically occupied and will likely occupy in the future.

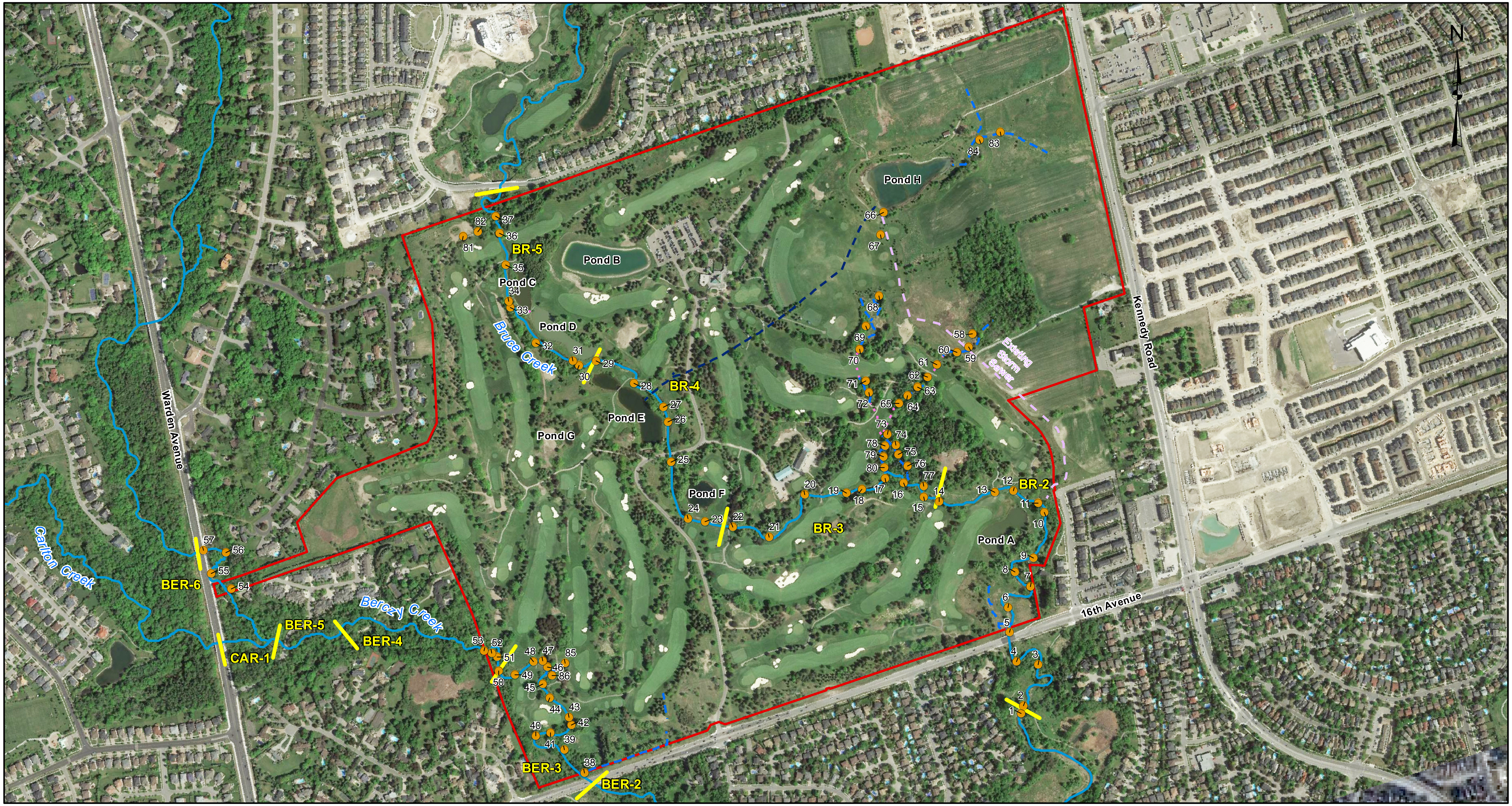
4.2.1 Historic Assessment

The following section presents an overview of historic conditions in the vicinity of the subject property with respect to land use, land cover and channel conditions. Historic analyses provide insight into the scale of natural and human-induced changes within a watershed, particularly the degree to which channel planform adjustment and land use has changed over time. In support of the historic assessment, black and white aerial photographs and digital colour imagery were analysed and compared to obtain a simple, qualitative assessment of the degree of land use and channel planform change over time (**Appendix A** and **Table 1**).

Table 1 provides a summary of specific observations regarding change in channel planform and land use based on available historical aerial imagery.

Table 1. Summary of Key Historical Observations

Time Period	Scale, Source	Observations
1961	1:12,000 Northway Photomap/Remote Sensing Ltd.	Forested areas converted to agricultural fields, with hedgerows, isolated pockets of forest cover and naturally vegetated areas restricted to the Berczy and Bruce Creek valley systems.
		Both the Berczy Creek and Bruce Creek channels are observed to have moderately sinuous planforms and are well-defined. Evidence active adjustment include the presence of avulsion (oxbow) scars within the floodplain, and bank erosion at meander bend (channel migration).
		Existing disturbances to Berczy and Bruce Creeks include several informal lane crossings, and the 16th Avenue and Warden Road crossings. West of the subject property, an online pond with an island can be observed on Berczy Creek.
		An open drainage feature can be observed draining to Bruce Creek within the subject property.
		Construction of Glenbourne Park Drive, northwest of the subject property, can be observed.
		A few residential homes can be observed along Kennedy Road, just north of 16th Avenue.
1974	1:12,000 Northway Photomap/Remote Sensing Ltd.	The majority of York Downs Golf and Country Club, including the Club House and maintenance building, has been constructed.
		Modifications to Bruce Creek associated with land use change included extensive channelization of the watercourse, and the construction of five (5) irrigation ponds within the floodplain. Eight (8) cart path crossings of Bruce Creek can be observed. With isolated exceptions, manicured grass and fairway extend to the edge of active watercourse.
		Modifications to Berczy Creek the construction one (1) cart path and the transition of naturalized buffer to manicured grass and fairway along the active watercourse.
		Berczy Creek has been straightened to accommodate the widening of 16th Avenue and associated crossing structure.
		Portions of the Bruce Creek open drainage feature have been piped to accommodate the golf course.
		Residential development can be observed along Glenbourne Park Drive and Cachet Parkway, northwest of the subject property. Residential development has also occurred south of 16th Avenue.
		Downstream of the confluence of Berczy and Bruce Creeks, Toogood Pond can be observed.
2002	1:15,000 First Base Solutions	The York Downs golf course has expanded. An additional **crossing of Bruce Creek** can be observed. **Two (2) additional cart path crossings of Berczy Creek** can be observed.



1:8,000

0 45 90 180 270 360

Legend

- ▭ Subject Property
- — Watercourse
- — Reach Break
- ● Photo Locations
- ⋯ Piped Feature
- - - Existing Storm Sewer
- - - Surface Flow
- - - Auxiliary Water

JD Barnes: Aerial Photograph, 2015;
MBTW: Subject Property, 2015;
Beacon Environmental: All other data 2017.

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FIGURE 2: Reach and Photo Locations

UTM Zone 17 N, NAD 83

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Time Period	Scale, Source	Observations
		A stormwater facility has been constructed in the north east corner of the subject property at the upstream extent of the **Bruce Creek drainage feature. The drainage feature has been enclosed along the majority of its length.**
		Increased residential development within the lands surrounding the subject property. Angus Glen Golf Club has been constructed along Bruce Creek to the north of the subject property.
2012	1:15,000 First Base Solutions	An additional irrigation pond can now be observed adjacent to the golf club house parking lot within the subject property. Additional residential development observed north of the subject property and east of Kennedy Road.

4.2.2 Stream Corridors (Unconfined Valley Settings)

Following the TRCA (2004) Chapter 5 procedures, the meander belt width was initially delineated for all unconfined portions of watercourse based on the position of governing meander bends within each reach. Using high resolution digital aerial imagery, historical imagery and topographic mapping, these belt width limits were then refined to ensure that the dimension was also sufficient to capture areas historical channel locations and zones of frequent inundation. The resultant preliminary belt widths are presented in **Table 2**. In accordance with the TRCA (2004) procedures, a 20% factor of safety (10% either side) was then applied to the preliminary belt width dimensions in order to account for long-term adjustments in channel form (channel erosion and migration), as well as potential post-development changes in hydrologic regime.

To review the meander belt width dimension, an empirical modelling approach was also employed that considers the channel dimensions, referencing geomorphic field data. To determine the belt width (B_w), these models use simple power functions based on field-based measurements of the average bankfull width (W_b) and cross-sectional area (A), following relations from Williams (1986 – Equations 1 and 2) and Ward (2001 – Equation 3). Research by Ward et al. (2002) indicated that the Williams (1986) equation, at times, under-predicted the belt width dimensions. As such, a modified approach to the relation, which incorporates a 20% factor of safety, was applied.

$$B_w = ([18*A^{0.65}]) \qquad [Eq. 1]$$
$$B_w = ([4.3*W_b^{1.12}])*1.2 \qquad [Eq. 2]$$
$$B_w = ([6*W_b^{1.12}]+W_b) \qquad [Eq. 3]$$

The results of the empirical relation analysis, which are summarized in **Table 2**, generally correlated to the desktop approach, with Reaches BR-2 and BER-3 representing notable outliers.

Recommended meander belt width dimensions presented in **Table 2** and **Figures 3A/3B** are based on the desktop mapping approach, and were verified through the field investigation (refer to **Section 4.3**) for the determination of erosion hazard limits for unconfined reaches. The recommended belt width dimensions include a 20% factor of safety which was deemed sufficient to account for long-term adjustments in channel form (channel erosion and migration) under the post-development condition.

It should be noted that while a meander belt width of 84 m is recommended for Reach BER-5 to provide continuity to this assessment, this reach was not walked as part of the field investigation. The belt width dimension for BER-5, instead, referenced historical and recent aerial imagery, and reference reaches immediately upstream and downstream (BER-4 and BER-6).

4.2.2.1 Erosion Hazard Limit

The erosion hazard limit for unconfined valley systems, as defined under the Provincial Policy Statement (MMAH, 2014), is delineated by the greater of the meander belt (**Table 2**) or flooding hazard limit, plus an additional erosion access allowance. In accordance with Provincial Policy, TRCA (O. Reg. 166/06) generally requires that an erosion access allowance of 10 m be applied to the greater of the meander belt or regulatory floodline. **Figure 5** of the Natural Environment Report/Environmental Impact Study (Beacon 2017) summarizes environmental constraints relevant to the subject property.

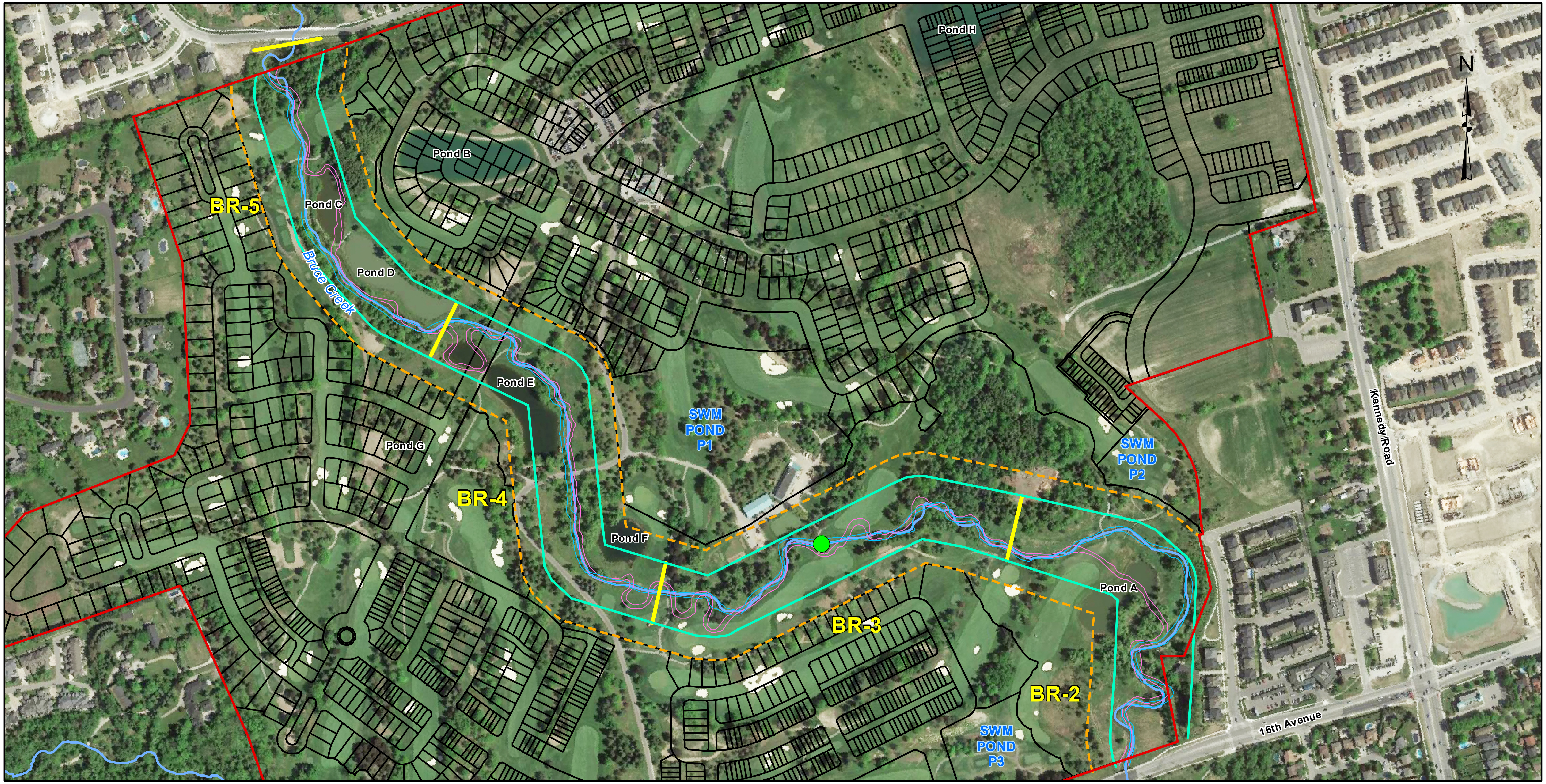
Table 2. Recommended Meander Belt Widths

Reach	Empirical Approach			Desktop Approach (Field Verified)		Recommended Meander Belt Width (m)
	Williams – Area (m) (1986)	Williams – Width (m) (1986)	Ward – Width (m) (2001)	Preliminary Belt Width (m)	Preliminary Belt Width plus 20% Factor of Safety (m)	
BR-2	72	56	75	100	120	**120**
BR-3	68	61	81	80	96	**96**
BR-4	67	56	75	80	96	**96**
BR-5	66	62	82	80	96	**96**
BER-3	53	43	58	130	156	**156**
BER-4	66	55	73	70	84	**84**
BER-5	Not Relevant to Subject Property (Reference Reach Approach)					**84**
BER-6	42	42	57	70	84	**84**

4.2.3 Valley Corridors (Confined Valley Settings)

4.2.3.1 Toe Erosion Allowance

Portions of Bruce Creek and Berczy Creek within or adjacent to the subject property are situated within a confined valley system. A detailed geotechnical study is required to determine the erosion hazard



1:5,000

0 25 50 100 150 200

Legend

- 🟥 Subject Property
- — Development Plan
- — Reach Break
- — Historic Watercourse (1974)
- — Historic Watercourse (1961)
- — Meander Belt Width
- - - Meander Belt + 30m
- ● Bruce Creek Detailed Field Site

JD Barnes: Aerial Photograph, 2015.
MBTW: Subject Property, 2015.
Beacon Environmental, 2017. All other data.

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FIGURE 3A: Meander Belt - Bruce Creek

UTM Zone 17 N, NAD 83

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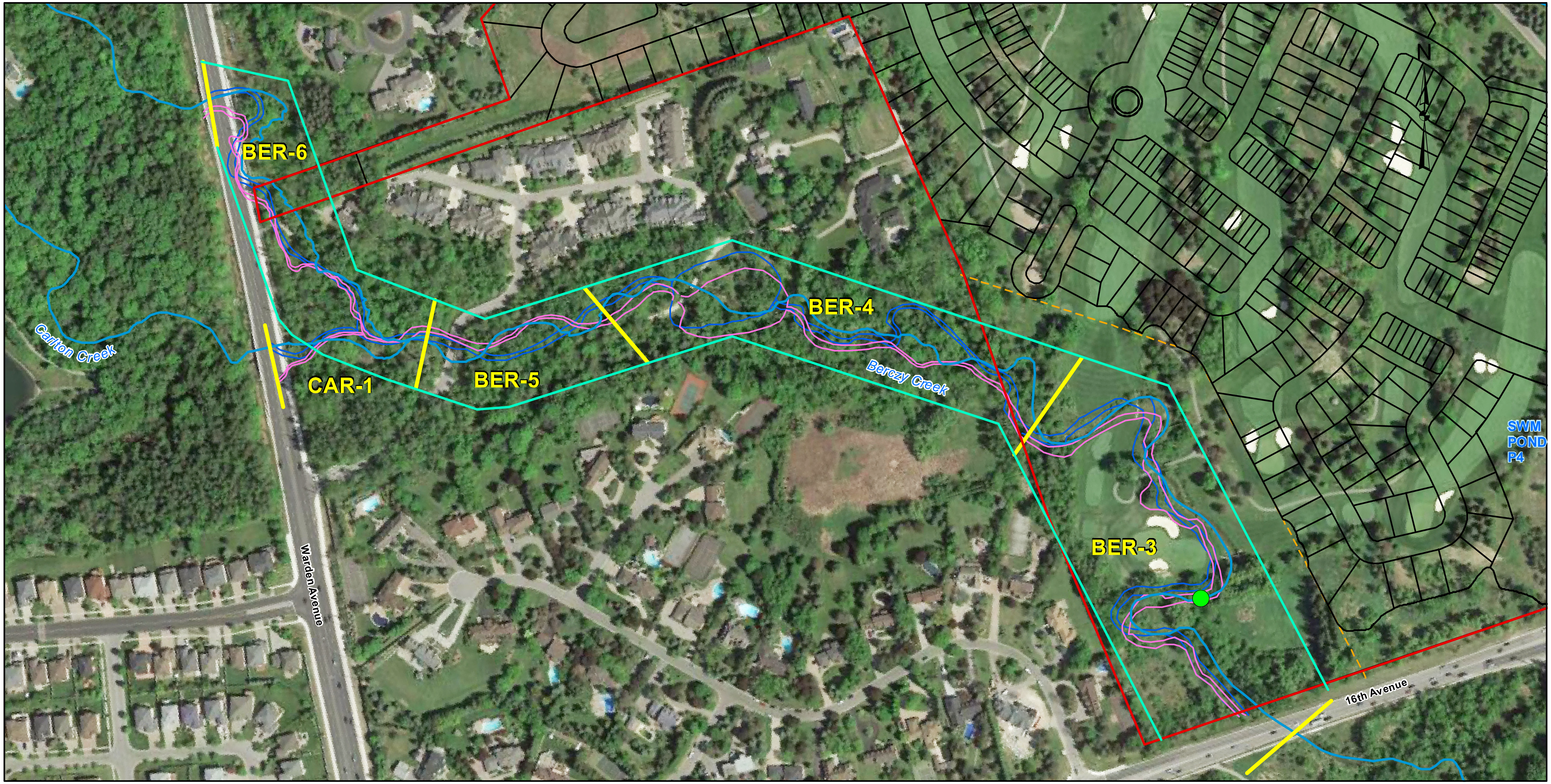

1:3,000

0 15 30 60 90 120

Legend

- ▭ Subject Property
- — Development Plan
- — Reach Break
- — Watercourse
- — Historic Watercourse (1961)
- — Historic Watercourse (1974)
- — Meander Belt Width
- - - Meander Belt + 30m
- ● Berczy Creek Detailed Field Site

JD Barnes: Aerial Photograph, 2015.
MBTW: Subject Property, 2015.
Beacon Environmental, 2017. All other data.

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FIGURE 3B: Meander Belt Width

UTM Zone 17 N, NAD 83

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limit for such areas. Technical support to geotechnical studies is typically provided from a geomorphic perspective through the recommendation of a toe erosion allowance. A toe erosion allowance setback should be applied in the determination of the long-term stable slope at any location where the watercourse is within 15 metres of the base of the valley wall (MMAH 2014).

Bruce Creek

A geotechnical study for the subject property was completed by Golder Associates (2016). Two (2) boreholes were completed in the vicinity of the creek to acquire soil conditions at creek elevation. Based on soil consisting of stiff to hard sandy silty clay till and sandy clayey silt till and referencing MNR Guidelines (Table 3, 2002), a toe erosion allowance of 8 m was recommended.

From a geomorphic perspective, the 8 m toe erosion allowance is considered appropriate, as it is in accordance with Provincial Policy (MMAH 2014) and is reflective of field observations relating to soil composition along the relevant reaches of watercourse, and rapid assessment results pertaining to channel stability.

Berczy Creek

Golder Associates provided comments on slope stability and natural hazard setback requirements for Berczy Creek in a technical memorandum (2016). Based on a visual inspection and soil conditions from boreholes drilled in the general area (soft to hard silty clay with zones of till-like silty clay), a toe erosion allowance of 15 m was recommended. From a geomorphic perspective, this toe erosion allowance is considered conservative, and in accordance with Provincial Policy (MMAH 2014).

Figure 5 of the Natural Environment Report/Environmental Impact Study (Beacon 2017) summarizes environmental constraints (including the Long Term Stable Slope limit) relevant to the subject property.

4.2.4 Stream and Valley Corridors

4.2.4.1 Ontario Regulation 242/08

As Ontario Regulation 242/08 does not distinguish between confined and unconfined systems, **Figures 3A** and **3B** identify lands within 30 m of the meander belt along the entire extent of Berczy Creek and Bruce Creek within the subject property in order to delineate the limits of occupied Redside Dace regulated habitat. As the procedures used to delineate the meander belt are in accordance with applicable guidelines (TRCA 2004), and it is our understanding that MNRF considers these procedures as the standard practice for the determination of occupied regulated habitat limits, it is our opinion that the findings of this report are in conformance with Ontario Regulation 242/08. **Figure 5** of the Natural Environment Report/Environmental Impact Study (Beacon 2017) summarizes environmental constraints relevant to the subject property.

4.3 Rapid Assessments

4.3.1 Methods

In order to characterize existing geomorphic conditions along relevant portions of Bruce Creek and Berczy Creek within the subject property, rapid field assessments were conducted on October 1 and October 7, 2015. The following standardized rapid visual assessment methods were applied:

1. **Rapid Geomorphic Assessment (RGA – MOE 2003)**

The RGA documents observed indicators of channel instability by quantifying observations using an index that identifies channel sensitivity. Sensitivity is based on evidence of aggradation, degradation, channel widening and planimetric form 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 in adjustment (score >0.41).

2. **Rapid Stream Assessment Technique (RSAT – Galli 1996)**

The RSAT uses an index to quantify overall stream health and includes the consideration of biological indicators (Galli 1996). Observations concerning channel stability, channel scouring/sediment deposition, physical in-stream habitat, water quality, and riparian habitat conditions are used to calculate a rating that indicates whether the channel is in poor (<13), fair (13-24), good (25-34), or excellent (35-42) condition.

3. **Downs Classification Method (Downs 1995)**

The Downs (1995; outlined in Thorne et al. 1997) classification method infers present and future potential adjustments based on physical observations, which indicate the stage of evolution, and type of adjustments that can be anticipated based on the channel evolution model. The resultant index classifies streams as stable, laterally migrating, enlarging, undercutting, aggrading, or recovering.

4.3.2 Results

Results of the rapid assessments are summarized in **Table 3** and **Table 4** below. A photographic record of site conditions at the time of the assessment is provided in **Appendix B**. Photo locations are shown in **Figure 2**.

4.3.2.1 Bruce Creek Reach BR-2

Reach BR-2 was characterized as a low-moderately sinuous, historically straightened channel situated within a partially confined valley setting. The reach displayed a moderate gradient and low degree of entrenchment. Riparian vegetation was characterized as fragmented, extending 5-25 m laterally and consisted of shrubs and herbaceous species with few trees. Channel morphology was heavily influenced by the grade control and backwater effect of Toogood Pond. Bank angles were steep with

30-100% of banks exhibiting erosion in the form of scour, slumping and undercutting. Bank materials were dominated by sand. Bankfull channel dimensions ranged from 5.5-8.7 m in width and 0.75-1.0 m in depth. Existing channel disturbances included the 16th Ave crossing, a 1250 mm pond outlet, and cart path and trail crossings.

Rapid assessment results indicated that Reach BR-2 was 'in adjustment', with a score of 0.43. Widening was identified as the dominant mode of adjustment with aggradation and planimetric form adjustment and degradation as secondary processes. Evidence of widening was observed in the form of leaning/fallen trees, exposed tree roots, large organic debris, basal scour through both sides of channel through riffles and slumping banks. Planimetic form adjustment was documented by chute formation, misaligned thalweg and poorly formed bars. Evidence of aggradation was observed via siltation, lateral bar formation and coarse material embedded in riffles. Degradation was noted in the form of exposed bridge/culvert footings and a visible suspended armour layer in the bank. An RSAT score of 16.5 indicated a 'fair' degree of overall ecological health, with channel stability and riparian habitat conditions identified as the primary limiting factors. The Downs model reflected the RGA evaluation of this reach through a classification of M - 'lateral migration' and R - 'recovering' based on observed evidence of migration at most bends within a previously straightened channel.

4.3.2.2 Bruce Creek Reach BR-3

Reach BR-3 was characterized as a well-defined channel situated within a partially confined valley setting. The reach displayed a moderate gradient and moderate degree of entrenchment. Riparian vegetation was characterized as fragmented, extending <1-5 channel widths laterally. Vegetation consisted of trees, shrubs and herbaceous species. Bank angles ranged from moderately steep to steep. Bank materials were dominated by sand. Bankfull widths and depths ranged from 9.0-9.8 m and 0.7-1.55 m, respectively. Riffle substrate consisted of sand, gravel and cobble with scattered boulders. Pool substrate consisted of clay/silt and sand at the margins and gravel and scattered boulders. Evidence of active erosion was observed in the form of undercutting, basal scour and slumping. Historically, the upstream portion of the reach has been channelized. Existing channel disturbances included the 16th Ave crossing, offline pond (Pond A – **Figure 2**), stormwater outfall (**Appendix B** – Photo 11) and cart path and trail crossings. No evidence of excessive scour or erosion (beyond reach-scale processes) was observed in association with the 16th Avenue crossing of Bruce Creek crossing. Within the structure, an overbank zone was observed, but it did not extend the length of the bridge and was only present on one bank (**Appendix B** – Photo 5). The remainder of the structure was inundated at the time of survey. This condition was attributed to the span of the structure relative to the average bankfull width, and backwater influence of the downstream Toogood Pond.

Rapid assessment results indicated that Reach BR-3 was 'in adjustment', with a score of 0.52. Widening was identified as the dominant mode of adjustment with degradation, planimetric form adjustment and aggradation as secondary processes. Evidence of widening was observed in the form of leaning/fallen trees, exposed tree roots, large organic debris, basal scour through greater than 50% of the reach including both sides of channel through riffles, outflanked gabion baskets, exposed previously buried pipe and slumping banks. Degradation was noted in the form of exposed bridge/culvert footings, undermined gabion baskets, a visible suspended armour layer in the bank and channel worn into undisturbed overburden (till). Planimetic form adjustment was documented via chute formation, misaligned thalweg and poorly formed bars. Evidence of aggradation included observed deposition in the overbank zone and coarse material embedded in riffles. An RSAT score of 19.5 indicated a 'fair' degree of overall ecological health, with channel stability and riparian habitat conditions identified as the primary limiting factors. The Downs model reflected the RGA evaluation of this reach through a classification of M - 'lateral migration' based on observed evidence of migration at most bends.

4.3.2.3 Bruce Creek Reach BR-4

Reach BR-4 was characterized as a straightened, well-defined channel situated within an unconfined valley setting. The reach displayed a moderate gradient and moderate degree of entrenchment. Riparian vegetation was characterized as fragmented, extending less than one channel width laterally. Vegetation consisted of shrubs and herbaceous species, with few trees. Bank angles were steep with some banks displaying erosion and undercutting. Bank materials were dominated by sand. Bankfull channel dimensions ranged from 6.0-10.7 m in width and 0.85-1.25 m in depth. Riffle substrate consisted of sand to cobble and pool substrate ranged from clay/silt to gravel. Existing channel disturbances included an internal road crossing for the golf course, as well as cart path crossings and, tile drain outlets and pond outlet. Historically, the reach has been channelized.

Rapid assessment results indicated that Reach BR-4 was 'in transition', with a score of 0.37. Widening was identified as the dominant mode of adjustment with degradation, planimetric form adjustment and aggradation as secondary processes. Evidence of widening was observed in the form of leaning/fallen trees, exposed tree roots, large organic debris, basal scour on both sides of the channel through riffles and slumping banks. Planimetic form adjustment was observed through misaligned thalweg and poorly formed bars. Evidence of aggradation was observed via lateral bar formation and coarse material embedded in riffles. Degradation was noted in the form of exposed bridge/culvert footings and a visible suspended armour layer in the bank. An RSAT score of 17 indicated a 'fair' degree of overall ecological health, with channel stability and riparian habitat conditions identified as the primary limiting factors. The Downs model reflected the RGA evaluation of this reach through a classification of m - 'lateral migration' based on observed alternating bank erosion in a previously straightened channel.

4.3.2.4 Bruce Creek Reach BR-5

Reach BR-5 was characterized as a well-defined channel situated within a partially confined valley setting. The reach displayed a moderate gradient and moderate degree of entrenchment. Riparian vegetation was characterized as fragmented extending less than one channel width laterally. Vegetation consisted of herbaceous species with some trees. Banks were steep with most banks displaying evidence of active erosion including scour and slumping. Bank materials were dominated by sand. Bankfull channel dimensions ranged from 5.9-12.6 m in width and 0.7-0.9 m in depth. Riffle substrate consisted of particles ranging from sand to cobble with some scattered boulders. Pool substrate consisted of mostly sand. Existing channel disturbances included golf cart and pedestrian crossings. Historically, the reach has been channelized.

RGA results indicated that Reach BR-5 was 'in transition', with a score of 0.35. Widening was identified as the dominant mode of adjustment with degradation, planimetric form adjustment and aggradation as secondary processes. Evidence of widening was observed in the form of leaning/fallen trees, exposed tree roots, large organic debris, basal scour on both sides of the channel through riffles and slumping banks. Planimetic form adjustment was observed through chute formation, misaligned thalweg and poorly formed bars. Degradation was noted in the form of exposed bridge/culvert footings and channel worn into undisturbed overburden (till). Minor evidence of aggradation in the form of later bar formation was observed. An RSAT score of 18.5 indicated a 'fair' degree of overall ecological health, with riparian habitat conditions and channel stability identified as the primary limiting factors. The Downs model reflected the RGA evaluation of this reach through a classification of m - 'lateral migration' based on observed alternating bank erosion in a previously straightened channel.

4.3.2.5 Berczy Creek Reach BER-3

Reach BER-3 was characterized as a well-defined channel situated within a partially confined valley setting. The reach displayed a moderate sinuosity, gradient and degree of entrenchment. Riparian vegetation was characterized as fragmented, extending less than one channel width laterally. Vegetation consisted of grasses and herbaceous species, with mature trees along the valley slopes. Bank angles were moderately steep to steep with most banks displaying erosion including slumping. Bank materials were dominated by sand and silt with some clay. Bankfull channel dimensions ranged from 5.0-11.3 m in width and 0.7-1.6 m in depth. Riffle substrate consisted of sand and gravel and pool substrate was comprised of silt, sand, gravel and till. Existing channel disturbances included tile drains, pedestrian crossing, gabion baskets, stone toe protection and the 16th Avenue crossing. No evidence of excessive scour or erosion (beyond reach-scale processes) was observed in association with the 16th Avenue crossing of Berczy Creek, however, the central wall of the twin cell culvert was observed to be accumulating organic debris (**Appendix B** – Photo 40). Sedimentation was observed within the secondary cell. No evidence of scour pool formation was observed downstream of the culvert.

Rapid assessment results indicated that Reach BER-3 was 'in adjustment', with a score of 0.46. Widening was identified as the dominant mode of adjustment with planimetric form adjustment degradation, and aggradation as secondary processes. These processes are consistent with the evidence of erosion observed through the City-Wide Stream Erosion Study Update (AECOM 2014). Evidence of widening was observed in the form of leaning/fallen trees, exposed tree roots, large organic debris basal scour through greater than 50% of the reach including both sides of channel through riffles and inside meander bends and slumping banks. Planimetic form adjustment was observed through chute formation, misaligned thalweg and poorly formed bars. Degradation was noted in the form of exposed bridge/culvert footings, undermined gabion baskets and channel worn into undisturbed overburden (till). Minor evidence of aggradation in the form of later bar formation and deposition in the overbank zone was observed. An RSAT score of 19.5 indicated a 'fair' degree of overall ecological health, with channel stability and riparian habitat conditions identified as the primary limiting factors. The Downs model reflected the RGA evaluation of this reach through a classification of U – 'undercutting' based on observed erosion along outer bank, scoured bed and low embeddedness.

4.3.2.6 Berczy Creek Reach BER-4

Based on the extent assessed, Reach BER-4 was characterized as a well-defined channel situated within a partially confined valley setting. The reach displayed a moderate sinuosity and gradient and low degree of entrenchment. Riparian vegetation was characterized as fragmented extending 6.0-30 m laterally. Vegetation consisted of deciduous and cedar trees and shrubs. Bank angles were moderately steep with bank treatment failure and undercutting. Bank materials were dominated by silt and fine sand. Bankfull channel dimensions ranged from 6.0-8.6 m in width and 0.8-1.3 m in depth. Riffle substrate was comprised of gravel and cobble with some sand and pool substrate was comprised of silt, sand and fine gravel.

Rapid assessment results indicated that Reach BER-4 was 'in adjustment', with a score of 0.43. Widening was identified as the dominant mode of adjustment with planimetric form adjustment degradation, and aggradation as secondary processes. Evidence of widening was observed in the form of leaning/fallen trees, exposed tree roots, large organic debris, basal scour on inside meander bends and outflanked bank treatments. Planimetic form adjustment was observed through chute formation, misaligned thalweg and poorly formed bars. Degradation was noted in the form of undermined crib walls, cut face on bar formations and channel worn into undisturbed overburden (till). Minor evidence of aggradation in the form of later bar formation and deposition in the overbank zone was observed. An RSAT score of 19 indicated a 'fair' degree of overall ecological health, with riparian habitat conditions and physical instream habitat identified as the primary limiting factors. The Downs model classified the reach as U – 'undercutting' based on observed erosion along outer bank, scoured bed and low embeddedness.

4.3.2.7 Berczy Creek Reach BER-6

Based on the extent assessed, Reach BER-6 was characterized as a well-defined channel situated within an unconfined valley setting. The reach displayed a moderate sinuosity, gradient and degree of entrenchment. Riparian vegetation was characterized as fragmented extending 6.0-30 m laterally. Vegetation consisted of established trees, shrubs and herbaceous species. Bank angles were moderately steep with bank treatment failure and undercutting. Bank materials were dominated by silt and fine sand. Bankfull channel dimensions ranged from 6.5-6.6 m in width and 0.55-0.6 m in depth. Riffle substrate was comprised of gravel, cobble, boulder and till and pool substrate was comprised of clay/silt, sand and fine gravel. Existing channel disturbances included Warden Ave crossing, debris jam, pedestrian crossing and road runoff outlet.

Rapid assessment results indicated that Reach BER-4 was 'in transition', with a score of 0.21. Widening was identified as the dominant mode of adjustment with degradation and planimetric form adjustment as secondary processes. Evidence of widening was observed in the form of leaning/fallen trees, exposed tree roots, basal scour on inside meander bends and outflanked bank treatments. Degradation was noted in the form of exposed bridge footings, undermined bank protection, and channel worn into undisturbed overburden (till). Minor evidence of planimetic form adjustment was observed through poorly formed bars. An RSAT score of 18 indicated a 'fair' degree of overall ecological health, with riparian habitat conditions and physical instream habitat identified as the primary limiting factors. The Downs model classified the reach as M – 'lateral migration' based on observed migration of most bends.

4.3.2.8 Ponds and Surface Drainage Features

There are a total of eight (8) ponds on the subject property, five of which are located within the Bruce Creek floodplain (PondA and Ponds C to F). The remaining ponds are located in the northeast corner of the property (Pond H – existing SWM Pond), one near the clubhouse (Pond B) and a smaller pond within the golf course (Pond G).

Several locations where surface drainage may occur were also identified through aerial photo interpretation, and were subsequently investigated as part of the fluvial geomorphology field program (**Figure 2**). All of these features are highly altered as a result of historic agricultural land use practices and the current golf course land use. A general description of their current form is provided in this section. A photographic record of conditions observed at the time of survey is provided in **Appendix**

B. For a complete description of surface drainage features within the subject property, please refer to Section 3.4.5 of the Beacon (2017) Natural Environment Report/Environmental Impact Study.

Ponds

Pond A is located at the southern extent of the property adjacent to Bruce Creek. The water level in this pond is controlled with a spillway. Overflow from the pond spills into Bruce Creek.

Pond B is used for irrigation purposes and was constructed after 2009. This pond is contained within a large berm and does not discharge to Bruce Creek.

Ponds C and D, function in series with an outlet at the south end and are used for golf course hazards and historically for irrigation purposes. Pond E is used for golf course hazard and backup irrigation purposes. Through discussions with golf course staff, it is our understanding that these ponds have not overtopped their banks in this history of the golf course.

Pond G is an isolated golf course hazard pond with no connection to Bruce Creek.

Pond H is a SWM pond that was designed and constructed in 1997, and provides quality and quantity control for the north east portion of the subject property as well as an external existing residential area east of Kennedy Road, and possible surface water run-off from surface drainage feature H2B (refer to Figure 1c of the Natural Environment Report/Environmental Impact Study). It is our understanding that Pond H was designed to discharge water via three different systems as described below:

- To Bruce Creek via an existing storm sewer outfall;
- Auxiliary pipe connection to Pond E to augment water for irrigation (Pond H was retrofitted in the early 2000's with a pipe and valve system and water was conveyed through a pipe under Bruce Creek and discharged in to Pond E as a backup); and
- A valve at the outlet of the pond which historically conveyed flows via a buried stone trench to an area of open conveyance (refer to **Figure 2**, **Photo Location #68**). Presently, it is understood that this control valve is no longer functional. Instead, under large precipitation events, water from the pond is conveyed overland through the existing golf course driving range (refer to **Figure 2**, **Photo Location #67**).

Table 3. General Reach Characteristics – Bruce Creek and Berczy Creek

Reach	Bankfull Width (m)	Bankfull Depth (m)	Substrate	Riparian Vegetation	Notes
BR-2	7.2-8.7	0.75-1.0	Clay/silt, sand, gravel, cobble and boulder	Shrubs and herbaceous species with limited trees	• Undercuts: 0.35-1.0 m • 1250 mm storm outfall • Channel morphology heavily influenced by Toogood Pond
BR-3	7.1-15.0	0.7-1.25	Clay/silt, sand, gravel, cobble and boulder, till	Trees, shrubs and herbaceous species	• Undermined and outflanked gabion baskets • Riprap bank protection • Woody debris
BR-4	6.0-10.7	0.85-1.25	Clay/silt, sand, gravel, cobble and boulder	Trees, shrubs and herbaceous species	• Undercut: 1.0 m • Slumping
BR-5	6.0-12.6	0.7-0.9	Sand, gravel, cobble and some boulder	Tress and herbaceous species	• Exposed till • Chute formation
BER-3	6.0-11.3	0.7-1.6	Silt, sand and gravel	Grasses and herbaceous species with limited trees	• Undermined gabion baskets • Exposed bridge footings • Stone toe protection
BER-4	6.0-8.6	0.8-1.3	Silt, sand, fine gravel, cobble	Trees and shrubs	• Undercuts: >1.5 m • Exposed till • Thalweg misalignment
BER-6	6.5-6.6	0.55-0.6	Clay/silt, sand, gravel, cobble and boulder, till	Trees, shrubs and herbaceous species	• Channel morphology influenced by Warden Ave crossing and road embankment

Table 4. Rapid Assessment Results – Bruce Creek and Berczy Creek

Reach	Rapid Geomorphic Assessment (RGA)			Rapid Stream Assessment Technique (RSAT)			Downs Classification Method
	Score	Condition	Dominant Mode of Adjustment	Score	Condition	Limiting Feature	
BR-2	0.43	In Adjustment	Widening with Aggradation and Planimetric Form Adjustment	16.5	Fair	Channel Stability, Riparian Habitat Conditions	M – 'lateral migration'
BR-3	0.52	In Adjustment	Widening with Degradation and Planimetric Form Adjustment	19.5	Fair	Channel Stability, Riparian Habitat Conditions	M – 'lateral migration' & R- 'recovering'
BR-4	0.37	In Transition	Widening with Planimetric Form Adjustment	17	Fair	Channel Stability, Riparian Habitat Conditions	m – 'lateral migration'
BR-5	0.35	In Transition	Widening with Planimetric Form Adjustment	18.5	Fair	Channel Stability, Riparian Habitat Conditions	m – 'lateral migration'
BER-3	0.46	In Adjustment	Widening with Planimetric Form Adjustment	19.5	Fair	Channel Stability, Riparian Habitat Conditions	U – 'undercutting'
BER-4	0.43	In Adjustment	Widening with Degradation and Planimetric Form Adjustment	19	Fair	Channel Stability, Physical Instream Habitat	U – 'undercutting'
BER-6	0.21	In Transition	Widening with Degradation	18	Fair	Physical Instream Habitat, Riparian Habitat Conditions	M – 'lateral migration'

4.4 Detailed Geomorphic Field Investigation

4.4.1 Selection Criteria for Detailed Field Sites

In support of the MESP, the purpose of undertaking detailed geomorphic data collection is to both provide calibration of the hydrologic model for more frequent return-period flow events, and determine thresholds for sediment entrainment that are used to guide the design of stormwater management facilities. The establishment of formalized geomorphic stations within the subject property will also support post-development monitoring of channel morphology. In consideration of these objectives, the selection of detailed field sites was governed by the following factors:

c) Spatial representation of the subject property;
d) Rapid assessment results which
    - Identify those reaches most sensitive to changes in land use and flow regime (i.e., exhibit evidence of instability); and
    - Classify indicators of channel instability into modes of adjustment to designate dominant processes on a reach basis, but also within the overall watercourse system;
e) Presence of a (relatively) natural channel form (i.e., minimal evidence of channelization or hardening);
f) Location of proposed location of stormwater management facilities (determine which stream reaches will receive stormwater contributions post-development); and
g) Land ownership (i.e., working within the subject property or public lands).

Based on these criteria, Reaches BER-3 and BR-3 were selected as detailed geomorphic field stations (**Figures 3A** and **3B**):

h) Both reaches provided appropriate spatial representation of the subject property;
i) RGA scores identified both reaches as the most sensitive reaches to alterations in land use and flow regime within each system based on
    - Highest overall score; and
    - Exhibiting modes of adjustment that were reflective of the overall system – specifically, both reaches exhibited evidence of bank erosion and widening which was flagged as a dominant theme along both Berczy Creek and Bruce Creek;
j) Presence of a (relatively) natural channel form
    - Results of the historic assessment identified extensive channelization along both Berczy and Bruce Creek – relative to other reaches within the subject property, Reaches BR-3 and BER-3 have retained a more natural meander geometry and channel form (i.e., sinuous planform with minimal bank protection);
k) Both reaches will receive stormwater post-development; and
l) Both reaches are located within the subject property.

By selecting the most sensitive reaches on each system, the erosion threshold will represent a conservative approach to managing the release of stormwater to Berczy and Bruce Creeks. The ultimate objective associated with this methodology is to minimize the risk of exacerbating existing rates of erosion within each watercourse (i.e., avoidance of impacts to channel morphology and aquatic habitat) under the post-development scenario.

4.4.2 Methodology and Results

Detailed geomorphic data collection was completed on various dates between December 2015 and April 2016. Field methods included measurements of bankfull or 'active' channel dimensions, using standard protocols and accepted field indicators. Additionally, a longitudinal survey of bed morphology, planform, and bankfull stage indicators was completed. Riparian cover, bank materials (type and strength) and general channel condition were documented using standard field protocols. A pebble count following Wolman (1954) was completed for each surveyed cross-section. Sediment samples of riffle substrate, pool substrate, composite bed materials, and bank materials were also collected and submitted to Thurber Engineering for laboratory analysis. Selected channel parameters from the detailed assessment are provided in **Table 5**, while a detailed summary of data collection results has been provided in **Appendix C**.

4.4.2.1 Bruce Creek, Reach BR-3

Overall, the surveyed portion of **Reach BR-3** had an average bankfull gradient of 0.44%. The channel displayed a moderate degree of entrenchment, and riffle-pool bed morphology. Bankfull channel widths (riffles and pools) varied from approximately 7.1 to 15.6 m, averaging about 10.7 m. The average bankfull depth was 0.65 m, resulting in a width-to-depth ration of 16.6. Selected channel parameters from the detailed assessment are provided in **Table 5**.

Cross-section measurements, bankfull characteristics and channel roughness were used to back-calculate bankfull hydraulics. Using a simple Manning's n (0.033) approach, the calculated bankfull velocity was 1.40 m/s and the calculated bankfull discharge was 6.6 m^3/s. The flow competency and critical shear stress for D_{50} (median particle size) were calculated using Komar (1987). A comparison of flow competency calculations to bankfull hydraulics indicates that sediment entrainment theoretically occurs well below the bankfull event; however, armouring of the coarsest component of the bed materials (large gravel to cobble) will not only influence hydraulic conditions under which bed mobilization occurs, but the boundary layer associated with these materials will influence the hydraulic conditions associated with 'threshold conditions' (i.e., entrainment of the median particle size).

4.4.2.2 Berczy Creek, Reach BER-3

Overall, the surveyed portion of **Reach BER-3** had an average bankfull gradient of 0.30%. The channel displayed a moderate degree of entrenchment, and riffle-pool bed morphology. Bankfull channel widths (riffles and pools) varied from approximately 6.0 to 11.9 m, averaging about 8.7 m. The average bankfull depth was 0.67 m, resulting in a width-to-depth ration of 14.4. Selected channel parameters from the detailed assessment are provided in **Table 5**.

Cross-section measurements, bankfull characteristics and channel roughness were used to back-calculate bankfull hydraulics. Using a simple Manning's n (0.033) approach, the calculated bankfull velocity was 1.20 m/s and the calculated bankfull discharge was 7.24 m^3/s. The flow competency and critical shear stress for D_{50} (median particle size) were calculated using Komar (1987).). As with BR-3, a comparison of flow competency calculations to bankfull hydraulics indicates that sediment entrainment theoretically occurs well below the bankfull event; however, armouring of the coarsest component of the bed materials (large gravel to cobble) will not only influence hydraulic conditions under which bed mobilization occurs, but the boundary layer associated with these materials will influence the hydraulic conditions associated with 'threshold conditions' (i.e., entrainment of the median particle size).

Table 5. Summary of Field-based and Calculated Parameters – Detailed Field Sites

Parameter	BR-3	BER-3
Governing energy gradient (%)	0.44	0.30
Average bankfull width (m)	10.7	8.7
Average bankfull depth (m)	0.65	0.67
Maximum bankfull depth (m)	0.85	0.92
Average width-depth ratio	16	13
Bank angles (degrees)	20-90	
Bank materials	Silt, sand, clay, gravel (with exposed till)	Silt, sand and gravel (with exposed till, cobble, boulder)
Undercut banks (%)	44	20
D10 (mm) – riffle	--	--
D50 (mm) – riffle	9.3	6.3
D84 (mm) – riffle	49	40
Manning's n-value (estimated)	0.030	0.030
Bankfull discharge (m^3/s)	6.6	7.2
Bankfull velocity (m/s)	1.4	1.2
Unit stream power (W/m^2)	29	22
Tractive force (N/m^2)	23	20
Flow competency for D_{50} (Komar, 1987 – m/s)	0.60	0.50

5. Analysis

The following section outlines methods of analysis and results for the fluvial geomorphic component of the MESP.

5.1 Erosion Threshold Determination

Erosion and deposition are natural processes that are necessary for the maintenance of channel form and function. Changes in land use can result in changes in the magnitude and duration of surface runoff produced by rain events, which can result in increased rates of erosion. Appropriate stormwater management techniques can typically mitigate the impacts associated with land use change by reducing the magnitude of post-development storm events. Surface runoff is collected and detained in stormwater management facilities (SWMF), then released at a prescribed flow rate. Ideally, this controlled release also closely mimics the duration of pre-development storms. The total volume of post-development runoff can also be reduced through the implementation of low impact development techniques (LIDs). The overall objective of these management tools is to match, to the extent possible, pre-development flow conditions.

Erosion thresholds often represent the hydraulic parameter by which pre- and post-development flow conditions are compared. An erosion threshold defines the theoretical hydraulic conditions under which sediment is entrained and transported within the channel. Specifically, the threshold represents a depth, velocity, or discharge at which sediment of a particular size class (usually the median or average grain size material) may potentially be entrained. This does not necessarily imply that systemic erosion (i.e., widening or degradation of the channel) will occur if the threshold is exceeded; it simply indicates flow conditions at which sediment entrainment (i.e., initiation of motion of materials) is likely to occur.

The TRCA (2012) Stormwater Management Criteria, provides geomorphologic methodologies for determining erosion thresholds. **Table 6** presents an overview of threshold analysis resources presented in the TRCA guidance document.

Table 6. Overview of Commonly Applied Sediment Entrainment Models (TRCA 2012)

Sediment Entrainment Model	Type	Range of Applicability
Chow (1959)	Critical Shear Stress	Cohesive materials (Clay and Silt)
Fischenich (2001)	Critical Shear Stress	Cohesive and non-cohesive material
Hjulstrom (1967)	Critical Velocity	Non-cohesive material (sand and coarser)
Komar (1987)	Critical Velocity	Non-cohesive material (gravel and larger)
Miller et al. (1977)	Critical Shear Stress	Non-cohesive material (sand and coarser)
Neill (1967)	Critical Velocity	Non-cohesive material (sand and coarser)
Temple (1982)	Tractive Force	Vegetated Channels
vanRijn (1984)	Critical Shear Stress	Non-cohesive material (medium sand and coarser)

5.1.1 Methodology and Results

For the purposes of this study, both Komar (1987) and Miller, *et al.* (1977) were applied to two reference riffle cross-sections for both Reaches BR-3 and BER-3 to determine hydraulic thresholds for sediment entrainment. Reach-averaged grain size distribution data (riffles and pools) was referenced to calculate the median grain size (D_{50}). It should be noted that the D_{50} for both sites fell within the fine gravel size class. Further, within both sites, hydraulic boundary roughness associated with an armoured gravel and cobble component of the bed was observed to limit the capacity of Berczy and Bruce Creeks to transport sediment under more frequent flow conditions.

In reviewing the calculated critical shear stress (Miller, *et al.* 1977) and permissible velocity (Komar, 1987) identified for each reach based on the D_{50}, and comparing this value to flow conditions (average and maximum water depth) observed at the time of survey, it was determined that a critical shear stress represented the most appropriate hydraulic parameter by which to establish an erosion threshold for Reaches BR-3 and BER-3. Based on our analysis of each system, the Komar (1987) model under-predicted velocities required for sediment entrainment. The source of this under-prediction by the theoretical model was attributed to the lack of uniform bed materials, and the influence of the coarser bed component on boundary layer conditions (larger substrate creating a ‘sheltering’ effect).

Critical shear stress values of 9.6 N/m^2 and 6.5 N/m^2 were identified for Bruce Creek and Berczy Creek, respectively. Based on this critical shear stress, threshold-condition hydraulic parameters were then back-calculated to identify an associated maximum water depth, average water depth, velocity and discharge values that would correlate to this condition. Results of the erosion threshold analysis are presented in **Appendix D** and **Table 7**. While the recommended thresholds were based on the median grain size of the bed materials, the potential for bank erosion under threshold hydraulic conditions was also considered through this analysis. As a result, the proposed targets are considered appropriate and reflective of the morphologic processes observed along Bruce Creek and Berczy Creek within the subject property.

Table 7. Summary of Erosion Threshold Analysis – Reaches BR-3 and BER-3

Watercourse	Erosion Threshold	Threshold-Condition Hydraulic Parameters (calculated using representative cross-sections)				Threshold Discharge as a Percentage of Bankfull Discharge (%)
	Critical Shear Stress (N/m^2)	Maximum Water Depth (m)	Average Water Depth (m)	Velocity (m/s)	Discharge (m^3/s)	
Bruce Creek (Reach BR-3)	9.6	0.31	0.22	0.74	0.90	14
Berczy Creek (Reach BER-3)	6.5	0.33	0.22	0.61	0.89	12

It should be noted that, in natural systems, erosion thresholds are exceeded regularly, ensuring the downstream delivery of sediment. As such, the key to maintaining natural channel function of a system is not to prevent exceedance of the threshold, but to ensure that the frequency and duration of time for which it is exceeded does not substantively increase under the post-development conditions (i.e., existing rates of erosion should not be exacerbated under the future land use scenario). **Section 6.0** describes additional verification of the erosion threshold through integration with the pre and post-development hydrologic and hydraulic modelling being completed by Stantec Engineering, as well as the results of the erosion threshold exceedance analysis.

6. Impact Assessment

The proposed residential development is detailed in the two draft plan of subdivision applications that accompany this OPA application. There is one draft plan of subdivision for the east portion of the property and one for the west portion of the property (**Figure 1**). The west draft plan of subdivision contains a mix of residential, mixed use, open space blocks, parks, and SWM ponds. The west draft plan of subdivision also contains the valleylands associated with both the Berczy Creek and the Bruce Creek. The east draft plan of subdivision contains a mix of residential, open space blocks, elementary school block, parks, and SWM ponds. In order to understand the potential impacts of the proposed development plan on channel morphology, an impact assessment was undertaken with respect to stormwater management (erosion control, SWM pond outfalls, foundation drain collectors and roof leader collectors), in addition proposed natural heritage system crossings.

6.1 Stormwater Management

6.1.1 Stormwater Erosion Control

6.1.1.1 Agency Consultation

Per the TRCA Watercourse Erosion Analysis Design and Submission Requirements in Support of Secondary Plans (2007d),

> *"When preparing a Master Environmental Servicing Plan, erosion analysis is required to assess the impact of development on in-stream erosion potential, and to establish erosion control targets for Stormwater Management facilities."*

Erosion analysis objectives include the determination of erosion thresholds along reaches sensitive to erosion through desktop and field analysis, prediction of stream response to changes in flow regime as a result of development and establishment of erosion control criteria to maintain existing in-stream erosion potential under post-development conditions (TRCA, 2007d).

A meeting with the TRCA was held on June 6, 2016 to review preliminary results relating to the fluvial geomorphic assessment, and discuss MESP submission requirements relating to stormwater management for erosion control for the 2016 Fluvial Geomorphology Report submission. Based on this consultation process, the following methodology was established for stormwater erosion analyses:

- Identification of reaches, of both Bruce Creek and Berczy Creek, sensitive to erosion based on collected detailed geomorphic field data;
- Referencing TRCA SWM criteria and flow conditions at the time of survey, establish thresholds for sediment entrainment for Bruce Creek and Berczy Creek;
- Estimate baseflow conditions for Bruce Creek and Berczy Creek, referencing TRCA gauging data, stream flow monitoring data, and geomorphic field data for each watercourse;
- Integrate the estimated baseflow component with the hydrologic model output (VO2) - 25 mm, 30 mm and 35 mm synthetic events;
- Calibrate and verify output from the VO2 hydrologic model by comparing the existing condition model to field-based estimates of flow (i.e., bankfull flow);
- Undertake a comparison pre- and post-development (controlled) flow conditions for the 25 mm, 30 mm and 35 mm storm events under 24 hour, 48 hour and 72 hour detention scenarios (event-based modelling) for nodes located at the downstream limit of the site to evaluate how closely post-development conditions can replicate existing condition hydrograph (peak, volume and form), focussing on those portions of the hydrograph above the critical discharge;
- Integration of the VO2 model output from the above scenarios into a software program which uses representative surveyed cross-sections of the active (bankfull) channel to calculate pre-development and post-development cumulative exceedance of the erosion threshold parameters for Bruce Creek and Berczy Creek. In this sense, continuous modelling for threshold exceedance will be undertaken for a finite time series (i.e., length of generated 25 mm, 30 mm and 35 mm storm event). Model outputs include:

    - Time of exceedance;
    - Cumulative effective velocity;
    - Cumulative effective discharge; and
    - Cumulative effective work/shear stress;
- To validate the modelled time of exceedance results, percent exceedance was also calculated manually using the raw time step hydrograph data provided by Stantec;
- For the purposes of the MESP, pre- to post-development flow conditions will be considered a match if post-development hours of exceedance, cumulative effective velocity, cumulative effective discharge and cumulative effective work/shear stress are within 5% of the existing condition.

As part of this report, and to address agency comments, the comparison of pre- and post-development (controlled) flow conditions was expanded to not only include the 25 mm, 30 mm and 35 mm storm events, but also the 5-year, 25-year and 100-year storms (12 hour AES) under 24 hour, 48 hour and 72 hour detention scenarios. This approach was discussed with TRCA staff during a conference call meeting held on September 8, 2017. At this time, it was also noted that the 30 mm event would be used as a surrogate for the 2-year modelled storm event in the erosion control analysis.

It should be noted that the larger storms events have a broader distribution and different time to peak than the 4 hour 25 mm, 30mm and 35mm previously analyzed. Additionally, these previously analyzed smaller storms for both Bruce Creek and Berczy Creek used the same control requirement of detaining the 25 mm storm for 24, 48 or 72 hours.

With the revised assessment, differences in the results between the two creeks were anticipated for the larger storms (5, 25 and 100 year events) as Bruce Creek requires quantity control for the 5, 25, 100 year storms while Berczy Creek does not. For Berczy Creek, the outflow from the pond is similar to the inflow (for both time to peak and peak flow) for larger storm events. For Bruce Creek, some over control within the ponds occurs for mid-range storms like the 5 and 25 year storm. As such, the length of time above the threshold flow may be longer than if no quantity control was required.

It should also be noted that the Bruce Creek proposed conditions hydrology model is more discretized than the existing conditions model provided by TRCA. The TRCA existing conditions model parameters incorporate one lumped catchment draining to one lumped pond. For the proposed conditions, the sub-catchment was discretized to include:

- Existing developed areas without controls;
- Undeveloped areas without controls;
- Existing developed areas with controls; and
- Proposed development areas with controls.

As a result, it was anticipated that the peak flow and length of time above the threshold flow may differ from the existing conditions model.

6.1.1.2 Verification of Modelled Storm Events

Field-based estimates of bankfull flow were compared to the modelled 25 mm and 2-year storm event. Results of the comparison (presented in **Table 8**) indicated a correlation between the modelled frequent flows, and the field-estimated bankfull discharge. Further, representative cross-sections from the detailed field investigation could be used to back-calculate flow depths associated with the modelled storm events (**Figure 4**).

Table 8. Verification of VO2 Synthetic Storm Events

Watercourse and Reach	Field-based Estimate Bankfull Discharge (m^3/s)	Modelled 25 mm Storm Event (m^3/s)	Modelled 2-year Storm Event (m^3/s)
Bruce Creek (Reach BR-3)	6.60	4.40	13.3
Berczy Creek (Reach BER-3)	7.24	3.60	11.5

6.1.1.3 Estimation of Baseflow Component

As the synthetic storm events generated by the VO2 model do not account for a baseflow condition within the watercourse, estimates of baseflow were developed for both Berczy and Bruce Creek. The estimated flows were back-calculated based on average water depths identified during the rapid field assessment work and two representative riffle cross-sections, the following baseflows were recommended:

- Berczy Creek: 0.12 cms (max water depth of 0.15 m, ave water depth of 0.08 m); and
- Bruce Creek: 0.22 cms (max water depth of 0.17 m, ave water depth of 0.12 m through riffle).

These flows were manually added to flows provided in the raw VO2 output files provided by Stantec Engineering to develop hydrographs for the 25 mm, 30 mm, 35 mm, 5-year, 25-year and 100-year storm events in order to incorporate a baseflow component.

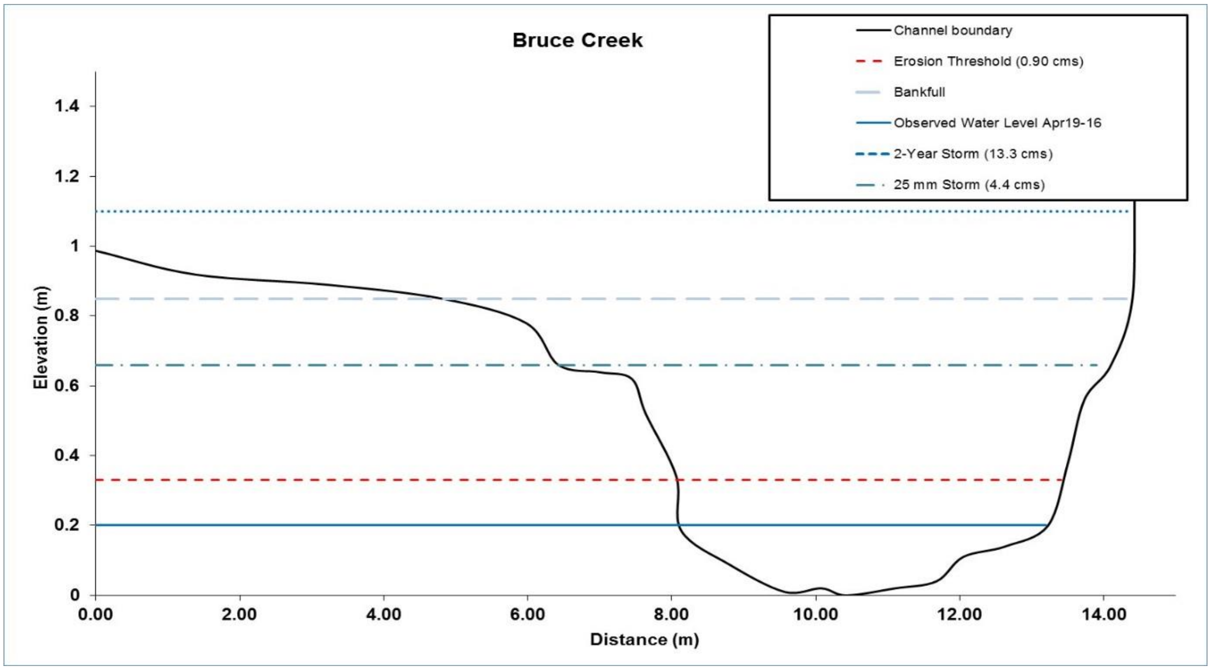


Figure 4. Sample verification of VO2 synthetic storm events (Bruce Creek).

6.1.1.4 Exceedance Analysis (Post-Development Condition)

For the erosion control analysis, output from the V02 model provided by Stantec Engineering was analyzed using an in-house erosion analysis model. In addition to the raw hydrograph time-step data, the following input parameters are required by the model:

- Representative channel cross-section – for the bankfull channel, a representative riffle cross-section from the detailed field investigation was used. For the floodplain and corridor dimension, a representative cross-section from the HEC-RAS model was provided by Stantec;
- Energy gradient – energy gradients referenced in the determination of erosion thresholds were used for the exceedance analysis;
- Manning's 'n' roughness coefficient – a roughness coefficient of 0.033 was utilized for the bankfull channel, and a roughness coefficient of 0.08 was utilized for the floodplain and corridor; and
- Erosion threshold – the critical shear stress of 9.6 N/m^2 and 6.5 N/m^2 was utilized for Bruce Creek and Berczy Creek, respectively.

The model then generates a rating curve based on the representative cross-section and routes the hydrograph, calculating the cumulative exceedance for each hydraulic parameter in relation to the entered erosion threshold value. An illustrative example of a representative cross-section is provided in **Figure 5**. Effectively, the model represents a tool by which the volume, magnitude and duration of post-development hydrologic events can be compared to pre-development conditions. The erosion threshold represents the control point of comparison by which to evaluate difference and, as such, potential impact. Hydraulic parameters associated with the rating curve were validated by comparing depths and flows to field-based data for Berczy Creek and Bruce Creek.

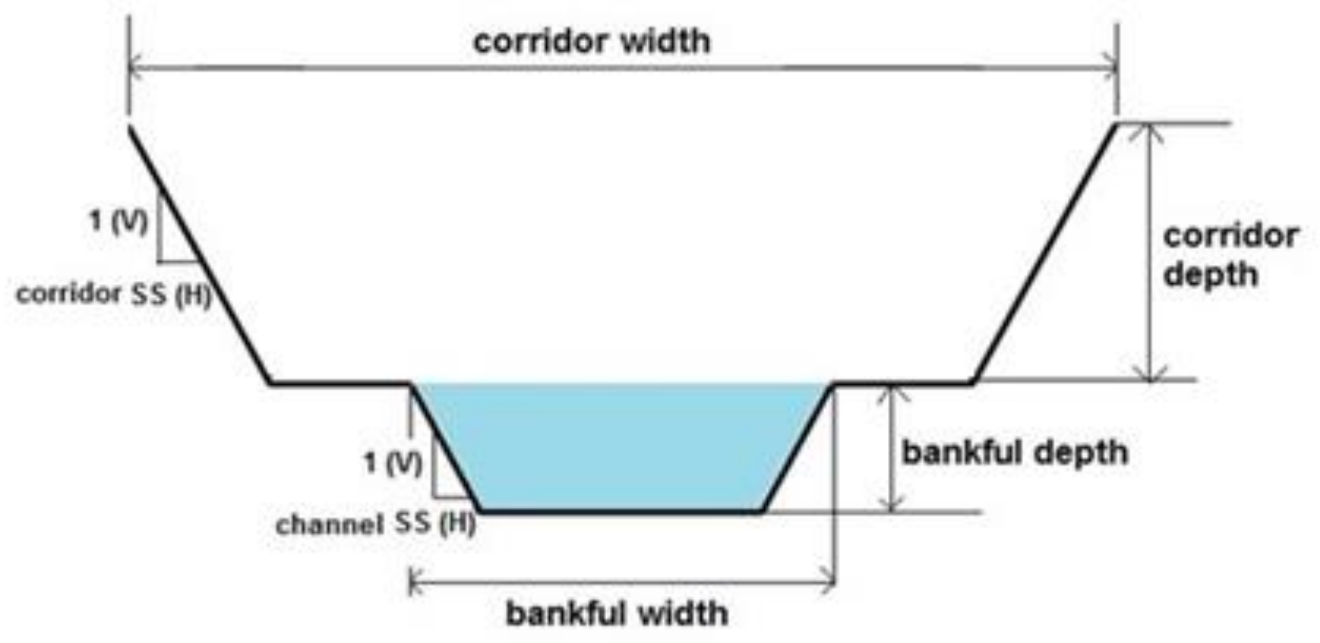


Figure 5. Schematic of representative cross-section.

6.1.1.5 Results

The cumulative exceedance analysis results for all evaluated pre-development and post-development scenarios are presented in **Tables 9** and **10**. These raw values were then converted to a percent difference to allow a quantitative comparison of pre-development and post-development hydraulic conditions within each watercourse (**Tables 11** and **12**).

Table 9. Berczy Creek Pre- and Post-development Cumulative Exceedance Results

Rain Event	**Development Condition**	**Detention Time**	**Berczy Creek Cumulative Pre-Development vs. Post-Development Conditions**				
			Time (hr)	**Discharge (cms)**	**Velocity (m/s)**	**Shear Stress (N/m^2)**	**Work/Stream Power (N/m)**
25 mm	Pre		19	92735	12784	207674	181823
	Post	24 hour	19	93193	12828	208417	182678
		48 hour	19	91905	12689	206047	180145
		72 hour	19	90772	12547	203690	177926
30 mm	Pre		20	166082	19545	326569	323354
	Post	24 hour	22	248891	25585	326981	323524
		48 hour	20	164915	19456	324890	321022
		72 hour	20	163500	19295	322184	318278
35 mm	Pre		21	248821	25545	436753	476377
	Post	24 hour	22	248891	25585	437258	476371
		48 hour	22	247894	25502	435776	474511
		72 hour	21	246208	25326	432783	471285
5-Year	Pre		26	622580	45584	850578	1173849
	Post	24 hour	26	622438	45572	850313	1173424
		48 hour	26	622698	45569	850374	1173870
		72 hour	26	619740	45335	846092	1168275
25-Year	Pre		27	1049149	60220	1203957	1928844
	Post	24 hour	27	1048220	60223	1204113	1928326
		48 hour	27	1049908	60283	1205568	1931413
		72 hour	27	1045455	60004	1200141	1923205
100-Year	Pre		28	1427488	69970	1450998	2522174
	Post	24 hour	28	1425644	69966	1451234	2521619
		48 hour	28	1428615	70066	1453649	2526802
		72 hour	28	1422852	69757	1447424	2516561

Table 10. Bruce Creek Pre- and Post-development Cumulative Exceedance Results

Rain Event	Development Condition	Detention Time	Bruce Creek Cumulative Pre-Development vs. Post-Development Conditions				
			Time (hr)	Discharge (cms)	Velocity (m/s)	Shear Stress (N/m^2)	Work/Stream Power (N/m)
25 mm	Pre		15	83236	11444	249171	269894
	Post	24 hour	15	94536	12771	278664	306609
		48 hour	15	88443	12082	263280	286806
		72 hour	15	85532	11733	255530	277350
30 mm	Pre		17	157085	18750	415767	507829
	Post	24 hour	18	172672	20270	450465	557621
		48 hour	18	163703	19441	431385	529032
		72 hour	17	159613	19009	421633	515938
35 mm	Pre		19	245364	25830	582580	784652
	Post	24 hour	19	263484	27387	618737	841172
		48 hour	19	253011	26503	598149	808456
		72 hour	19	248997	26077	588551	795732
5-Year	Pre		23	674186	51253	1265812	2200924
	Post	24 hour	30	703185	54467	1339022	2295250
		48 hour	29	690841	53416	1313825	2255129
		72 hour	28	686107	52826	1300736	2239894
25-Year	Pre		24	1167373	71140	1864793	3781759
	Post	24 hour	34	1207595	76025	1974577	3913486
		48 hour	33	1194155	74921	1948023	3870198
		72 hour	32	1189225	74292	1934181	3854445
100-Year	Pre		25	1607316	85088	2309527	5141343
	Post	24 hour	36	1656884	91313	2448847	5304689
		48 hour	36	1642577	90158	2421083	5258878
		72 hour	35	1637628	89506	2406837	5243065

The results of the Berczy Creek exceedance analysis presented in **Table 11** indicate a minimal change in flow conditions under all evaluated scenarios. These results are reflective of the subject property's relatively small contribution to the total catchment area of Berczy Creek. That stated, negative exceedance values were identified for the 48-hour and 72-hour detention time scenarios for the more frequent storm events, and the 72-hour detention time scenario for the larger storm event (5, 25 and 100 year storms). As quantity control is not provided beyond the 25 mm event for Berczy Creek (SWM Pond 4), this result reflects the initial abstraction of volume by Pond 4, as well as the differing timing and distribution of flows between the 25 mm, 30 mm, and 35 mm storms (peaky 4 hour storms) and the larger storm events (12 hour AES storm with a broader distribution and time to peak). As the relative difference between detention time scenarios for all of the analyzed storm events fall within the tolerances/accuracy of the models employed, none were considered to be sufficient to justify a recommendation with respect to erosion control that is in contradiction of the preferred flood control scenario of a 48 hour detention time.

Table 11. Berczy Creek Exceedance Analysis – Percent Difference

Rain Event	Detention Time	Berczy Creek Cumulative Exceedence Parameters (%) Pre-Development vs. Post-Development Conditions				
		Time (hr)	Discharge (cms)	Velocity (m/s)	Shear Stress (N/m^2)	Work/Stream Power (N/m)
25 mm	24 hour	1.0%	0.5%	0.3%	0.4%	0.5%
	48 hour	1.0%	-0.9%	-0.7%	-0.8%	-0.9%
	72 hour	0.02%	-2.1%	-1.9%	-1.9%	-2.1%
30 mm	24 hour	1.5%	0.1%	0.2%	0.1%	0.1%
	48 hour	1.1%	-0.7%	-0.5%	-0.5%	-0.7%
	72 hour	0.8%	-0.9%	-0.6%	-0.7%	-1.6%
35 mm	24 hour	0.3%	0.0%	0.2%	0.1%	0.0%
	48 hour	-0.04%	-0.4%	-0.2%	-0.2%	-0.4%
	72 hour	-0.4%	-1.1%	-1.3%	-1.3%	-1.1%
5-Year	24 hour	0.5%	0.0%	0.0%	0.0%	0.0%
	48 hour	0.2%	0.0%	0.0%	0.0%	0.0%
	72 hour	-0.1%	-0.5%	-0.5%	-0.5%	-0.5%
25-Year	24 hour	0.2%	-0.1%	0.0%	0.0%	0.0%
	48 hour	0.2%	0.1%	0.1%	0.1%	0.1%
	72 hour	-0.1%	-0.4%	-0.4%	-0.3%	-0.3%
100-Year	24 hour	1.3%	-0.1%	0.0%	0.0%	0.0%
	48 hour	1.0%	0.1%	0.1%	0.2%	0.2%
	72 hour	0.7%	-0.3%	-0.3%	-0.2%	-0.2%

For Bruce Creek, the exceedance results presented in **Table 12** reflect the larger contribution of drainage area from the subject property relative to the upstream catchment area. Typically increases in exceedance associated with stormwater pond contributions occur within the falling limb of the hydrograph, as volumes associated with the 'shaved' peak of the hydrograph augment the tail end of the storm. In reviewing the pre- and post-development hydrographs for each scenario, it was noted that the increases in exceedance under the post-development scenario were primarily evident on the rising limb of the curve. In essence, these results indicate that the SWM ponds are performing as intended, with minimal differences in the falling limb between the three scenarios.

Percent exceedance under the 24-hour detention time scenario were consistently higher for all hydraulic parameters and all analyzed storm events, with the highest exceedances and relative difference observed for the frequent storm events. For this reason, the 24-hour detention scenario was identified as the least preferred SWM design option for Bruce Creek.

Results for the 48- hour and 72-hour detention scenarios were similar, with percent exceedance values generally falling within 5% for all hydraulic parameters. Consequently, any apparent improvements between the 48- and 72-hours scenarios in erosion control that could be interpreted from the results presented in **Table 12** do not appear to be a function of volume detention, but more closely reflect the parameterization inherent within the VO2 model, and timing of peak flows routing through the subject property relative to flows from the upstream catchment area.

Table 12. Bruce Creek Exceedance Analysis – Percent Difference

Rain Event	Detention Time	Bruce Creek Cumulative Exceedence Parameters (%) Pre-Development vs. Post-Development Conditions				
		Time (hr)	Discharge (cms)	Velocity (m/s)	Shear Stress (N/m^2)	Work/Stream Power (N/m)
25 mm	24 hour	6.6%	14%	12%	12%	14%
	48 hour	5.8%	6.3%	5.6%	5.7%	6.3%
	72 hour	3.8%	2.8%	2.5%	2.6%	2.8%
30 mm	24 hour	5.6%	9.9%	8.1%	8.3%	9.8%
	48 hour	5.6%	4.2%	3.7%	3.8%	4.2%
	72 hour	3.6%	1.6%	1.4%	1.4%	1.6%
35 mm	24 hour	5.3%	7.4%	6.0%	6.2%	7.2%
	48 hour	6.3%	3.1%	2.6%	2.7%	3.0%
	72 hour	3.3%	1.5%	1.0%	1.0%	1.4%
5-Year	24 hour	5.6%	4.3%	6.3%	5.8%	4.3%
	48 hour	5.6%	2.5%	4.2%	3.8%	2.5%
	72 hour	3.4%	1.8%	3.1%	2.8%	1.8%
25-Year	24 hour	4.8%	3.4%	6.9%	5.9%	3.5%
	48 hour	4.9%	2.3%	5.3%	4.5%	2.3%
	72 hour	2.9%	1.9%	4.4%	3.7%	1.9%
100-Year	24 hour	5.8%	3.1%	7.3%	6.0%	3.2%
	48 hour	5.7%	2.2%	6.0%	4.8%	2.3%
	72 hour	3.7%	1.9%	5.2%	4.2%	2.0%

Given this understanding of factors driving the exceedance analysis results for Bruce Creek, the 48-hour detention approach was selected as the preferred post-development SWM scenario as it generally achieves percent difference for all hydraulic parameters of within 5%, while most accurately reflecting modelled existing conditions that indicate conveyance of peak flows associated with drainage from the subject property moving through the system ahead of flows from lands upstream. It is understood that this approach is also preferred from a flood control perspective. Further, this approach ensures avoidance, to the greatest extent possible, of stormwater overcontrol which is undesirable in both Bruce

Creek and Berczy Creek, as the transport of sand-sized material and washload within both systems is critical to the long-term maintenance of channel morphology and aquatic habitat conditions.

6.1.2 SWM Pond Outfalls

The location of proposed SWM Pond outfalls are identified on Figures 2.8-2.11 of the MESP Servicing and Grading Report (Stantec 2017). All of the proposed SWM Pond outfalls achieve an appropriate offset from the active channel in order to mitigate long-term risk of erosion to this infrastructure. Outfalls associated with Ponds 1, 3 and 4 are located outside of the meander belt limit. The Pond 2 design proposes the use of an existing headwall that is located at the meander belt limit. The use of this existing headwall will minimize disturbance to the stream corridor and, based on observations collected during the field investigation, no erosion or channel impacts were observed at the time of assessment.

6.1.3 Foundation Drain Collectors and Roof Leader Collectors

A foundation drain collection (FDC) system is needed in areas where the storm sewer is not low enough for basement connections (Stantec 2017). The proposed FDC will collect cool clean water which can be directly released into the valley system through stone trenches. Perforated Roof Leader Collector (RLC) pipes are proposed to collect roof drainage and promote infiltration within the road right-of-way. In one location, a perforated RLC pipe will outlet into an FDC pipe, and is referred to as an FDRLC. This pipe outlets to wetland stone reservoir within the old golf course irrigation pond. A separate RLC pipe is proposed to collect clean water and release it to a proposed enhancement ‘Area E’ located west of Street “D” East. A flow dispersal mechanism will be installed at the outfall of the RLC pipe prior to release of the flow into the open space area.

Figure 2.13 of the MESP Servicing and Grading Report (Stantec 2017) illustrates the proposed FDC, RLC, and FDRLC as well as outlet locations. **Figure 2.14** illustrates the proposed FDC outfall detail. The volume of drainage being directed to these outlets will be reviewed during subsequent stages of the detailed design process in order to ensure that potential impacts relating to erosion are mitigated.

6.2 NHS Crossings

6.2.1 Bruce Creek Road Crossing

One road crossing of the NHS is proposed as part of the development plan (refer to Figure 8.1 of the MESP Servicing and Grading Report). Inadequately designed crossing structures can negatively impact hydraulic conditions, channel form and channel functions (sediment transport processes) along valley and stream corridors. In an effort to provide direction to proponents regarding the location and design of road crossings with respect to natural hazard and natural heritage issues, the TRCA developed a Crossings Guideline for Valley and Stream Corridors (2015). The Guideline identifies submission requirements for crossing infrastructure works based on the stage in the land use planning process; the MESP process is classified under the early stage of the planning process, at which time alternative route alignments and, as appropriate, conceptual designs and impact assessment analyses are undertaken.

The following design criteria for new road crossings were considered in accordance with the Guideline:

- The crossing location should be located:
    - Along a relatively straight reach of channel, where possible;
    - Outside of the potential future migration zone of upstream meanders (a 100-year planning horizon);
    - At an orientation that is perpendicular to the channel, whenever possible.

- The crossing opening should address the potential for channel migration, with the aim to minimizing or avoiding the requirements for armouring or impacting channel migration or adjustment, considering post-development conditions (i.e., abutments are located outside the 100 year erosion limit).

- Crossings will avoid, to the best extent possible, watercourses that have fine sediment banks and are vegetation controlled. Where it is not possible to avoid fine sediment banks and vegetation control, formalizing the channel with appropriate bed and/or bank treatments may be required to avoid splaying/braiding under low flow conditions.

- The crossing opening should not:
    - Impact channel velocity for frequent storm events
    - Increase flood risk for design storm events up to, and including, the Regulatory storm;
    - Impact the local existing meander pattern; and
    - Impact sediment transport processes for frequent storm events.

The proposed road alignment is considered to be optimal from a geomorphic perspective, as the road crosses the NHS on a relatively straight section of Bruce Creek along a riffle feature at an angle that is perpendicular to the central tendency of the watercourse. Taking into account the modified nature of the channel planform (post-1961), and the presence of the existing offline ponds, the road is also located outside of the potential future migration zone of upstream meanders.

In order to provide recommendations with respect to crossing span, a scoped field investigation was undertaken to confirm existing geomorphic conditions along Bruce Creek in the immediate vicinity of the road crossing. **Table 15** provides the results of this scoped assessment, in addition to relevant data from the reach-based rapid field assessment work. As part of the scoped assessment, a governing meander amplitude of 24 m was measured in the field; bankfull widths ranged from 5.80 to 6.80 m. While evidence of widening (slumping banks, basal scour) was observed within the channel, the majority of this erosion was attributed to the influence of an existing cart path crossing, and localized stone toe protection measures that had been implemented to protect the crossing footings. RGA results for Reach BR-4 of Bruce Creek indicated that the reach was in a stressed, or transitional state, with evidence of widening.

From a design and constructability perspective, it is our understanding that the maximum clear span bridge that can currently be constructed is limited by the length of available pre-engineered beams. Most clear span bridge designs require provision of pre-engineered beams to support the structure and delivery of these beams to a given location is largely dependent on existing road geometries and widths. Presently, the longest pre-engineered beam that can be transported on the existing Greater Toronto

Area roadway system is in the order of 40 metres in length. Based on this understanding, the 40 m clear span Bruce Creek crossing plan and profile developed by Stantec was reviewed from a geomorphic perspective.

At 40 m, the proposed span is sufficient to accommodate the field-based meander amplitude, as well as the governing amplitude measured in the vicinity of the crossing based on the proposed road alignment. That stated, these governing meander amplitudes were measured downstream of the revised road crossing location. As the general trend in channel migration between 1974 and 2016 (post-channelization) is in the down-valley direction (refer to **Figure 6**), it is not anticipated that future migration of this meander bend would pose a risk to the structure. Further, the crossing structure has been centred on a straight section of the creek and provides a lateral offset of approximately 15 m on either side of the active (bankfull) channel. As data from the 42 year historic record indicates minimal lateral channel migration the proposed 40 m crossing span was deemed appropriate to accommodate long-term adjustments in channel form and meander geometry.

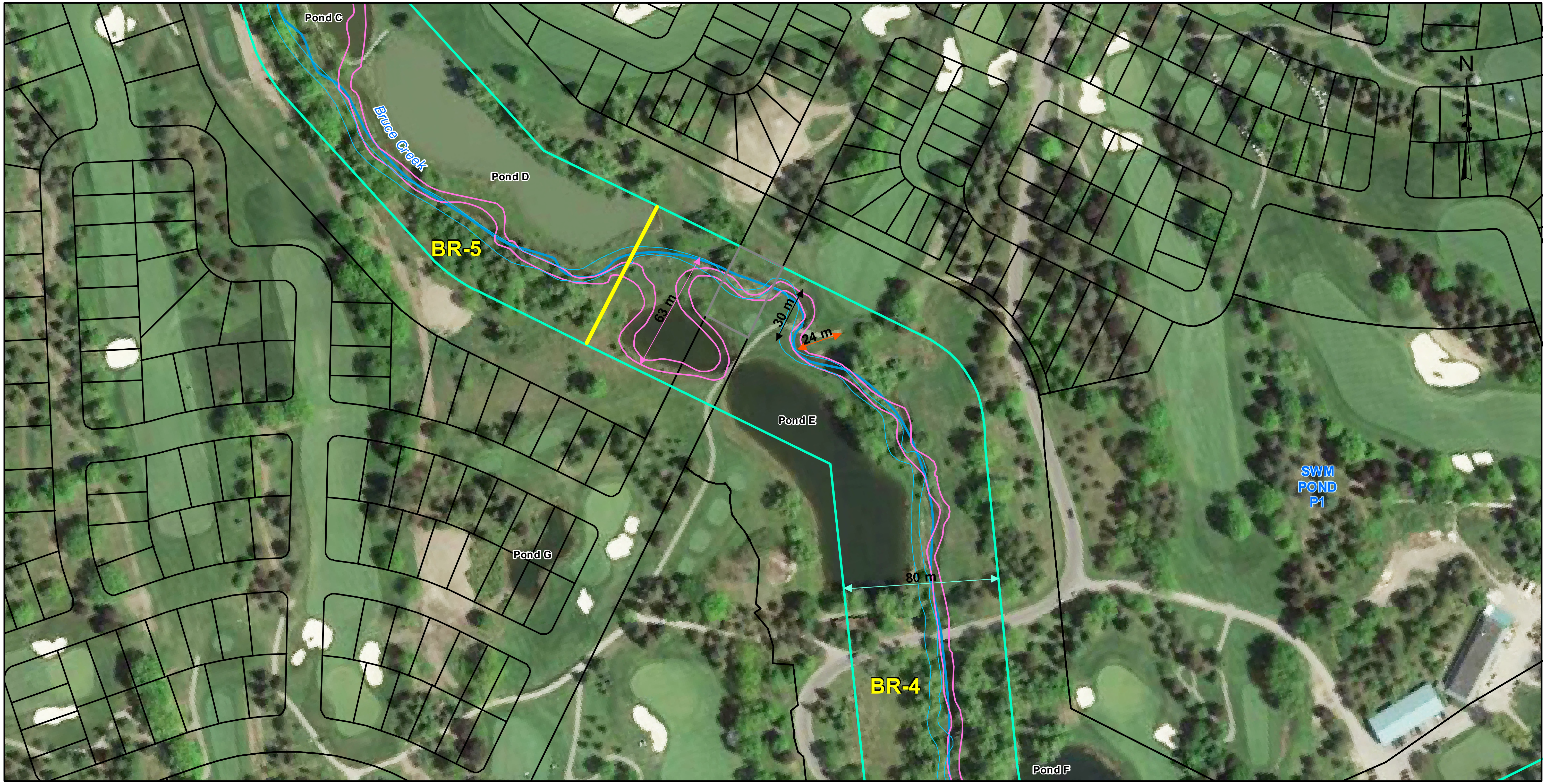
It should be noted that 100-year erosion rates were not quantified for the relevant portion of Reach BR-4 of Bruce Creek due to the historically modifications (channelization) that occurred between 1961 and 1974. Instead, available historic data was considered and presented in relation to the proposed road alignment and crossing span. As the error associated with ortho-rectifying scanned aerial imagery and measuring relatively minor shifts in channel planform typically outweighs the migration rate calculated in cases such as this, we consider our approach to be an appropriate methodology to evaluate the potential risk to the crossing due to erosion. It is also important to consider that a larger span opening would mandate the need for a central pier which would be located in closer proximity to Bruce Creek than the 40 m clear span bridge footings. With this in mind, a 40 m clear span design is preferred to a larger bridge span with central pier from a geomorphic perspective.

The proposed crossing location and design will need to be reviewed, confirmed and refined in the future as part of the detailed design process.

As Reach BR-4 of Bruce Creek is classified as occupied Redside Dace habitat, the proposed road crossings will be subject to review by the Ministry of Natural Resources and Forestry (MNRF) under the *ESA* (2007). This review process will require the consideration of measures to limit permanent and temporary disturbances to regulated habitat associated with the proposed activities. Based on this information, MNRF may determine that a 17(2)(c) Overall Benefit permit is required to complete the road works.

Table 13. NHS Road Crossing – Geomorphic Considerations

Reach	**Meander Amplitude to be Accommodated**		**Bankfull Width in Vicinity of Crossing (m)**	**RGA Score**	**Bank Materials**	**Crossing Span (m)**
	Optimal Skew (m)	**Road Alignment (m)**				
BR-4	23.5	30	5.8 - 6.8	0.37 (in transition)	Silt, sand and clay (some gravel)	**40**



0 10 20 40 60 80
1:2,000

Legend

- Development Plan
- Reach Break
- Watercourse
- Historic Watercourse 1974
- Historic Watercourse 1961
- Meander Belt Width
- Meander Belt + 30m
- Proposed 40 m Clear Span Bridge
- Meander Amplitude - Optimal Skew (24 m)
- Meander Amplitude - Road Alignment (30 m)
- Historic Meander Amplitude (63 m)
- Meander Belt Width Dimension (80 m)

JD Barnes: Aerial Photograph, 2015.
MBTW: Subject Property, 2015.
Beacon Environmental, 2017. All other data.

MASTER ENVIRONMENTAL
SERVICING PLAN FOR
4134 16TH AVE

FIGURE 6: Road Crossing Analysis

UTM Zone 17 N, NAD 83

Project 215200.1
November 2017

Output data from the HEC-RAS model as provided by Stantec Consulting for Bruce Creek upstream and downstream of the crossing are summarized in **Table 16**. Data from the model indicates a minimal impact on instream hydraulics as a result of the crossing under the more frequent storm events. It is not anticipated that this increase will result in exacerbated rates of erosion within Bruce Creek.

Table 14. Summary of Hydraulic Parameters - Proposed 40 m Clear Span Bridge

River Station	Location of Station Relative to Proposed Crossing	Velocity (m/s)		Bruce Creek Bankfull Velocity (m/s)
		2 Year	5 Year	
7216.175	Upstream	1.27	1.18	1.40
7216.172		1.65	1.89	
7216.171		1.34	1.32	
Road Crossing				
7216.168	Downstream	1.73	1.94	
7216.165		1.45	1.60	
7216.16		1.43	1.66	

6.2.2 NHS Trail Crossings

A trail system is proposed as part of the development plan that will extend along the Bruce and Berczy Creek corridors, as well as within SWM pond blocks and through Park Block 7. Four pedestrian crossings of Bruce Creek are proposed, utilizing existing cart path crossing locations. The trail is also proposed to extend to the west of the subject property though Park Block 11 adjacent to Warden Avenue. The proposed trail system is presented in the MBTW Community Design Plan 2017.

In general, all of the existing cart path crossings of Bruce Creek were found to be performing well with respect to erosion and channel migration. In consideration of this existing condition, and that the proposed approach will avoid requirements for instream works, the proposed trail crossing design concept was considered appropriate from a geomorphic perspective.

As part of this report, and to address agency comments, the trail crossing locations were also reviewed to consider a future scenario in which the existing cart path crossings were fully replaced. The TRCA Crossing Guideline for Valley and Stream Corridors (2015) states the following with respect to recreational trails:

> *"The direct public safety risks and economic consequences associated with the impacts of flooding and erosion on recreational trails are lower than those associated with road and rail crossings. For this reason, TRCA's trail requirements will typically be less stringent than those required for road or rail crossings."*

TRCA is currently developing a Trail Strategy to provide specific design criteria for trails and trail crossings. That stated, it is understood that typical TRCA design requirements for new trail crossings include a 25-year channel migration assessment to determine whether proposed crossing abutments are at risk to erosion and channel migration. The 2015 Guideline also encourages that the same principles of natural hazard risk management applied to road crossings also be applied to trail crossing design.

Due to the historically modified nature of Bruce Creek, 25-year migration rates were not quantified in support of the trails analysis. Instead, the 42-year post-channelization historic record was reviewed in relation to the proposed trail alignment and crossing locations. In this regard, all of the trail crossing locations are optimally placed to avoid governing meander bends and are aligned to cross the watercourse at an optimal angle of 90 degrees. Using this approach, a 15 m crossing span was deemed suitable to accommodate trends in channel migration over a 42-year record. It is, therefore, anticipated that this span dimension also addresses the 25-year erosion limit.

The proposed crossing location and design will need to be reviewed, confirmed and refined in the future as part of the detailed design process.

As the relevant reaches of Bruce Creek are classified as occupied Redside Dace habitat, the proposed pedestrian crossings will be subject to review by the Ministry of Natural Resources and Forestry (MNRF) under the *ESA* (2007). This review process will require the consideration of measures to limit permanent and temporary disturbances to regulated habitat associated with the proposed activities. Based on this information, MNRF may determine that a 17(2)(c) Overall Benefit permit is required to complete the trail and pedestrian crossing works.

6.2.3 Bruce Creek Sanitary Sewer Crossing

One (1) sanitary sewer crossing of Bruce Creek is proposed. The crossing will be installed using directional drilling and will achieve a depth of cover of 2.5 m under the channel bed invert. While observations collected during the field investigation did not identify substantial evidence of downcutting (incision) in the vicinity of the proposed sanitary crossing, it is recommended that, at subsequent detailed design stages, a scour analysis be undertaken to confirm the depth of cover required to mitigate long-term potential erosion risks to the sewer.

7. Policy Conformance

It is our opinion that the methods and procedures outlined above are consistent with the applicable policy including the Region of York Official Plan (2009) and the Town of Markham Official Plan (2014). Furthermore, it is our opinion that the intent of the PPS (2014), TRCA LCP (2014), Belt Width Delineation Procedures (2004) document, Stormwater Management Criteria (2012) and Crossings Guideline for Valley and Stream Corridors (2015) have been met. It is our understanding that the meander belt width procedures as identified in this document are also in conformance with Ontario Regulation 242/08.

8. Conclusions

The purpose of this assessment was to characterize existing geomorphic conditions, contribute to the determination of development constraints, and provide input to stormwater servicing plans for the subject property. Based on a background review of available materials (topographic mapping, aerial photography, watershed reports, relevant studies, site plan), portions of Berczy Creek and Bruce Creek relevant to the subject property were delineated into reaches. An historic assessment was then undertaken to determine changes in land use and channel planform over time. Results of this assessment identified extensive channelization of both Berczy and Bruce Creek within the subject property between 1961-present. Many of the ponds currently being used by the golf course for irrigation are located in former channel meander bends. This information was referenced in the delineation of meander belt limits for stream corridors (unconfined watercourses) to aid in the determination of erosion hazard limits, and the delineation of occupied Redside Dace regulated habitat (referencing meander belt plus 30 m) for stream and valley corridors to aid in the determination of development limits for the subject property.

In order to characterize existing geomorphic conditions, standard rapid field assessment tools (RGA, RSAT, Down's) were applied on a reach basis. Results of this field investigation identified channel widening as the dominant mode of adjustment along both Berczy and Bruce Creeks. Reaches BR-3 (Bruce Creek) and BER-3 (Berczy Creek) were identified within their respective systems as being the most sensitive to land use change (i.e., highest RGA scores). Detailed field assessments, including a topographic survey of the channel centerline and cross-sectional form, were completed on each of these reaches for the purpose of determining erosion thresholds. Referencing the median grain size and flow conditions at the time of survey, critical shear stress values of 9.6 N/m^2 and 6.5 N/m^2 were identified for Bruce Creek and Berczy Creek, respectively.

In order to understand the potential impacts of the proposed development plan on channel morphology, an impact assessment was undertaken with respect to stormwater management, in addition to NHS crossings. For the erosion control analysis, a comparison of pre- and post-development (controlled) flow conditions was undertaken for the 25 mm, 30 mm, 35 mm, 5-year, 25-year and 100-year storm events under 24 hour, 48 hour and 72 hour detention scenarios for nodes located at the downstream limit of the subject property to evaluate how closely post-development conditions can replicate existing condition hydrograph (peak, volume and form), focusing on those portions of the hydrograph above the critical discharge. Results of the analysis indicated that, for both Berczy Creek and Bruce Creek, the 48-hour detention scenario was able to most closely replicate modelled existing conditions without resulting in an over-control of flows. Over-control of stormwater within the system is undesirable as the transport of sand-sized material and washload within both Berczy and Bruce Creeks is critical to the maintenance of aquatic habitat conditions, channel form and function. As such, the 48-hour detention scenario was identified as the preferred erosion control approach for Berczy Creek and Bruce Creek, through which exacerbation of existing rates of channel erosion are not anticipated under the post-development condition.

Only one road crossing of the Natural Heritage System (NHS) is proposed through the development plan. A 40 m clear span bridge is proposed to cross Bruce Creek. In accordance with the TRCA Crossings Guideline for Valley and Stream Corridors, an evaluation of channel planform (both current and historic) was undertaken at the proposed crossing location. Based on this evaluation, the 40 m span was deemed sufficient to accommodate long-term trends in channel form and meander geometry. Further, a review of the HEC-RAS model output for more frequent storm events in vicinity of the proposed crossing indicated a minimal impact on instream hydraulics.

Pedestrian crossings proposed as part of the trail system were also reviewed. The proposed trail crossings will be located at existing cart path crossings and will utilize the existing bridge footings. As no instream works are proposed in association with the trail crossings, and the existing crossings appear to be performing well, additional geomorphic design criteria have not been identified for these crossings.

Should the crossings be replaced at some point in the future, recommendations with respect to crossing span requirements were provided.

A sanitary sewer crossing of Bruce Creek is also proposed. The crossing will be installed using directional drilling and will achieve a depth of cover of 2.5 m under the existing channel bed. Based on the results of the rapid assessment field investigation, which indicated widening as the dominant process along Bruce Creek, the 2.5 m depth of cover was deemed sufficient to mitigate long-term risk to this infrastructure due to active erosion (i.e., channel incision). Recommendations for subsequent detailed design stages included a scour analysis to confirm the depth of cover required to mitigate long-term potential erosion risks to the sewer.

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Appendix A

Historic Aerial Imagery

Coverage:	Spring 1961	**Scale:**	1:12,000
Image ID:	1961_6446_L14_32	**Source:**	Northway Photomap/Remote Sensing Ltd.

Coverage: Spring 1974 **Scale:** 1:12,000

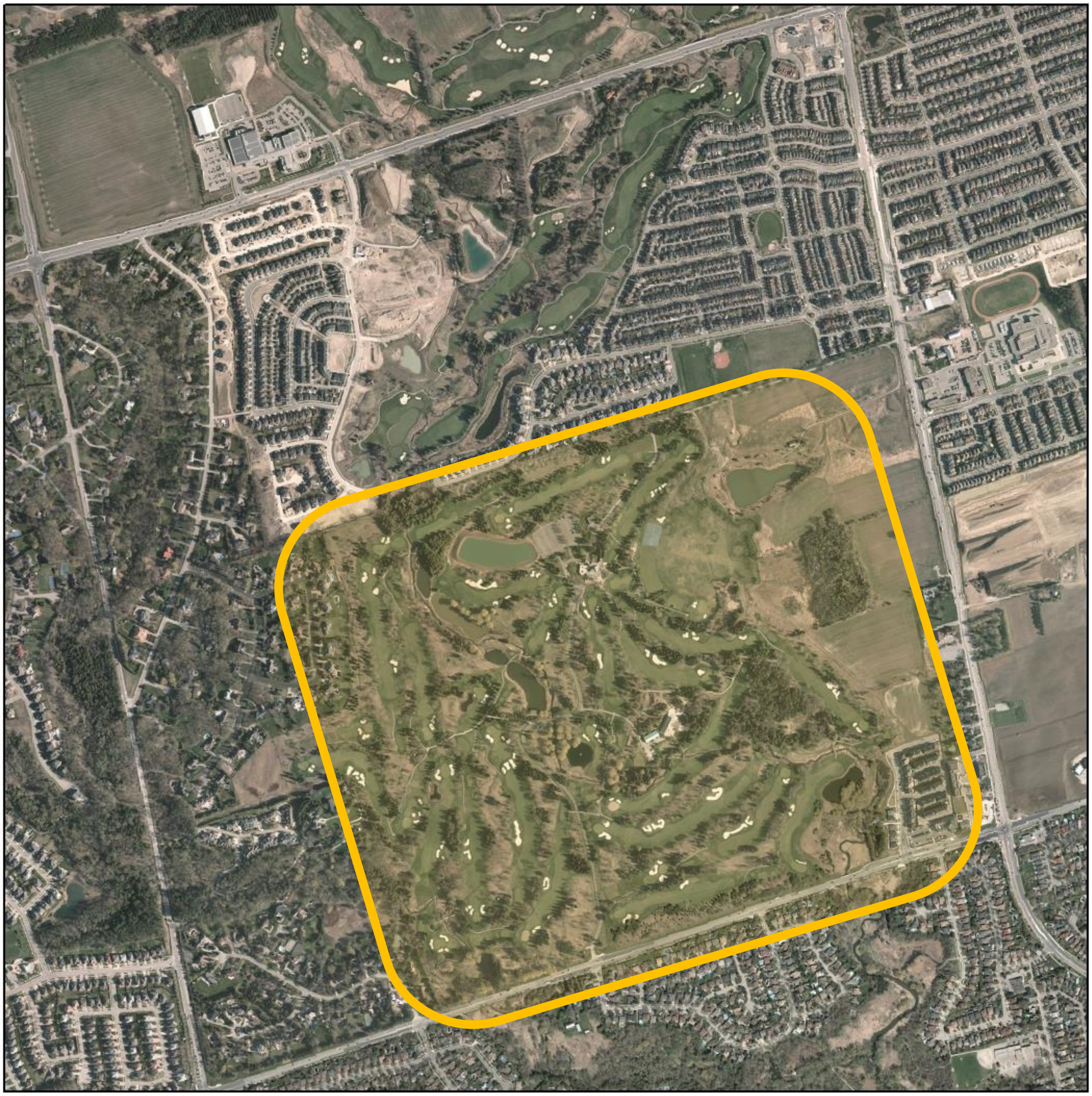
Image ID: 1974_74023_L15_32 **Source:** Northway Photomap/Remote Sensing Ltd.

Coverage: Spring 1974 **Scale:** 1:12,000

Image ID: 1974_74023_L15_32 **Source:** Northway Photomap/Remote Sensing Ltd.

Coverage: 2002 **Scale:** 1:15,000

Image ID: N/A **Source:** First Base Solutions



Coverage: 2012

Scale: 1:15,000

Image ID: N/A

Source: First Base Solutions

Appendix B

Photographic Record

Photo 1
BR-1. Downstream view from pedestrian trail bridge at upstream reach extent. Note widened channel due to backwater from downstream Toogood Pond.

Photo 2
BR-2. Upstream view from pedestrian trail crossing at downstream reach extent.

Photo 2
BR-2. Downstream view of general channel conditions. Note stone bank protection on left bank.

Photo 4
BR-2. Looking upstream at failing (undermined and outflanked) cribwall along outside meander bend.

Photo 5
BR-2. Downstream view under 16th Avenue crossing.

Photo 6
BR-2. Basal scour on both side through riffle.

Photo 7
BR-2. Exposed tree roots and slumping banks at outside meander bend viewed downstream.

Photo 8
BR-2. Vegetated bar with chute formation viewed upstream.

Photo 9
BR-2. Vegetated bar viewed downstream. Note also old bridge footing remains within channel.

Photo 10
BR-2. Valley wall contact on left bank (photo right) viewed upstream.

Photo 11
BR-2. 1250 mm storm outfall on left bank.

Photo 12
BR-2. Looking upstream at pedestrian crossing. Note vegetated bar within the channel.

Photo 13
BR-2. Looking upstream toward golf cart path crossing.

Photo 14
BR-2. Looking upstream at pedestrian crossing at upstream extent of the reach. Note the slumping with chute formation in behind.

Photo 15
BR-3. Looking downstream at exposed tree roots and under right bank.

Photo 16
BR-3. Looking downstream confluence with surface flow feature. Note large sand deposit.

Photo 17
BR-3. Looking upstream at debris jam creating backwater area. Note confluence with surface flow feature into backwater area.

Photo 18
BR-3. Looking upstream pedestrian crossing. Note gravel bar within the channel.

Photo 19
BR-3. Looking upstream from pedestrian crossing at golf cart path crossing. Note manicured grass riparian vegetation.

Photo 20
BR-3. Looking upstream at exposed previously buried pipes in left bank (photo right/centre).

Photo 21
BR-3. Looking downstream at outflanked and undermined gabion basket on right bank.

Photo 22
BR-3. Looking at upstream at golf cart path crossing.

Photo 23
BR-4. Looking at upstream at general reach conditions. Note degree of entrenchment.

Photo 24
BR-4. Looking downstream erosion along right bank.

Photo 25
BR-4. Looking upstream at driveway crossing.

Photo 26
BR-4. Looking downstream at bar formation

Photo 27
BR-4. Looking downstream at fallen cedar tree, exposed roots and undercut bank.

Photo 28 (Location 28)
BR-4. Looking downstream from golf cart path crossing. Note proximity to online pond.

Photo 29 (Location 28)
BR-4. Looking upstream from golf cart path crossing at meander bend. Note manicure grass riparian vegetation.

Photo 30 (Location 29)
BR-4. Pond outlet to creek.

Photo 31 (Location 30)
BR-5. Tile drain outlet on right bank.

Photo 32 (Location 31)
BR-5. Looking downstream at general conditions. Note vegetated island within the channel and degree of entrenchment.

Photo 33 (Location 32)
BR-5. Looking downstream at erosion along right bank.

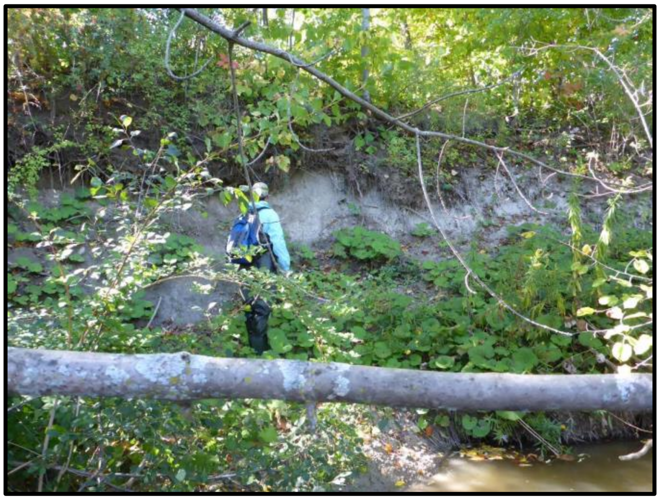


Photo 34 (Location 33)
BR-5. Looking downstream at surface flow feature through an actively farmed field. Note lack of defined channel and isolated pockets of standing water

Photo 35 (Location 33)
BR-5. Looking upstream at wood debris jam and pedestrian crossing.

Photo 36 (Location 34)
BR-5. Looking downstream at island within the channel. Note the armoustone bank treatment along the left bank.

Photo 37 (Location 35)
BR-5. Looking upstream at golf cart path crossing. Note riffle substrate size.

Photo 38 (Location 36)
BR-5. Exposed bridge footings of pedestrian crossing on right bank viewed downstream.

Photo 39 (Location 37)
BR-5. Looking downstream of fallen cedar tree and bar formation. Note the confluence with surface flow feature.

Photo 40 (Location 38)
BER-3. Looking downstream at 16th Avenue Road crossing.

Photo 41 (Location 39)
BER-3. Looking downstream toward meander bend and general conditions.

Photo 42 (Location 40)
BER-3. Looking upstream at meander bend. Note point bar formation on left bank (photo right) and scour on inside bend.

Photo 43 (Location 41)
BER-3. Looking downstream at sharp meander bend. Note erosion on outside of bend, point bar formation on inside of bend and basal scour on both sides.

Photo 44 (Location 42)
BER-3. Looking downstream at leaning tree and lateral bar.

Photo 45 (Location 43)
BER-3. Looking downstream at pedestrian crossing.

Photo 46 (Location 44)
BER-3. Looking downstream at general reach conditions. Note degree of entrenchment.

Photo 47 (Location 45)
BER-3. Looking downstream at golf cart path crossing.

Photo 48 (Location 46)
BER-3. Looking downstream at leaning tree with exposed roots at sharp meander bend with a deep pool.

Photo 49 (Location 47)
BER-3. Looking upstream at valley wall contact and outflanked gabion basket bank protection on left bank (photo right).

Photo 50 (Location 48)
BER-3. Looking downstream at pedestrian crossing.

Photo 51 (Location 50)
BER-3. Looking downstream at ad-hoc bank protection on right bank.

Photo 52 (Location 51)
BER-4. Looking downstream at large wood debris jam.

Photo 53 (Location 51)
BER-4. Looking downstream at riffle within a meander bend. Note point bar with cut face and exposed tree roots.

Photo 54 (Location 52)
BER-4. Looking upstream at leaning tree with exposed roots on the left bank.

Photo 55 (Location 53)
BER-4. Looking downstream at lateral bar and valley wall contact on left bank. Note also misalignment of thalweg.

Photo 56 (Location 54)
BER-6. Looking downstream at a bridge crossing at the downstream extent assessed. Note the large deep scour pool and failing footings under the bridge and the erosion on right bank (photo left).

Photo 57 (Location 55)
BER-6. Looking upstream at meander bend against Warden Avenue bridge.

Photo 58 (Location 56)
BER-6. Looking upstream at boulder step-pool. Note outer bank erosion on meander bend in background.

Photo 59 (Location 57)
BER-6. Looking upstream at Warden Avenue crossing.

Surface Flow - Photo 60 (Location 58)
General riparian conditions along surface drainage feature.

Surface Flow - Photo 61 (Location 59)
Existing 500 mm culvert under laneway crossing.

Surface Flow - Photo 62 (Location 60)
Downstream view of surface drainage feature. Note density of riparian vegetation and poorly defined nature of feature.

Surface Flow - Photo 63 (Location 61)
Downstream view of potential overland conveyance area across the existing fairway. Surface drainage feature is piped.

Surface Flow - Photo 64 (Location 62)
Upstream view of surface drainage feature and tile drain outlet.

Surface Flow - Photo 65 (Location 63)
Upstream view of culvert under existing golf cart path.

Surface Flow - Photo 66 (Location 64)
Downstream view of surface drainage feature. Note: poorly defined nature of feature and multiple surface flow paths.

Surface Flow - Photo 67 (Location 65)
Existing 300 mm CSP culvert.

Surface Flow - Photo 68 (Location 66)
Existing catch basin associated with Pond H.

Surface Flow - Photo 69 (Location 67)
South-facing view of surface conveyance area associated with Pond H along the existing golf course driving range.

Surface Flow - Photo 70 (Location 68)
Existing pipe outlet.

Surface Flow - Photo 71 (Location 69)
Upstream view of surface drainage feature. Note: feature was poorly defined.

Surface Flow - Photo 72 (Location 70)
Downstream view of pipe inlet.

Surface Flow - Photo 73 (Location 71)
Downstream view of surface drainage feature.

Surface Flow - Photo 74 (Location 72)
Upstream view of surface drainage feature and existing laneway crossing.

Surface Flow - Photo 75 (Location 73)
Upstream view of pipe outlet.

Surface Flow - Photo 76 (Location 74)
Upstream view of surface drainage feature. Note: presence of woody debris and poorly defined nature of feature.

Surface Flow - Photo 77 (Location 75)
Downstream view of surface drainage feature.

Surface Flow - Photo 78 (Location 76)
Upstream view of surface drainage feature.

Surface Flow - Photo 79 (Location 77)
Upstream view of surface drainage feature
confluence with Bruce Creek (Reach BR-3).

Surface Flow - Photo 80 (Location 78)
Downstream view of surface drainage feature.

Surface Flow - Photo 81 (Location 79)
Upstream view of existing twin culvert under laneway crossing of surface drainage feature.

Surface Flow - Photo 82 (Location 80)
Upstream view of surface drainage feature confluence with Bruce Creek (Reach BR-3). Note 0.4 m drop to creek bed.

Surface Flow - Photo 83 (Location 81)
Upstream view of surface drainage feature.

Surface Flow - Photo 84 (Location 81)
Downstream view of surface drainage feature.

Surface Flow - Photo 85 (Location 82)
Upstream view of existing gully feature observed along valley slope.

Surface Flow - Photo 86 (Location 82)
Downstream view of gully feature and tile drain outlet to Bruce Creek.

Surface Flow - Photo 87 (Location 83)
Upstream view of surface drainage feature.

Surface Flow - Photo 88 (Location 84)
Downstream view of surface drainage feature (towards Pond H).

**Surface flow - Photo 89 (Location 85)
Downstream of overland conveyance area and existing culvert under cart path.**

**Surface Flow - Photo 90 (Location 86)
Upstream view of surface drainage feature.**

Appendix C

Summary of Detailed Field Data

Geomorphology Group
Summary of Detailed Field Data

Date: November 2015, April 2016
Project: 215200.1
Client: Sixteenth Land Holdings Inc.
Watercourse: Berczy Creek
Location: 4134 16th Avenue, Markham, ON
Reach: BER-3

Length Surveyed: **199 m**
Number of Cross Sections: **8**

General Site Characteristics

Drainage Area:	**Not measured**	Riparian Vegetation:	
Geology/Soils:	**Glacial lacustrine (Till)**	Dominant Type:	**Trees, shrubs, grasses**
Surrounding Land Use:	**Golf Course**	Buffer Zone Continuity:	**Fragmented**
Channel Disturbances:	**Channelization, crossings, bank protection**	Channel Encroachment:	**Minimal**
Aquatic Vegetation:		Large Woody Debris:	**Moderate**
Dominant Type:	**N/A**		
Portion of Reach:	**0%**		

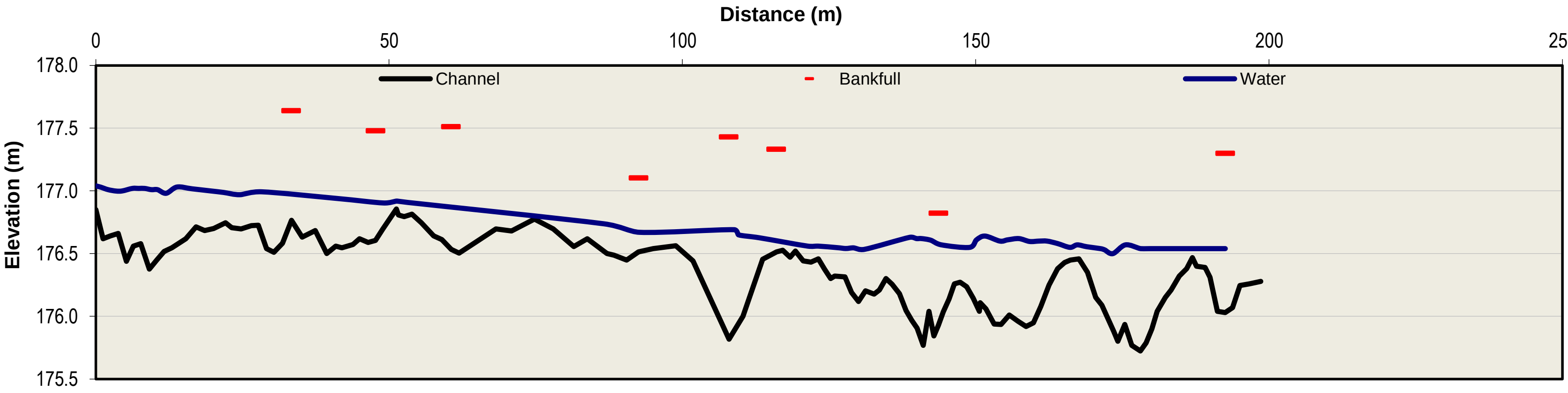
General Field Observations

Reach BER-3 was characterized as a historically modified (channelized) watercourse flowing within a partially-confined valley setting. The reach exhibited evidence of widening, with degradation, planimetric form adjustment and aggradation as secondary processes. Evidence of active erosion was observed in the form of undercutting, basal scour and slumping.

Planform Characteristics

Profile			*Meander Geometry*		
Bankfull Gradient:	**0.30**	%	Sinuosity:	**2.7**	
Channel Bed Gradient:	**0.36**	%	Belt Width:	**156**	m
Max Riffle Gradient:	**3.6**	%	Radius of Curvature:	**Not calculated**	m
Riffle Length:	**n/a**	m	Amplitude:	**Not calculated**	m
Riffle-Pool Spacing:	**n/a**	m	Wavelength:	**Not calculated**	m

Longitudinal Profile



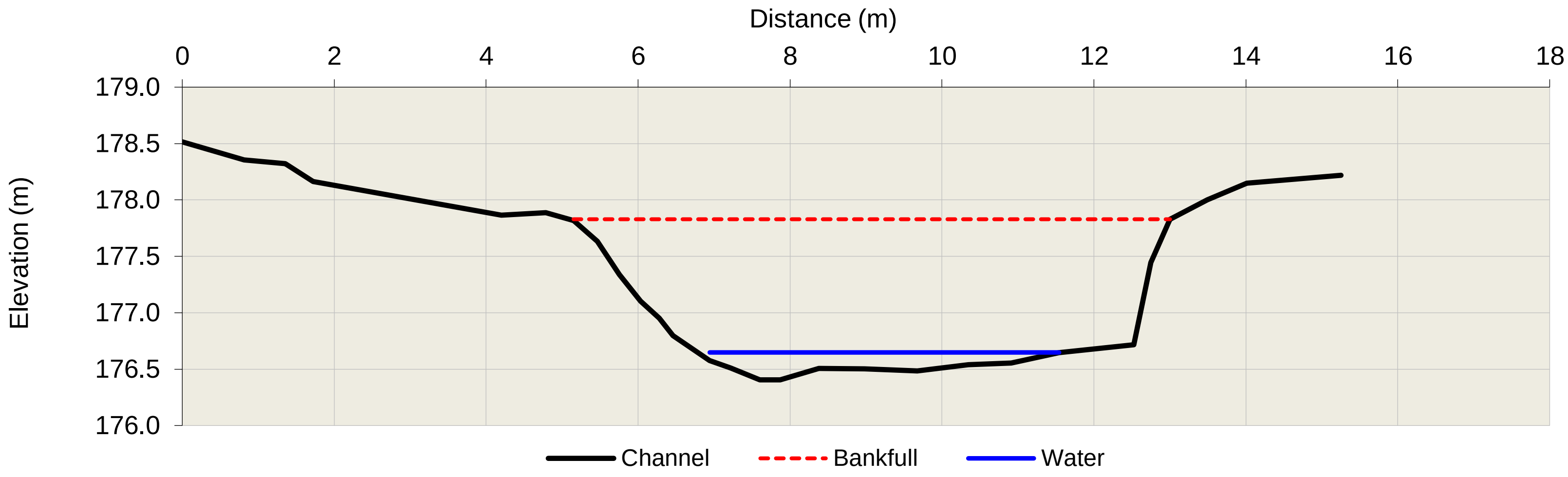
Bank Characteristics

	Minimum	*Maximum*	*Average*
Bank Height (m):	**0.80**	**1.60**	**1.21**
Bank Angle (degrees):	**45**	**90**	**82**
Root Depth (m):	**0.05**	**0.50**	**0.28**
Root Density (%):	**0**	**90**	**33**
Undercut Banks (%)		**20**	
Depth of Undercut (m):	**0.11**	**0.25**	**0.17**
Bank Strength:			
Torvane Value (kg/cm^2):	**0.07**	**0.20**	**0.13**
Penetrometer Value (kg/cm^2):	**0.73**	**1.25**	**0.97**

Bank Material (range): **silt - gravel and till with some cobble, boulder, clay**

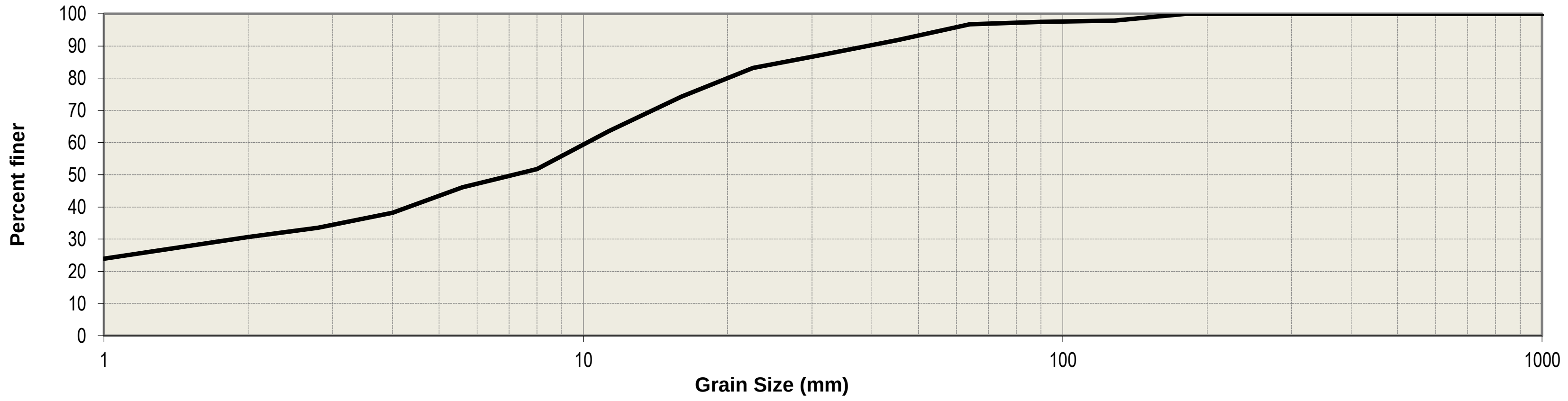
Cross-sectional Characteristics

	Minimum	*Maximum*	*Average*
Bankfull Width (m):	**6.0**	**11.9**	**8.7**
Average Bankfull Depth (m):	**0.47**	**1.15**	**0.67**
Bankfull Width/Depth:	**5.8**	**22.1**	**14.4**
Wetted Width (m):	**5.1**	**9.7**	**6.2**
Average Water Depth (m):		**0.67**	
Average Wetted Width/Depth:		**41.6**	
Max. Wetted Depth (m):		**1.0**	
Manning's n:		**0.030**	


Representative Cross-Section (#4B)

Substrate Characterization

Particle size		Subpavement:	**till**
D_{10}	**-** mm	Particle shape:	**sub-angular**
D_{50}	**6.3** mm	Embeddedness (%):	**10-20**
D_{90}	**40** mm	Particle range (riffle):	**sand - gravel**
		Particle Range (pool):	**silt - gravel, till**


Cumulative Particle Size Distribution

Hydrology

Measured Discharge:	**Not measured**	m^3/s	Calculated Bankfull Discharge:	**7.20**	m^3/s
Modelled 2-year Discharge:	**11.5**	m^3/s	Calculated Bankfull Velocity:	**1.20**	m/s
Modelled 2-year Velocity:	**1.36**	m/s			

Channel Thresholds

Flow Competency:		Tractive Force at Bankfull:	**20** N/m^2
for D_{50}:	**0.5** m/s	Tractive Force at 2-year flow:	**Not calculated** N/m^2
for D_{84}:	**0.9** m/s	Critical Shear Stress:	**6.5** N/m^2
Unit Stream Power at Bankfull:	**22.3** W/m^2	Critical Discharge:	**0.89** m^3/s
		Critical Water Depth:	**0.33** m

Geomorphology Group

Summary of Detailed Field Data

Date:	November 2015, April 2016	**Project:**	215200.1
Client:	Sixteenth Land Holdings Inc.	**Watercourse:**	Bruce Creek
Location:	4134 16th Avenue	**Reach:**	BR-3
Length Surveyed:	**228 m**	Number of Cross Sections:	**8**

General Site Characteristics

Drainage Area:	**Not measured**	Riparian Vegetation:	
Geology/Soils:	**Glacial lacustrine (Till)**	Dominant Type:	**Trees, shrubs, grasses**
Surrounding Land Use:	**Golf Course**	Buffer Zone Continuity:	**Fragmented**
Channel Disturbances:	**Channelization, crossings, VWCs, woody debris**	Channel Encroachment:	**Minimal**
Aquatic Vegetation:		Large Woody Debris:	**Moderate**
Dominant Type:	**N/A**		
Portion of Reach:	**N/A**		

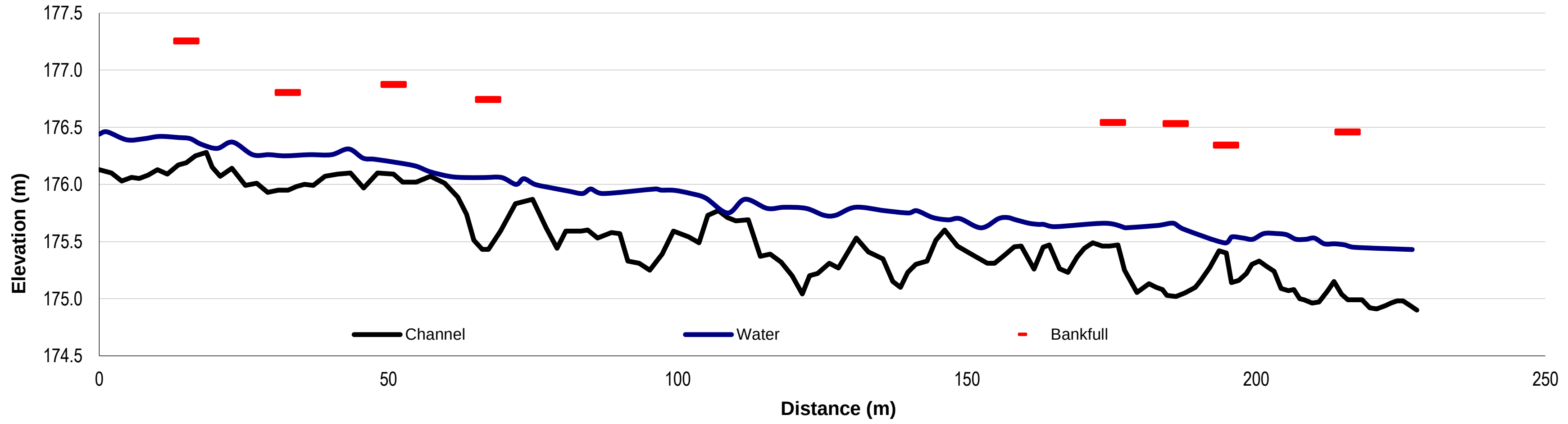
General Field Observations

Reach BR-3 was characterized as a historically modified (channelized) watercourse flowing within a partially-confined valley setting. The reach exhibited evidence of widening, with degradation, planimetric form adjustment and aggradation as secondary processes. Evidence of active erosion was observed in the form of undercutting, basal scour and slumping.

Planform Characteristics

Profile			*Meander Geometry*		
Bankfull Gradient:	**0.3**	%	Sinuosity:	**1.4**	
Channel Bed Gradient:	**0.5**	%	Belt Width:	**96**	m
Max Riffle Gradient:	**0.6**	%	Radius of Curvature:	**Not calculated**	m
Riffle Length:	**13.0**	m	Amplitude:	**Not calculated**	m
Riffle-Pool Spacing:	**33.0**	m	Wavelength:	**Not calculated**	m

Longitudinal Profile



Bank Characteristics

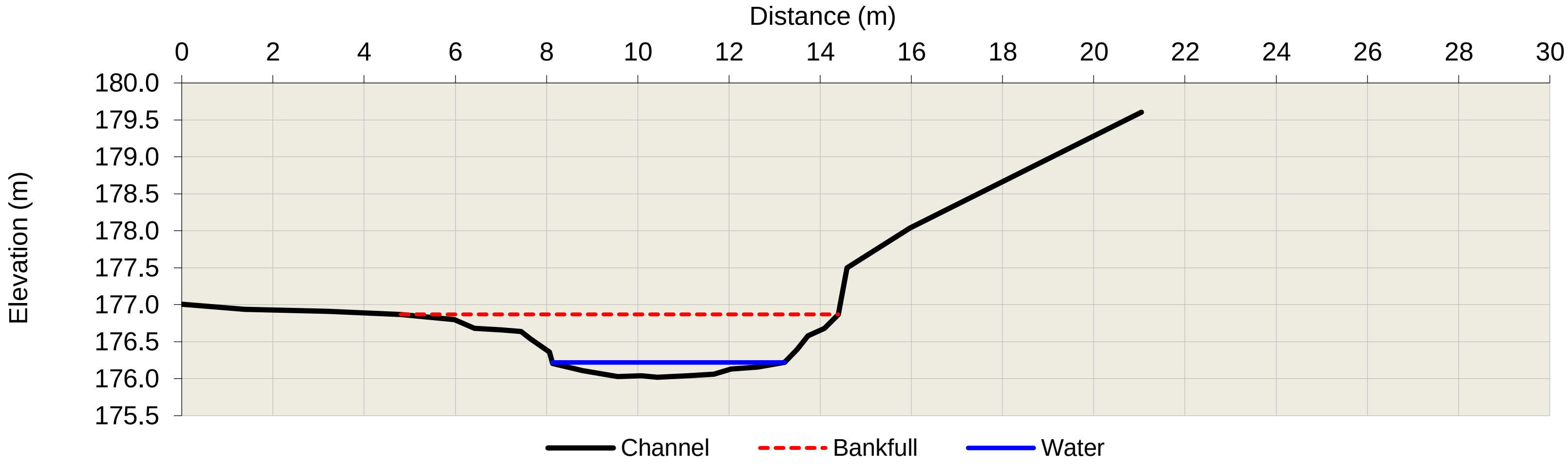
	Minimum	*Maximum*	*Average*
Bank Height (m):	**0.30**	**1.30**	**0.79**
Bank Angle (degrees):	**20**	**90**	**68**
Root Depth (m):	**0.00**	**0.50**	**0.18**
Root Density (%):	**5**	**75**	**29**
Undercut Banks (%)		**44**	
Depth of Undercut (m):	**0.00**	**0.22**	**0.03**
Bank Strength:			
Torvane Value (kg/cm^2):	**0.04**	**0.16**	**0.10**
Penetrometer Value (kg/cm^2):	**0.60**	**1.23**	**0.90**

Bank Material (range): **Silt, sand, clay, gravel, till**

Cross-sectional Characteristics

	Minimum	*Maximum*	*Average*
Bankfull Width (m):	**7.1**	**15.6**	**10.7**
Average Bankfull Depth (m):	**0.48**	**0.76**	**0.65**
Bankfull Width/Depth:	**9.7**	**23.5**	**16.6**
Wetted Width (m):	**2.1**	**6.3**	**4.5**
Average Water Depth (m):		**0.65**	
Average Wetted Width/Depth:		**16.6**	
Max. Wetted Depth (m):		**0.7**	
Manning's n:		**0.030**	

Representative Cross-Section (#6)

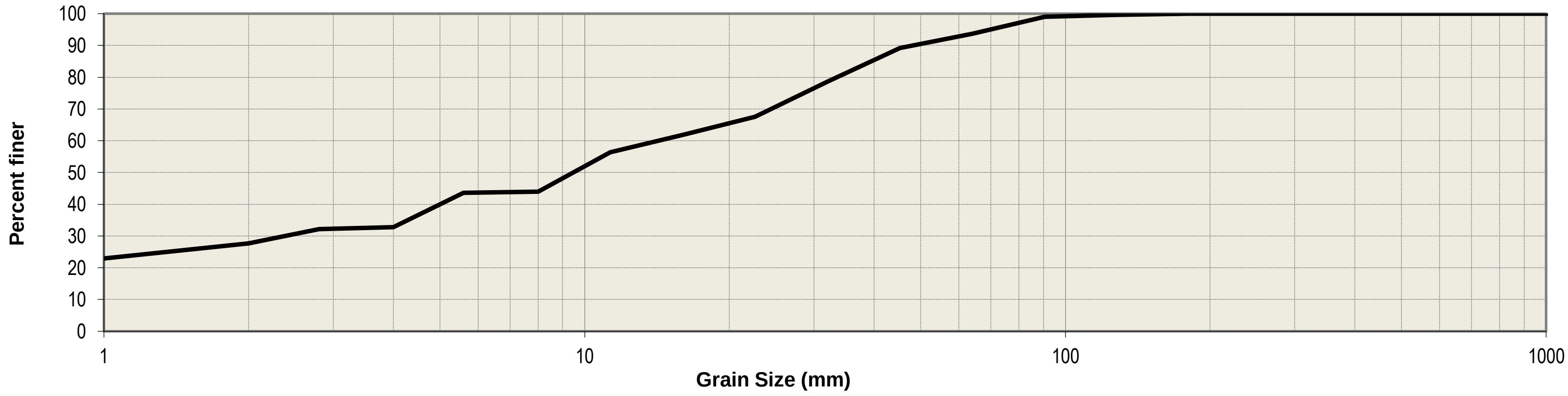


Substrate Characterization

Particle size

D_{10}	**-** mm	Subpavement:	**sand, gravel**
		Particle shape:	**sub-rounded**
D_{50}	**9.3** mm	Embeddedness (%):	**20-30**
D_{90}	**49** mm	Particle range (riffle):	**sand - boulder**
		Particle range (pool):	**clay - gravel**

Cumulative Particle Size Distribution



Hydrology

Measured Discharge:	**Not measured**	m^3/s	Calculated Bankfull Discharge:	**6.60**	m^3/s
Modelled 2-year Discharge*:	**13.6**	m^3/s	Calculated Bankfull Velocity:	**1.40**	m/s
Modelled 2-year Velocity*:	**1.33**	m/s			

Channel Thresholds

Flow Competency:			Tractive Force at Bankfull:	**23**	N/m^2
for D_{50}:	**0.6**	m/s	Tractive Force at 2-year flow:	**Not calculated**	N/m^2
for D_{84}:	**1.1**	m/s	Critical Shear Stress:	**9.6**	N/m^2
Unit Stream Power at Bankfull:	**29.0**	W/m^2	Critical Discharge:	**0.9**	m^3/s
			Critical Water Depth:	**0.31**	m

Appendix D

Summary of Erosion Threshold Analysis

Geomorphology Group

Summary of Erosion Threshold Analysis

Date: May 2016
Project: 215200.1
Client: Kylemore/Metropia (YD) Management Ltd.
Watercourse: Berczy Creek
Location: York Downs Golf Club, Markham, ON
Reach: BER-3
Length Surveyed: 200 m
Representative Cross-sections: XS 1 and 3 (of 8)

Summary of Calculated Hydraulic Parameters

Bankfull Channel:

Discharge (m^3/s): **7.24**
Velocity (m/s): **1.20**
Maximum Depth (m): **0.92**
Tractive Force (N/m^2): **17.8**

Flow Competency (Komar, 1987):
for D_{50} (m/s): **0.46**
for D_{84} (m/s): **0.92**

Shear Stress (Miller et al., 1977):
for D_{50} (N/m^2): **4.6**
for D_{84} (N/m^2): **20.4**

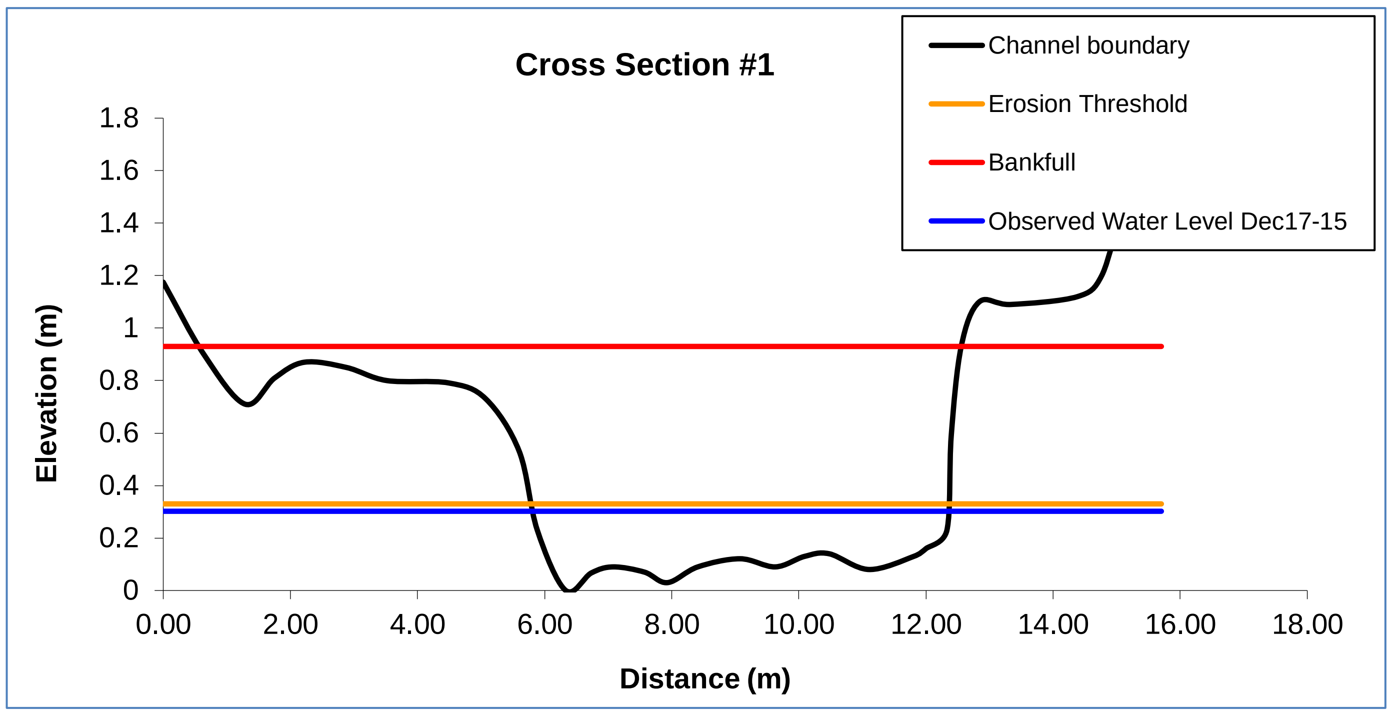
Erosion Threshold:

Critical Discharge (m^3/s): **0.89**
Critical Velocity (m/s): **0.61**
Critical Depth (m): **0.33**
Critical Shear Stress (N/m^2): **6.5**
Percent of Bankfull Discharge (%): **12**

* Sediment entrainment not observed at the time of survey

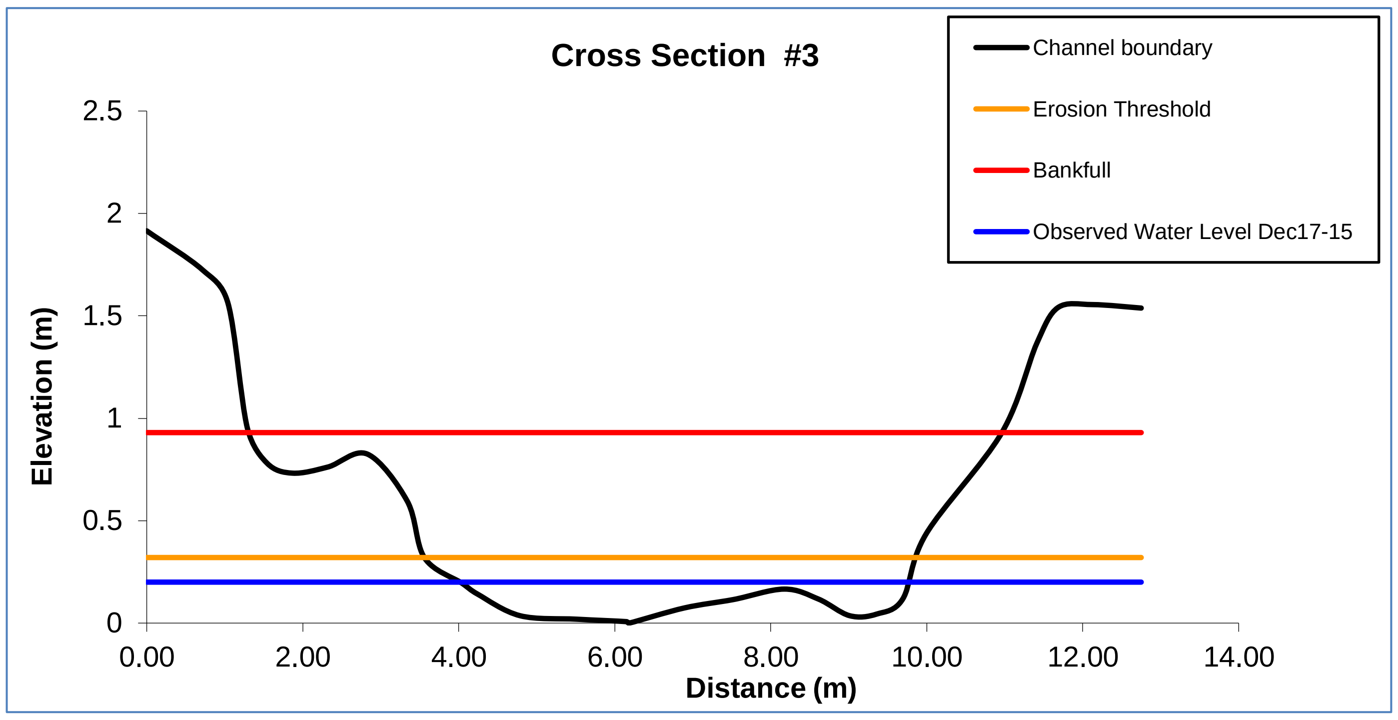
Cross-Section 1:

Critical Depth (m)	0.33
Slope (m/m)	0.003
Manning's n	0.033
Average Water Depth (m)	0.22
Velocity (m/s)	0.60
Discharge (m^3/s)	0.90
Bed Shear Stress (N/m^2)	6.5
Bed Sediments	
D_{50} (m)	0.0063
D_{84} (m)	0.028
Komar (1987) D_{50} (m/s):	0.46
Miller et al (1977) D_{50} (N/m^2)	4.59



Cross-Section 2:

Water Depth (m)	0.32
Slope (m/m)	0.003
Manning's n	0.033
Average Water Depth (m)	0.22
Velocity (m/s)	0.61
Discharge (m^3/s)	0.87
Bed Shear Stress (N/m^2)	6.5
Bed Sediments	
D_{50} (m)	0.0063
D_{84} (m)	0.028
Komar (1987) D_{50} (m/s):	0.46
Miller et al (1977) D_{50} (N/m^2)	4.59



BEACON
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Summary of Erosion Threshold Analysis

Date: May 2016
Project: 215200.1
Client: Sixteenth Land Holdings Inc.
Watercourse: Bruce Creek
Location: York Downs Golf Club, Markham, ON
Reach: BR-3
Length Surveyed: 230 m
Representative Cross-sections: XS 6 and 7 (of 8)

Summary of Calculated Hydraulic Parameters

Bankfull Channel:

Discharge (m^3/s):	**6.60**
Velocity (m/s):	**1.40**
Maximum Depth (m):	**0.85**
Tractive Force (N/m^2):	**21.8**
Flow Competency (Komar, 1987):	
for D_{50} (m/s):	**0.55**
for D_{84} (m/s):	**1.05**
Shear Stress (Miller et al., 1977):	
for D_{50} (N/m^2):	**6.8**
for D_{84} (N/m^2):	**27.7**

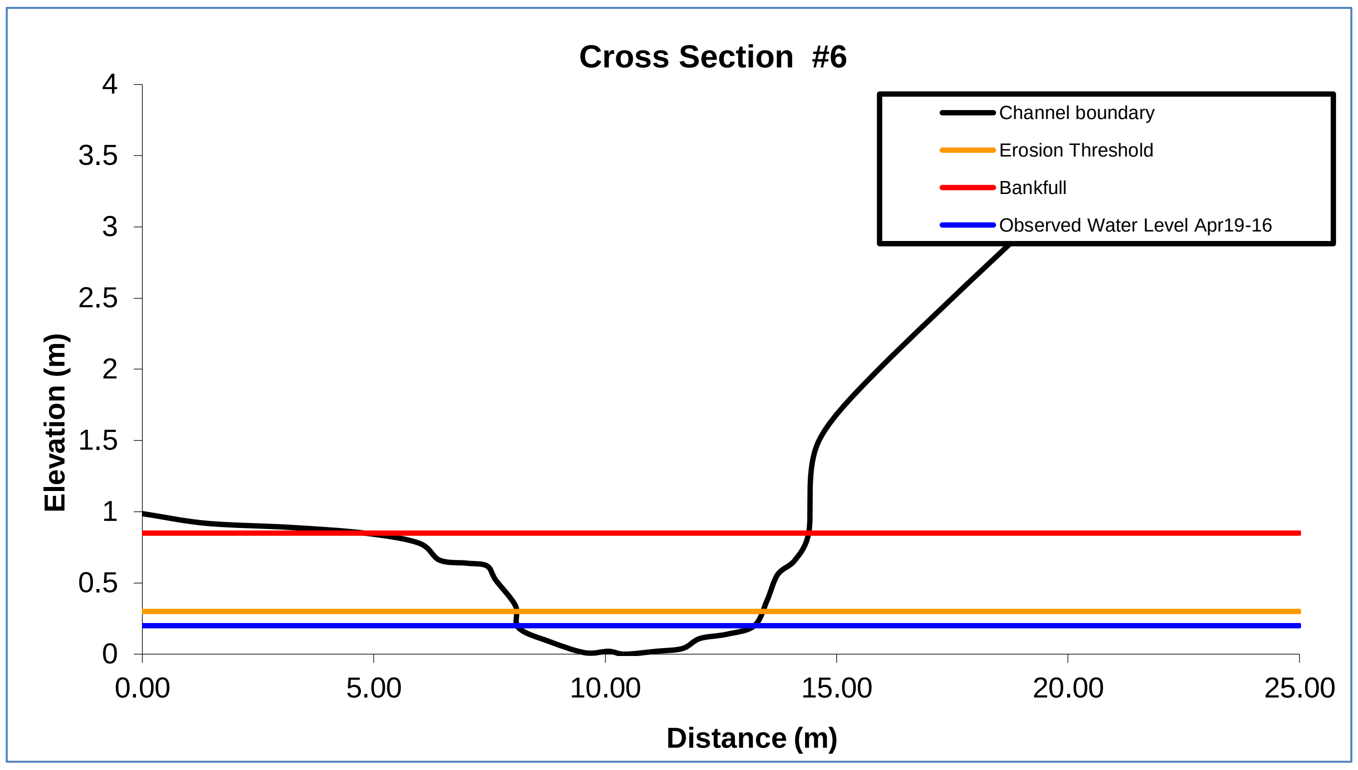
Erosion Threshold:

Critical Discharge (m^3/s):	**0.90**
Critical Velocity (m/s):	**0.74**
Critical Depth (m):	**0.31**
Critical Shear Stress (N/m^2):	**9.6**
Percent of Bankfull Discharge	**14**

* Sediment entrainment not observed at the time of survey

Cross-Section 1:

Critical Depth (m)	0.30
Slope (m/m)	0.0044
Manning's n	0.033
Average Water Depth (m)	0.22
Velocity (m/s)	0.72
Discharge (m^3/s)	0.85
Bed Shear Stress (N/m^2)	9.4
Bed Sediments	
D_{50} (m)	0.0093
D_{84} (m)	0.038
Komar (1987) D_{50} (m/s):	0.55
Miller et al(1977) D_{50} (N/m^2)	6.77



Cross-Section 2:

Water Depth (m)	0.32
Slope (m/m)	0.0044
Manning's n	0.033
Average Water Depth (m)	0.23
Velocity (m/s)	0.76
Discharge (m^3/s)	0.95
Bed Shear Stress (N/m^2)	9.8
Bed Sediments	
D_{50} (m)	0.0093
D_{84} (m)	0.038
Komar (1987) D_{50} (m/s):	0.55
Miller et al(1977) D_{50} (N/m^2)	6.77