Submitted to:

**Credit Valley Conservation**

1255 Old Derry Road
Mississauga, ON L5N 6R4

# Lake Ontario Integrated Shoreline Strategy Moore Creek: Fluvial Geomorphology Assessment

A report submitted by:

**Aquafor Beech Ltd.**

October 31, 2014


**Contact:**
Roger Phillips, Ph.D., P.Geo.
*Fluvial Geomorphologist*
Aquafor Beech Ltd.
phillips.r@aquaforbeech.com
2600 Skymark Avenue
Building 6, Unit 202
Mississauga, ON L4W 5B2
T. 905.629.0099 ext.235


Aquafor Beech Reference: 65461

## Executive Summary Tables

| Study Results | Key Findings |
|---|---|
| Geomorphic Assessment | Four reaches described, with severe erosion upstream (Reach 3), then erosion and sediment transport (Reach 2), and net sediment accumulation downstream (Reach 1). Abrupt drops in the channel elevation (i.e., knickpoints) observed at the upstream culvert outfall (Reach 3) and at the lake shore (Reach 0). |
| Hydrology and Hydraulics | Stream flow assessed based on topographic channel surveys, hydraulic modeling, continuous water level logging, and five discharge measurements. Multiple lines of evidence used to substantiate the bankfull discharge, with the design flow recommended at value of **0.7 $m^3/s$**. |
| Erosion Hazard Assessment | Based on meander belt delineation procedures (and corroborated by an independent volumetric erosion modeling method in GIS), including factor of safety erosion and side slope allowances, the recommend width for the final *erosion hazard limit* of Moore Creek is **32 m**. |
| Sediment Supply to the Lake | Annual sediment supply to the lake has been estimated to be ~**9 tonnes**, with one-third from suspended sediment and two-thirds from bedload transport. This estimate corresponds to a sediment yield in the range of **40 $t/yr/km^2$**. |

| Management Recommendations | | Priority |
|---|---|---|
| Corridor Erosion Hazards | • Existing erosion along Moore Creek to be preserved within a 32 m wide erodible corridor, with residents limiting activities within 10 m from active channel banks. For Reaches 1 and 2, no direct intervention is recommended in terms of bank or channel restoration, other than select riparian plantings (**Figure I**). | **Medium** |
| Channel Restoration | • Severe erosion issues and bank failures in Reach 3 require mitigation by way of channel engineering and restoration (**Figure I**). It is recommended that these works maintain gravel sediment supply to downstream reaches, balancing vertical channel realignment and slope stabilization with dynamic fluvial processes within a restored meander belt and stream corridor. | **High** |
| Riparian Habitat | • Prevent further clearing of vegetation and dumping of yard waste along creek banks (**Figure I**). | **Medium** |
| | • Implement riparian plantings to strategically enhance riparian vegetation and bank stability for select locations (**Figure I**). | **Medium** |
| Aquatic Habitat | • Implement a groundwater and water quality study | **High** |
| | • Enhance fish passage at pedestrian bridge near lake shore | **Medium** |
| | • Monitor effects of large woody debris, particularly in Reach 1 | **Low** |
| Pedestrian Bridge Replacement | • The downstream bridge (Px1) requires consideration of grade control, structure span, channel materials, and fish passage. | **Medium** |
| | • The upstream bridge (Px2) requires consideration of structure span, channel materials, and trail drainage. | **Low** |

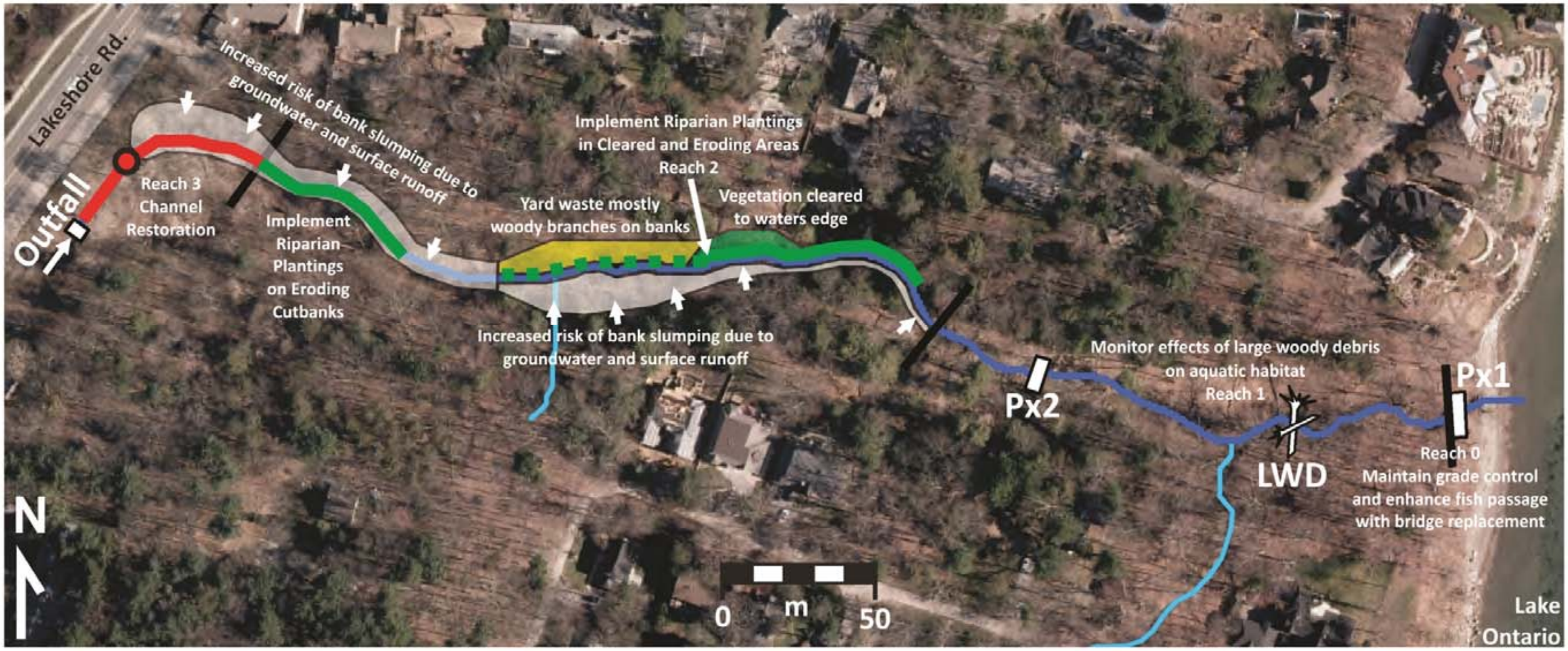



**Figure I:** Moore Creek fluvial geomorphology assessment executive summary map. Recommended stream restoration of Reach 3 is highlighted in red. General areas of recommended riparian plantings in Reach 2 are highlighted in green (e.g., on eroding cutbanks in upstream sections of Reach 2), also including areas of cleared vegetation and yard waste shaded in green and yellow, respectively. General areas of high groundwater input are shaded in white (with white arrows) based on field evidence of saturated banks and slumping. **Notes:** Other general notes where indicated; Px1 and Px2 are the pedestrian bridges; LWD = large woody debris jam.

**TABLE OF CONTENTS**

# 1 INTRODUCTION

The impetus for the fluvial geomorphic assessment of Moore Creek stems from the undertaking of the Lake Ontario Integrated Shoreline Strategy (LOISS) study which was undertaken by Credit Valley Conservation (CVC) and Aquafor Beech Limited. The LOISS study involved an assessment of existing conditions on the watercourses discharging directly to Lake Ontario and the Lake Ontario waterfront (see **Figure 1.1** for study area). During the LOISS study, Aquafor undertook fluvial geomorphology assessments of 11 watercourses within the study area (Aquafor, 2011). The purpose of the LOISS stream assessments was to gain insight into the interaction of the watercourses and Lake Ontario, to identify watercourses most sensitive to backwater from the lake, and to identify watercourses providing the highest sediment inputs to the shoreline. Since Moore Creek is contained within private property of the Lorne Park Estates and access permission had not been established, this creek was not assessed during the LOISS study. The fluvial geomorphic assessment of Moore Creek was consequently identified as a data gap. CVC was subsequently granted access to Moore Creek and retained Aquafor to undertake this study to complement the LOISS dataset.

The following tasks were completed for the Moore Creek Fluvial Geomorphology Assessment:

- Characterization of Moore Creek existing conditions, including topographic surveys;
- Assessment of channel hydrology and hydraulics;
- Definition of existing and future erosion hazards; and
- Assessment of sediment supply to the lake.

The study results then provided the basis to make management recommendations with respect to restoration opportunities for Moore Creek and special considerations for possible repair or replacement of two pedestrian bridges.


**Figure 1.1**: Study area for LOISS study and location of Moore Creek.

# 2 GEOMORPHIC FIELD ASSESSMENT

A geomorphic field assessment of Moore Creek was completed on August 23, 2013. Field observations of channel morphology, boundary materials, riparian conditions, and other modifying influences were collected. The existing conditions were also documented in a photographic inventory (**Appendix A**). Preliminary stream reach delineation was confirmed and revised according to field observations. The geomorphic condition of Moore Creek was evaluated using the Rapid Geomorphic Assessment (RGA) technique for each stream reach (MOE, 1999; **Appendix B**). To further strengthen the reach delineation assessment, field observations were compared with longitudinal profile information extracted from a digital elevation model (DEM) obtained from the City of Mississauga (see Section 7.1 for further details).

Moore Creek is about 550 m in length between a 750 mm diameter storm outfall south of Lakeshore Rd W and the creek's outlet at Lake Ontario (**Figure 2.1**). In total, four (4) stream reaches were identified within the study area, with the majority (85%) of the channel length contained within two reaches (Reaches 1 and 2). As such, Reaches 0 and 3 were identified as transitional reaches upstream of Lake Ontario and downstream of Lakeshore Road, respectively. Although at least two small tributary drainage features were noted in the field and in the base mapping, channel slope, boundary materials, and fluvial processes were instead the primary criteria used for reach delineation. Tributary confluences may be appropriate locations to designate divisions between sub-reaches of Reaches 1 and 2. The locations of two pedestrian bridges were also confirmed in the field and added to the base mapping. With reference to **Figure 2.1** and photographs in **Appendix A**, the field conditions and RGA scores for each stream reach are outlined below proceeding from the outlet at Lake Ontario upstream to Lakeshore Rd:

**Reach 0** is a short transitional reach between the creek outlet at Lake Ontario and the first pedestrian bridge (Px1; reach length ~30 m). Beach-ridge cobble deposits (and perhaps the pedestrian bridge structure) act as established grade control for Moore Creek resulting in a ~1.5 m drop from the invert of the bridge orifice to the lake level (slope of ~5%). This drop includes a number of cobble/tree-root steps with intervening plunge pools. Scour associated with the pools has exposed bank material locally, including some fine-grained glacial till or beach deposits. The average RGA stability index for Reach 0 was calculated to be 0.37 which is considered to be a *transitional* score based on some field evidence of stream adjustments. Given that this reach represents a knickpoint in the profile of Moore Creek, processes of channel degradation were most evident. However, aggradational features were also present.

**Reach 1** extends upstream from the first pedestrian bridge (Px1) to about 30 m upstream of the second pedestrian bridge (Px2; reach length ~170 m). The average RGA stability index for Reach 1 was calculated to be 0.47 which is considered to be an *in adjustment* score based on field evidence of stream adjustments. Indicators of **aggradational** processes were most dominant (all 7 indicators were observed), with minor evidence of other fluvial adjustment processes also observed in Reach 1 (i.e., degradation, widening, planform adjustment). The average stream gradient from the DEM longitudinal profile was estimated to be 0.9% (with range of 0.3 – 2%); however, more than half of the elevation drop (0.6 of 1.1 m) occurs locally where there is an accumulation of large woody debris (LWD, **Figure 2.1**). Consequently, low gradients (0.3 – 0.4%) and associated aggradational processes tend to limit most sediment transport to sand grain-sizes which move during frequent storm flow events, with temporary storage in bars.

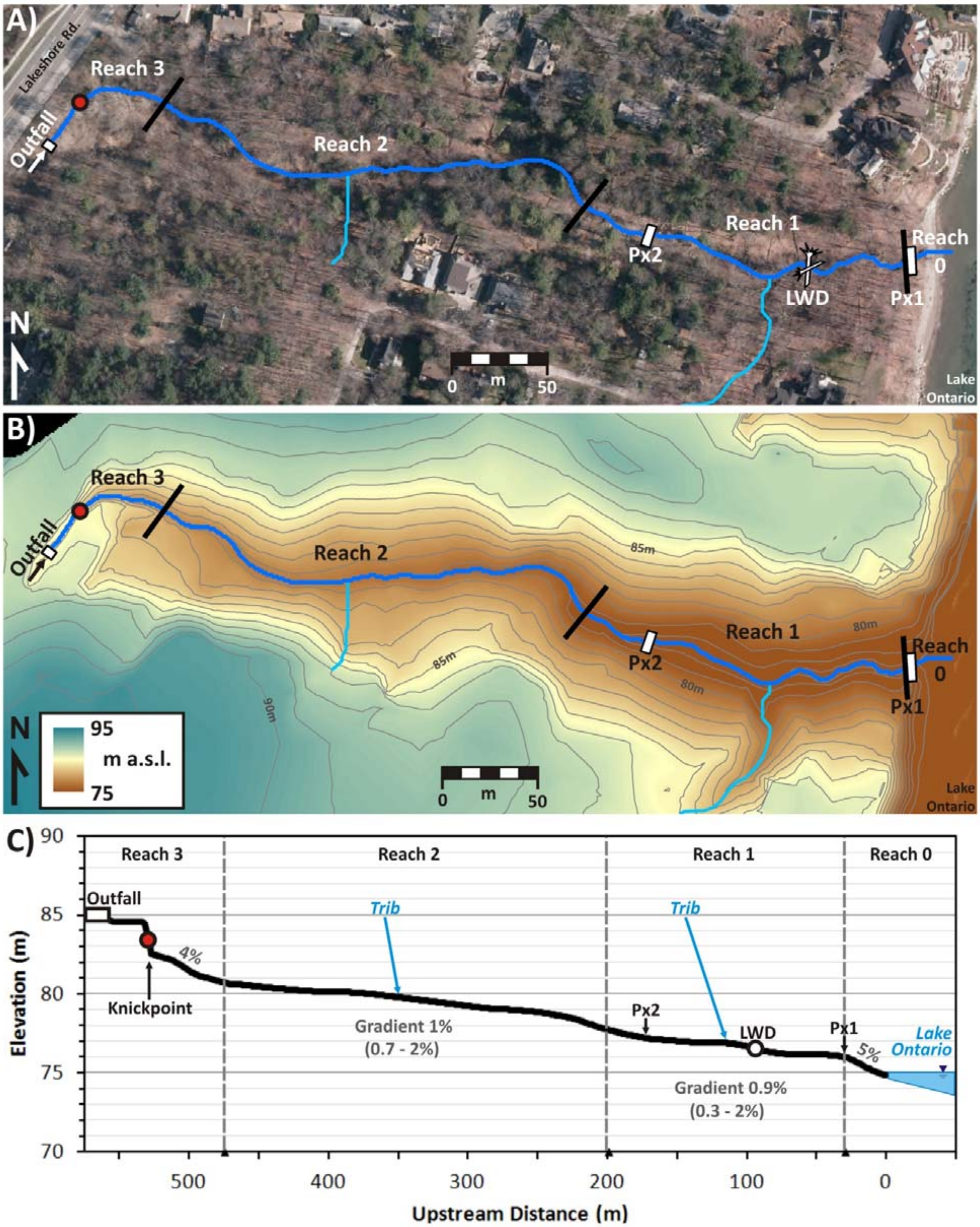



**Figure 2.1:** Stream reaches for Moore Creek. **A)** Reach breaks (black lines) and features of interest with 2013 aerial photography (source: CVC); **B)** Digital elevation model (1 x 1 m DEM) and 1 m contour interval (source: City of Mississauga); **C)** Longitudinal profile (generalized) based on DEM data with interpreted channel gradients for each stream reach (Vertical Exaggeration x10). **Notes:** Px1 and Px2 are the pedestrian bridges; LWD = large woody debris.

**Reach 2** extends upstream about 275 m from its transition with Reach 1. The average RGA stability index for Reach 2 was calculated to be 0.46 which is considered to be an *in adjustment* score based on field evidence of stream adjustments. Indicators of **aggradational** processes were most dominant (5 of 7 indicators were observed); however, more evidence of degradation and widening processes was also observed as compared to Reach 1. The average stream gradient from the DEM longitudinal profile was estimated to be 1% (with a range of 0.7 – 2%; note most sediment transport during storm flow events is expected under energy gradients of 0.7 – 1%). The bed material in Reach 2 was observed to be a mix of sand and gravel, with some local exposure of the underlying glacial deposits. During the field assessment, sand and gravel bed materials were typically stored as lateral bars and point bars associated with dynamic bedload transport and channel meander bend development. Meander bend migration and lateral channel adjustments were notable in the upstream and downstream sections of the reach; however, a relatively straight (and entrenched) section was observed mid-reach immediately downstream of the small tributary (see Figure 2). A riffle-pool bed morphology was partially to irregularly developed in association with channel planform dynamics in Reach 2; however, dynamic sediment bar deposits and channel debris appeared to limit well-developed riffle-pool bed forms.

**Reach 3** extends upstream approximately 75 m from Reach 2 and is connected to the upstream drainage areas by a culvert outfall (750 mm diameter) on the south side of Lakeshore Rd. Reach 3 was clearly distinguished by a significant knickpoint (~2 m drop) in the stream profile dividing two sub-reaches. As the ~25 m length of channel upstream of the knickpoint was considered to be relatively stable, the focus of the geomorphic assessment was on the downstream portion of Reach 3 (about 50 m length). The average RGA stability index for Reach 3 was calculated to be 0.60 which is strongly considered to be an *in adjustment* score based on field evidence of stream adjustments. Given the ~2 m knickpoint observed in the stream profile, indicators of **degradational** processes were most dominant (9 of 10 indicators were observed); however, significant evidence of widening and aggradational processes was also observed. The average stream gradient for Reach 3 downstream of the knickpoint estimated from the DEM longitudinal profile was 4%. Channel materials in Reach 3 were observed to be a disorganized accumulation of sand, gravel, cobble, and artificial debris deposited from the historical downcutting of the channel and the failing channel banks.

### *Overall Geomorphic Assessment of Moore Creek*

The overall geomorphic form and function of Moore Creek is bracketed between two knickpoints near the upstream and downstream limits of the study area respectively. It is suspected that the grade control and pedestrian bridge structure at Reach 0 has been historically stable (relatively), thus limiting downcutting and promoting overall aggradation upstream in Reach 1 (however, some under cutting of the concrete headwall was evident). This stability may be explained by some combination of cobble beach-ridge deposits, established tree roots, and/or the artificial bridge structure which have so far prevented channel incision.

In contrast, the upstream knickpoint in Reach 3 is considered to be severely unstable. The historic and continued erosional processes in Reach 3 are contributing to extreme bank and slope instability within the reach and thus this portion of the Moore Creek system is considered a significant source of sediment to the downstream reaches. The banks and bed materials appear to be a mixture of native glacial deposits (sand/silt, and small gravel percentage) and artificial land fill materials from construction of Lakeshore Road and adjoining properties.

Reach 2 exhibits evidence of a range of aggradational, degradational, and widening processes, as well as lateral meander bend migration associated with sand/gravel point bar deposits and undercut stream banks. Sand and fine-gravel transported through Reach 2 tends to contribute to the prevailing aggradational processes within Reach 1. As such, Reach 1 is dominated by sandy bed materials and bed forms, with temporary and long-term storage in lateral bars and point bars, respectively. Effectively Reach 1 is considered to have a relatively low gradient for sediment transport processes (in range of 0.3 – 0.4%) due to the localized energy dissipation maintained by a semi-stable accumulation of large woody debris (LWD) in the middle of the reach.

More detailed analysis of channel morphology, sediment properties, hydraulics, sediment transport, and erosion hazards are explored in subsequent sections of the report, primarily focusing on Reaches 1 and 2 of Moore Creek. Final management recommendations will consider the entire Moore Creek system south of Lakeshore Road, including all reaches identified in **Figure 2.1**.

## 3 TOPOGRAPHIC SURVEY AND CHANNEL GEOMETRICS

Field sites in Reaches 1 and 2 were selected to collect detailed survey information on Moore Creek, particularly in terms of channel cross-sections and profiles. This information was then used to document channel geometrics in terms of bankfull properties and channel gradient, as well as to construct hydraulic models for estimates of channel capacity and sediment transport. Two survey events were conducted: the first on September 5-6, 2013 to document baseline conditions; and the second on December 6, 2013 to test the amount of intra-annual variability from natural and survey sources. The locations and extents of the two field sites are presented in **Figure 3.1**. Surveys at each field site included the channel thalweg profile and 10 cross-sections, with 2 cross-sections monumented at each site for repeated measurements. The detailed survey results are documented in **Appendix C** and channel geometric properties are summarized below in **Table 3.1**.


**Figure 3.1:** Locations and extents of detailed topographic surveys on Moore Creek completed in Summar/Fall 2013: Upstream (Reach 2) and Downstream (Reach 1) sites, respectively. Red square points represent locations of installed iron bars (IBs) for survey control monuments (4 per site) at "master" cross-sections (2 per site).

**Table 3.1:** Channel geometrics from topographic survey of Moore Creek

| Field Site | Bankfull Parameters: Width (m) | Depth (m) max [avg] | XS Area ($m^2$) | Entrenchment Ratio | Surveyed Slope |
|---|---|---|---|---|---|
| Downstream (Reach 1) | 4.8 | 0.53 [0.32] | 1.5 | 2.2 – 2.7 | 1.05% (0.4 – 2%) |
| Upstream (Reach 2) | 2.8 | 0.51 [0.35] | 1.0 | 2.2 | 1.08% |

* Additional summary data from the topographic survey is provided in Appendix C.

Only minor cross-sectional variations were noted between repeated survey events (September and December, 2013), most notably associated with sediment bar dynamics limited to the active channel bed. No bank erosion was recorded at any of the 4 monumented cross-sections. Repeated channel profiles at the two field sites show considerable small-scale variation again interpreted to be associated with active sediment dynamics; however, the locations of prominent riffle and pool features was largely unchanged between the two survey events. Cross-section and profile figures are presented in **Appendix C**.

# 4 SEDIMENT CHARACTERIZATION

As part of the geomorphic assessment of Moore Creek, the grain-size distribution of channel bed materials was measured using bulk sampling and Wolman pebble counting techniques. Frequent sediment bars were observed in Reaches 1 and 2, and were expected based on evidence of dynamic sediment transport and storage within the channel. As such, bar deposits were photographed and mapped within each field site (**Appendix A**) to document sediment dynamics and to evaluate the volume of sediment stored within the active channel per metre of channel length. As summarized in the geomorphic assessment, Reach 1 is dominated by sand and fine gravel received from Reach 2. Reach 2 is characterized by sandy gravel supplied from local bank erosion processes, as well as from significant sources in Reach 3 due to extensive erosion.

A summary of the grain size data for Reaches 1 and 2 is provided in **Table 4.1**. The average thickness of sediment bar deposits based on field observations was 0.25 m and 0.15 m for Reaches 1 and 2 respectively. Topographic surveys of representative bar areas and channel deposits within each reach were used to estimate the approximate volumes of sediment storage within the bankfull channel. Representative grain size classifications are shown in **Figure 4.1**.

**Table 4.1:** Sediment grain size results and storage volumes within the active bankfull channel

| Field Site | Bulk Grain Size Samples: Percentage[a] (%) | $D_{95}$ (mm) | $D_{84}$ (mm) | $D_{50}$ (mm) | Sediment Bar Storage: Unit Volume $m^3$/m | Reach Volume $m^3$ |
|---|---|---|---|---|---|---|
| Downstream (Reach 1) | sand/silt: 62%<br>f. gravel: 31%<br>c. gravel: 8% | 22 | 13 | < 2<br>[12][b] | 1 – 1.5 | ~200[c] |
| Upstream (Reach 2) | sand/silt: 32%<br>f. gravel: 40%<br>c. gravel: 28% | 28 | 22 | 8<br>[14][b] | 0.5 – 1 | ~200[c] |

[a] Sand/silt = < 2 mm; fine (f.) gravel = 2 – 16 mm; coarse (c.) gravel = > 16 mm
[b] [$D_{50}$] also given for gravel fraction excluding sand/silt (< 2 mm)
[c] Reach volumes based on average unit volumes times reach lengths given in Section 2 of the report

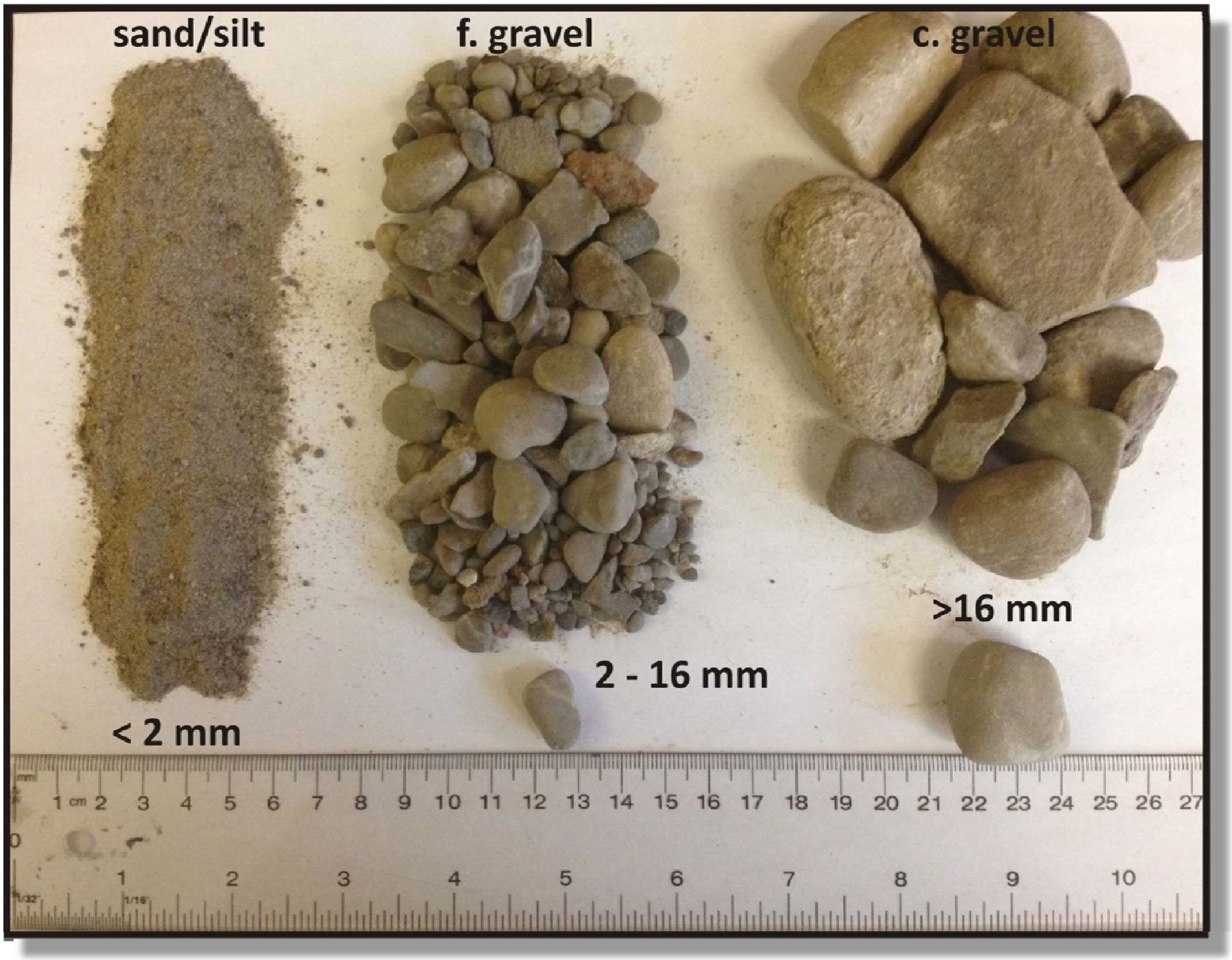



**Figure 4.1** – Representative bed material grain sizes for Moore Creek Reaches 1 and 2.

# 5 HYDROLOGY

Prior to this study, no flow data were available for Moore Creek. No gauging data had been collected for this creek nor had a hydrologic model been developed to predict return period flows based on standard design storms. As such, Aquafor developed return period flows based on known flows in surrounding watersheds and installed a water-level logger at the start of the study to allow for the development of a gauging station over the course of the study. These two items are described in further detail in the sections below.

## 5.1 Return Period Flow Estimation

Since no flow record was available for Moore Creek, no direct frequency analysis could be completed to predict return period flows for this watercourse. Instead, flows from adjacent watersheds with similar land uses were used to pro-rate Moore Creek flows based on drainage area. Data from the LOISS study included available return period flows and drainage areas for Birchwood, Tecumseh, and Turtle Creeks at Lake Ontario (Aquafor Beech Ltd., 2011). The drainage area for Moore Creek was calculated to be 21 ha (0.21 km$^2$) using the digital elevation model (DEM) from the City of Mississauga (**Figure 5.1**). The drainage areas and return period flows at Lake Ontario for the three adjacent watercourses (Birchwood, Tecumseh, and Turtle Creeks) are summarized in **Table 5.1**.


**Figure 5.1**: Moore Creek catchment area including storm sewers based on DEM and storm sewer datasets from City of Mississauga. Estimated drainage area of Moore Creek is 21 ha (or 0.21 km$^2$).

**Table 5.1:** Return period flows for adjacent LOISS watercourses (drainage areas = $A_d$)

| Return Period | Flows (m$^3$/s) Birchwood Creek $A_d$ = 340 ha | Tecumseh Creek $A_d$ = 167 ha | Turtle Creek $A_d$ = 213 ha |
|---|---|---|---|
| 2-Year | 8.9 | 3.1 | 4.2 |
| 5-Year | 11 | 5.5 | 6.3 |
| 10-Year | 12 | 8 | 9 |
| 25-Year | 15 | 10.7 | 11.5 |
| 50-Year | 18 | 12.8 | 14 |
| 100-Year | 20 | 15.1 | 17 |
| Regional | 35 | 19.1 | 25.5 |

Using the available flow and drainage area data, the return period flows for Moore Creek at Lake Ontario were predicted using the drainage-area-ratio method (Ministry of Transportation Ontario, 1997):

$$Q_2 = Q_1 \times \left[\frac{A_2}{A_1}\right]^{0.75} \quad [1]$$

where $Q_1$ = known flow for watershed 1 [m$^3$/s],
$A_1$ = drainage area for watershed 1 [m],
$A_2$ = drainage area for watershed 2 [m], and
$Q_2$ = predicted flow for watershed 2 [m$^3$/s].

The resulting return period flows for Moore Creek are presented in **Table 5.2**.

**Table 5.2** Flows pro-rated by drainage area for Moore Creek

| Return Period | Pro-Rated Flows for Moore Creek ($m^3/s$) | | | Mean Pro-Rated Flow ($m^3/s$) |
|---|---|---|---|---|
| | Birchwood | Tecumseh | Turtle | |
| 2-Year | 1.09 | 0.65 | 0.73 | 0.83 [0.7][a] |
| 5-Year | 1.35 | 1.15 | 1.10 | 1.20 |
| 10-Year | 1.47 | 1.67 | 1.57 | 1.57 |
| 25-Year | 1.84 | 2.24 | 2.01 | 2.03 |
| 50-Year | 2.21 | 2.68 | 2.44 | 2.44 |
| 100-Year | 2.46 | 3.16 | 2.97 | 2.86 |
| Regional | 4.30 | 4.00 | 4.45 | 4.25 |

[a] Average pro-rated results from Tecumseh and Turtle creek with smaller drainage areas were used to estimate the 2-Year flow for Moore Creek.

Based on the data presented, a 2-year flow of 0.7 $m^3/s$ and a Regional flow of 4.25 $m^3/s$ were used for hydraulic modeling on Moore Creek. Although these values represent the flows at Lake Ontario, they were applied to the entire Moore Creek channel for the purposes of this study.

## 5.2 Water-level Monitoring

On August 23, 2013, a water-level logger was installed in Moore Creek in the pool downstream of the pedestrian bridge by the lake shore (Px1, **Figure 2.1A**). This location was deemed appropriate since the downstream knickpoint (which was deemed to be stable for the expected duration of the study) provided control on the water-level in the pool. The water-level logger was set to record a water-level reading every 5 minutes.

Water level data was collected for the period of August 23, 2014 to September 10, 2014, with the intention of representing a complete hydrologic year. However, there remains a few data gaps over the monitoring period due to instrument errors, including in November 2013 and in May-June, 2014. As well, the winter ice conditions from December 2013 to March 2014 significantly limit the accuracy of the data over this period (e.g., negative water levels under frozen conditions and exaggerated positive water levels with pressurized flow under ice). Based on water level monitoring during the non-winter months the minimum water levels recorded were in the range of 0.008 – 0.100 m, and zero discharge was assumed at a water level of ~0.005 m.

To correlate the water-level reading to discharge in the creek, direct flow measurements are required for a range of known water levels. Aquafor collected 5 flow measurements using the velocity-area method. The results of these measurements are presented in **Table 5.3**. Stage-discharge rating curves are presented **Figure 5.2**, including two alternative models: **Eq. 2** is a second-order polynomial equation which shows a high degree of fit with the data ($r^2 = 0.9966$), but may overestimate discharges for higher discharge flood events; and **Eq. 3** is a linear equation which shows more reasonable extrapolation to the bankfull discharge. All subsequent analysis of the discharge records in this report are based on **Eq. 2** for water levels less than 0.175 m and on **Eq. 3** for water levels greater than 0.175 m (i.e., the black curve in **Figure 5.3**).

To relate rainfall to flows within Moore Creek, precipitation data were taken from the closest available CVC rain gauging station. This station was installed by Aquafor Beech Ltd. and is located at the Imax Centre on Speakman Drive in Mississauga (north of the QEW and east of Winston Churchill Boulevard). This station is approximately 9 km south-east of Moore Creek and, due to the localized nature of rainfall, does not represent the actual rainfall on the Moore Creek watershed. However, for the purposes of this study, this gauge provides a reasonable indication of the magnitude and temporal distribution of the rainfall within the Moore Creek watershed.

The continuous discharge record and rainfall data are presented in **Figure 5.3** for the period of August 23, 2013 to September 10, 2014. While the lowest summer baseflows are likely less than 1 L/s, more typical low-flows are about 3 L/s and in the range of 5 – 10 L/s in the wet seasons of fall and spring. Based on **Eq. 3**, the highest extrapolated peak flow over the monitoring period was 483 L/s (or 0.483 $m^3/s$) on August 27, 2013. Additional peaks above 0.4 $m^3/s$ were also recorded for July 2014. Although the plotted discharges above 0.11 $m^3/s$ have been extrapolated with **Eq. 3** and should be interpreted cautiously, the 2013-2014 discharge records for Moore Creek provided a reasonable basis to compare sub-bankfull flows in terms of hydraulic modeling (Section 6) and to estimate sediment transport to the lake (Section 7).

**Table 5.3:** Measured discharges ($Q$) and suspended sediment concentrations ($C_{ss}$) for recorded water levels

| Date | Time (EST) | Water Level (m) | Discharge, $Q$ ($m^3/s$) | Suspended Sediment $C_{ss}$ (g/L) |
|---|---|---|---|---|
| 23-Aug-13 | 15:00 | 0.130 | 0.00026 | 0.209 |
| 04-Oct-13 | 8:45 | 0.140 | 0.0091 | 0.206 |
| 04-Oct-13 | 9:00 | 0.139 | 0.0079 | 0.128 |
| 04-Apr-14 | 15:15 | 0.171 | 0.03651 | 16.3 |
| 29-Apr-14 | 12:10 | 0.203 | 0.11099 | 11.3 |

**Table 5.4:** Correlations between water-level and discharge

| ID | Water-level Reading, $d$ (m) | Equation for Discharge, $Q$ ($m^3/s$) |
|---|---|---|
| **Eq. 2** | $d < 0.175$ m | $Q = 18.866\, d^2 - 4.8187\, d + 0.3111$ |
| **Eq. 3** | $d > 0.175$ m | $Q = 2.3276\, d - 0.3615$ |

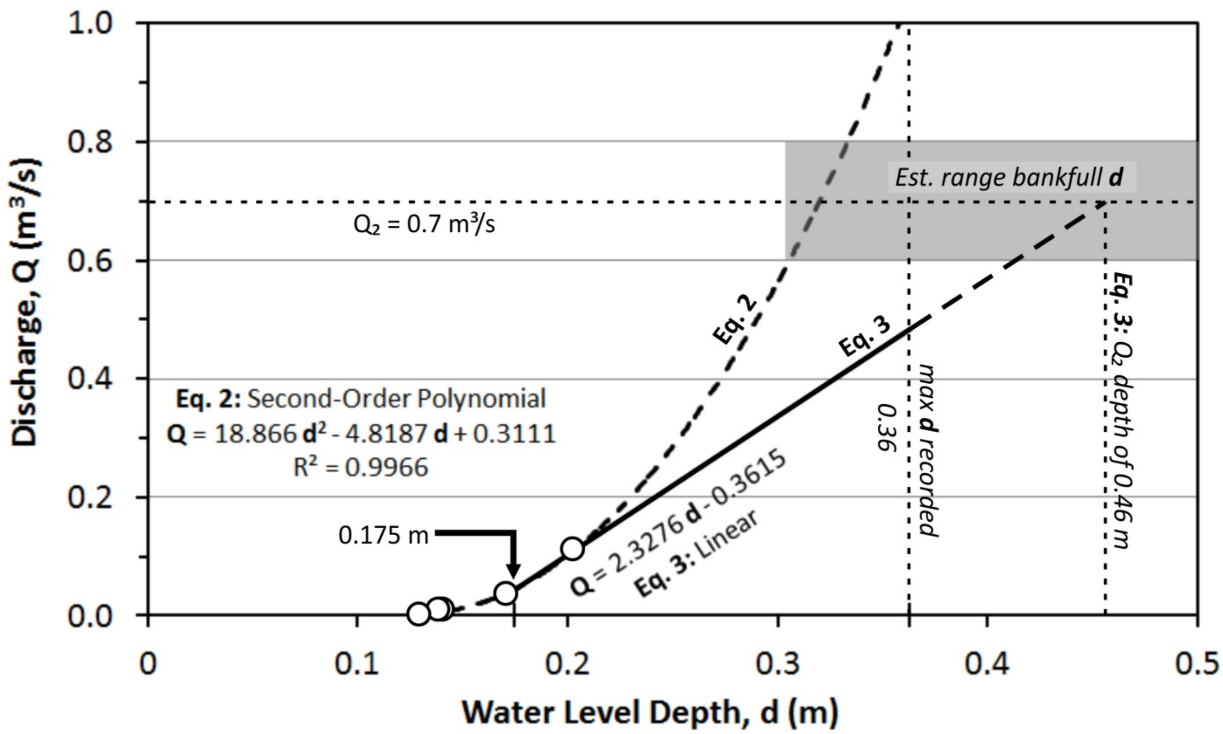



**Figure 5.2:** Stage-discharge rating curve(s) for Moore Creek based on 5 discharge measurements (white circles) using the velocity-area method (Table 5.3). See discussion in text and caption for Figure 5.3 regarding models using Eq. 2 (second-order polynomial) and Eq. 3 (linear) to extrapolate to higher discharges beyond the sampled measurements.

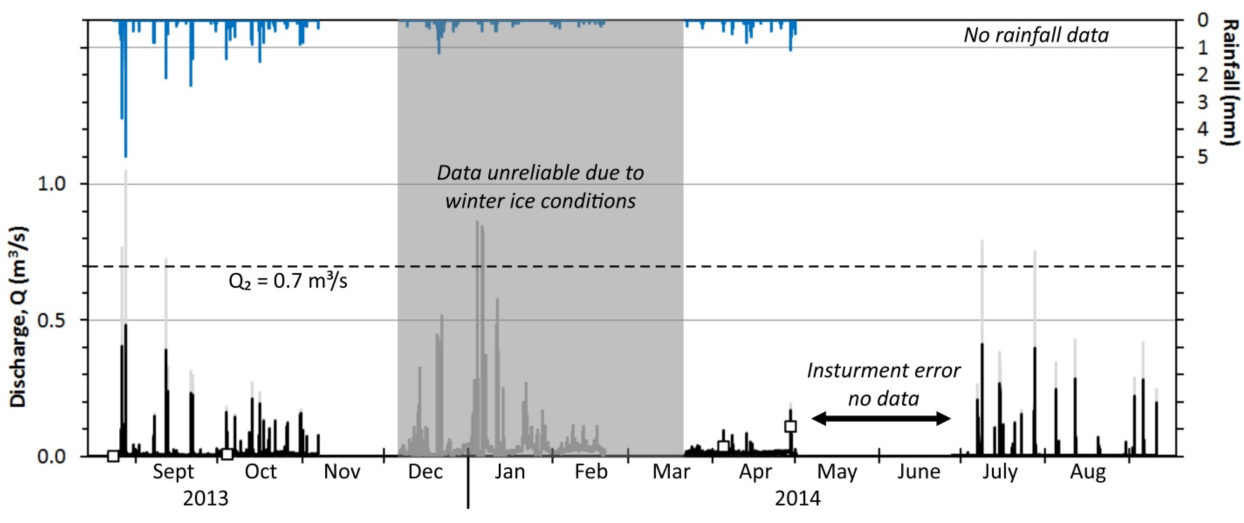



**Figure 5.3:** Continuous (5 minute interval) discharge record for Moore Creek (August 23, 2013 to September 10, 2014), with nearby rainfall data (blue lines). As per Figure 5.2, discharges for water levels less than 0.175 m were calculated based on Eq. 1. For water level values above 0.175 m and discharge values above 0.045 $m^3$/s the black time series is based on Eq. 2 (linear) and the light grey time series is based on Eq. 1 (second order polynomial). Black squares represent sampled discharge measurements as summarized in Table 5.3.

# 6 HYDRAULICS AND EROSION THRESHOLDS

For the monitoring sites, the topographic survey data from September 5, 2013 were used to create hydraulic models in HEC-RAS. At the Upstream Site (Reach 2), one hydraulic model was created using the monumented cross-sections and the additional cross-sections picked up during the September survey. The model was run under subcritical flow conditions with normal depth and a slope of 0.01 m/m assumed for the downstream boundary condition (i.e., the slope was calculated based on the survey data collected, **Table 3.1** and **Appendix C**). For the Downstream Site (Reach 1), the monumented cross-sections were separated by more than 50 m with an abrupt elevation drop associated with the large woody debris between them (**Figure 3.1**). To adequately represent the hydraulic conditions, 2 models were set-up at this site, one for each monumented cross-section and surrounding additional cross-sections. The models were run under subcritical flow conditions with normal depth and a slope of 0.007 m/m assumed for the downstream boundary conditions (i.e., the slope was calculated based on the survey data collected and was the same for both locations, excluding the section with large woody debris).

For all models, channel and overbank roughness values were selected based on CVC's modeling standards. A Manning's n value of 0.035 was assigned to the channel. The overbank areas were represented by a roughness value of 0.055 which is appropriate for a meadow condition. The models were run for the estimated 2-year flow and Regional flows (**Table 5.2**). The 2-year flow represents an estimate of the effective discharge which acts as the channel-forming flow in a watercourse (i.e., the bankfull discharge). The Regional storm is equivalent to Hurricane Hazel in 1954 which represent the highest flows on record for Southern Ontario (i.e., the regulatory flow). Although the storm sewer outfall downstream of Lakeshore Road conveys only the minor system flows to Moore Creek, the major system flows are expected to be directed to the creek via the road system. As such, the Regional flow of 4.25 $m^3/s$ has used in the hydraulic model.
In addition to these two flows, hydraulic modeling was also undertaken in association with expected substrate movement. A range of flows were run through the HEC-RAS models and the channel shear stress values were reviewed to determine the approximate flows at which particles in the $D_{50}$ to $D_{84}$ range (12 – 22 mm diameter) were entrained at each site. Two *gravel entrainment* flows were identified as:

- **0.15 $m^3/s$** = fine gravel entrainment in Reach 2, but generally only sand transport in Reach 1. This discharge is reasonable for frequent storm flow events as demonstrated by the preliminary discharge results in **Figure 5.2**.
- **0.45 $m^3/s$** = coarse gravel entrainment in Reach 2 and fine gravel entrainment in Reach 1. This discharge represents approximately the half-bankfull flow.

Detailed hydraulic modeling (HEC-RAS) results are provided in **Appendix D**, with shear stress and sediment entrainment results summarized in **Table 6.1**. These results generally support the interpretation of the geomorphic assessment. Specifically, fluvial sediment transport processes in Reach 2 are generally effective at transporting fine gravels (and finer sands) through the reach with regular sediment transport events throughout the year (except under winter frozen conditions). Sediments delivered downstream to Reach 1 tend to be deposited in what is primarily an aggradational environment. It is expected that sand bed materials in Reach 1 are transported frequently throughout the year; however, transport of fine gravels (e.g., 12 – 14 mm range) require between half-bankfull and bankfull flow events for sediment transport in Reach 1. Consequently, based on preliminary discharge records and field observations it is likely that gravel transport events in Reach 1 only occur a few times per year at most.

Hydraulic model results for the 2 year flow as presented in the cross-sections (Appendix D) further corroborate the interpreted bankfull channel and **the recommended design flow of 0.7 m$^3$/s**.

**Table 6.1:** Flows modeled in HEC-RAS with associated shear stress and grain-sizes entrained.

| | | Average Shear Stress (N/m$^2$) | | Grain Size Entrained[a] (mm) | |
|---|---|---|---|---|---|
| | Flow (m$^3$/s) | Reach 1 | Reach 2 | Reach 1 | Reach 2 |
| | 0.15 | 6 | 10 | 8 < [$D_{50}$][b] | **14 ~ [$D_{50}$][b]** |
| | 0.45 | 9 | 16 | **13 ~ $D_{84}$** | **22 ~ $D_{84}$** |
| 2-Year | 0.70 | 11 | 20 | 15 < $D_{95}$ | **27 ~ $D_{95}$** |
| Regional | 4.25 | 32 | 37 | 43 > $D_{99}$ | 51 ~ $D_{99}$ |

[a] Grain size entrained based on standard Shield's equation of $\tau_{cr}$ = 728Dx (m). Percent-finer Dx values given relevant to sediment grain-size distribution results presented in Table 4.1. **Bold** results demonstrate strong agreement between modeled shear stress values under selected flow conditions and sampled substrate data from Table 4.1 for most relevant grain sizes $D_{50}$, $D_{84}$, and $D_{95}$ from sediment transport theory.
[b] [$D_{50}$] for gravel fraction excluding sand/silt (< 2 mm)

# 7 DESKTOP EROSION HAZARD ASSESSMENT

The purpose of the following erosion hazard assessment of Moore Creek is to quantify the erosion risks to properties surrounding the watercourse, to identify restoration opportunities, and to recommend management strategies. Further, details of the geomorphic and hydraulic assessments of Moore Creek allow for some consideration of sediment transport rates and ultimately sediment delivery to the lake. In the context of existing and predicted erosion conditions, broad-level management recommendations will also reference special considerations for the potential repair or replacement of the existing pedestrian bridges in the future.

## 7.1 Definition of Erodible Corridor

A meander belt is defined as the area that a channel currently occupies, or which it may be expected to occupy in the future. As such, it is preferable that expected bank erosion processes are preserved within an appropriate erodible corridor (Piégay et al. 2005). Meander belt delineation approaches (e.g., TRCA, 2004) typically involve mapping procedures and/or empirical relations based on physical channel properties. Definition of an erodible corridor includes mapping of the preliminary existing meander belt, plus an additional 100-year erosion allowance and/or factor of safety. Mapping procedures and estimates of erosion rates are generally based on historical and recent aerial photography. However, given the small size of Moore Creek and the dense forest canopy of the study area, airphoto approaches could not be used for this erosion hazard assessment. As such, for this study the meander belt delineation was completed by integrating information from a number of sources, including the 1 x 1 m digital elevation model (DEM) from the City of Mississauga; the field data from the geomorphic assessment; and the 2013 aerial photography from CVC.

Initially, the channel planform and longitudinal profile (**Figure 2.1C**) were extracted from the DEM using methods similar to those described by Phillips and Desloges (2014). Based on observations collected during the geomorphic assessment, areas of erosion and aggradation were mapped as presented in **Figure 7.1**. In the areas of most pronounced meander bend migration, field measurements of the preliminary meander belt width were collected using a laser range finder. The maximum meander amplitude measured within Reaches 1 and 2 was **16 m**. Specifically within Reach 2, the approximate meander bend alignments missing from the DEM analysis were added to the mapping based on the field measurements (**Figure 7.1**).

To provide some baseline estimates of erosion rates, six (6) erosion pins were installed within Reaches 1 and 2 where evidence of ongoing bank migration was observed in the field (2 within Reach 1 and 4 within Reach 2, **Figure 7.1**). Results of the erosion pin measurements taken over a 105 day period from August 23rd, 2013 to December 6th, 2013 are presented in **Table 7.1**. Extrapolated annual erosion rates range from 0 to 0.5 m/yr (average = 0.17 m/yr); however, these should be interpreted very cautiously given the limited monitoring period. Further, given that most of Moore Creek within Reaches 1 and 2 is slightly to moderately entrenched (i.e., entrenchment ratios of 2.2 to 2.7 as per **Table 3.1**), these high lateral erosion rates are not considered realistic in the sense that the volumes of sediment to be eroded from entrenched banks (> 2 – 2.5 m in height) are much greater than the short term erosion of the bank toe by the active bankfull channel (~0.3 – 0.5 m in height). For example, a slump of bank material documented at EP2.4 has temporarily moved the bank toe back towards the active channel and lateral recession of the entire bank will require reworking of the slumped material before erosion of the entrenched embankment is more fully realized.

In lieu of accurate long-term erosion rates for entrenched banks on Moore Creek, a 1.25 factor of safety was applied for a **20 m** final meander belt width, which is expected to include a 100-year erosion allowance. The final meander belt mapping is presented in **Figure 7.2A**. However, due to the moderately entrenched channel conditions, an additional stable slope allowance is also required to contain the erosion hazard. Based on average entrenched bank heights of ~2 m and standard stable slope recommendations for sandy materials of 3 horizontal to 1 vertical (MNR, 2002), an additional stable slope allowance of 6 m was also delineated on either side of the meander belt erodible corridor (dashed lines in **Figure 7.2A; total corridor width = 32 m**).


**Figure 7.1:** Erosion mapping for Moore Creek, including the locations of 6 erosion pins. Approximate meander bend alignments missing from the DEM data have been subsequently mapped based on field measurements (light blue lines).

**Table 7.1:** Extrapolated annual erosion rates based on erosion pin data over 105 day period

| Erosion Pins | Easting (m) | Northing (m) | Lateral Bank Erosion (m) | Period (days) | Extrapolated Erosion Rate (m/yr) |
|---|---|---|---|---|---|
| EP1.1 | 613108 | 4820911 | 0 | 105 | 0 |
| EP1.2 | 613072 | 4820899 | 0 | 105 | 0 |
| EP2.1 | 612962 | 4820941 | 0.14 | 105 | 0.5[a] |
| EP2.2 | 612960 | 4820955 | 0 | 105 | 0 |
| EP2.3 | 612774 | 4820983 | 0.06 | 105 | 0.2 |
| EP2.4 | 612756 | 4820978 | 0.09 | 105 | 0.3[b] |

[a] loss of bank toe material was considered a combination of groundwater saturation of the sediments and disturbance by the erosion pin installation.
[b] erosion rate based on two observations, with erosion pin buried by bank slump on December 6, 2013

To deal with inconsistencies between lateral migration rates of the active bankfull channel and volumetric erosion rates for incised and entrenched channels, Phillips (2009) tested a basic volumetric erosion rate model for Highland Creek (Toronto) using a high resolution DEM – an approach termed the Topographic Erodible Corridor (TEC). As presented in **Figure 7.2B** for Moore Creek, the 100-year erosion rates (colour scale) depict the areas of erosion risk on an equivalent volumetric basis *assuming lateral migration rates represent volumes associated with the active bankfull channel only*. For example, an active 0.3 m deep bankfull-channel erosion rate of 30m/100yrs (~9 $m^2$) would only migrate 3.9m/100yrs laterally into a 2.3 m high bank.

Comparison of traditional meander belt mapping and the TEC model (**Figure 7.2C**) shows favourable agreement between the two independent methods. Generally, areas within the 20 m meander belt envelope would require bankfull lateral migration rates in the order of 0.5 m/yr (yellow zone) for equivalent volumetric erosion hazards within 100 years. Areas where meander bends are situated close to the corridor boundary may be subject to greater hazards at bankfull erosion rates of less than 0.3 m/yr (within range of data in **Table 7.1**), however, these rates are still considered to be conservatively high for Moore Creek. It should also be noted that the TEC model does not represent some meander bends upstream in Reach 2 which are missing in the DEM dataset. Generally, the TEC modeling approach confirms erosion hazard expectations as delineated by standard meander belt mapping techniques.

A 100-year erosion hazard assessment has not been provided for Reach 3 due to severe entrenchment and considerable evidence of erosion within the reach (**Appendix A**; **Figures 7.1 and 7.2**). Erosion problems within this reach of Moore Creek require detailed assessments of slope stability and channel engineering measures to mitigate the erosion hazards. As it is understood that most or all of Reach 3 is situated within an adjacent private property outside the boundaries of the Lorne Park Estates, it has been assumed that erosion hazards within this reach are to be addressed by others. Specifically it is understood that owners of the subject property (990-994 Lakeshore Road West) associated with Reach 3 of Moore Creek are proposing new developments with preliminary plans submitted to the City of Mississauga. It is assumed that CVC will be responsible for a technical review of any engineering measures associated with Moore Creek, and will evaluate any potential changes to erosion patterns and sediment supply to downstream reaches (see Section 8.2). Any further consideration of Reach 3 management issues are beyond the scope of this present Fluvial Geomorphology Assessment report.

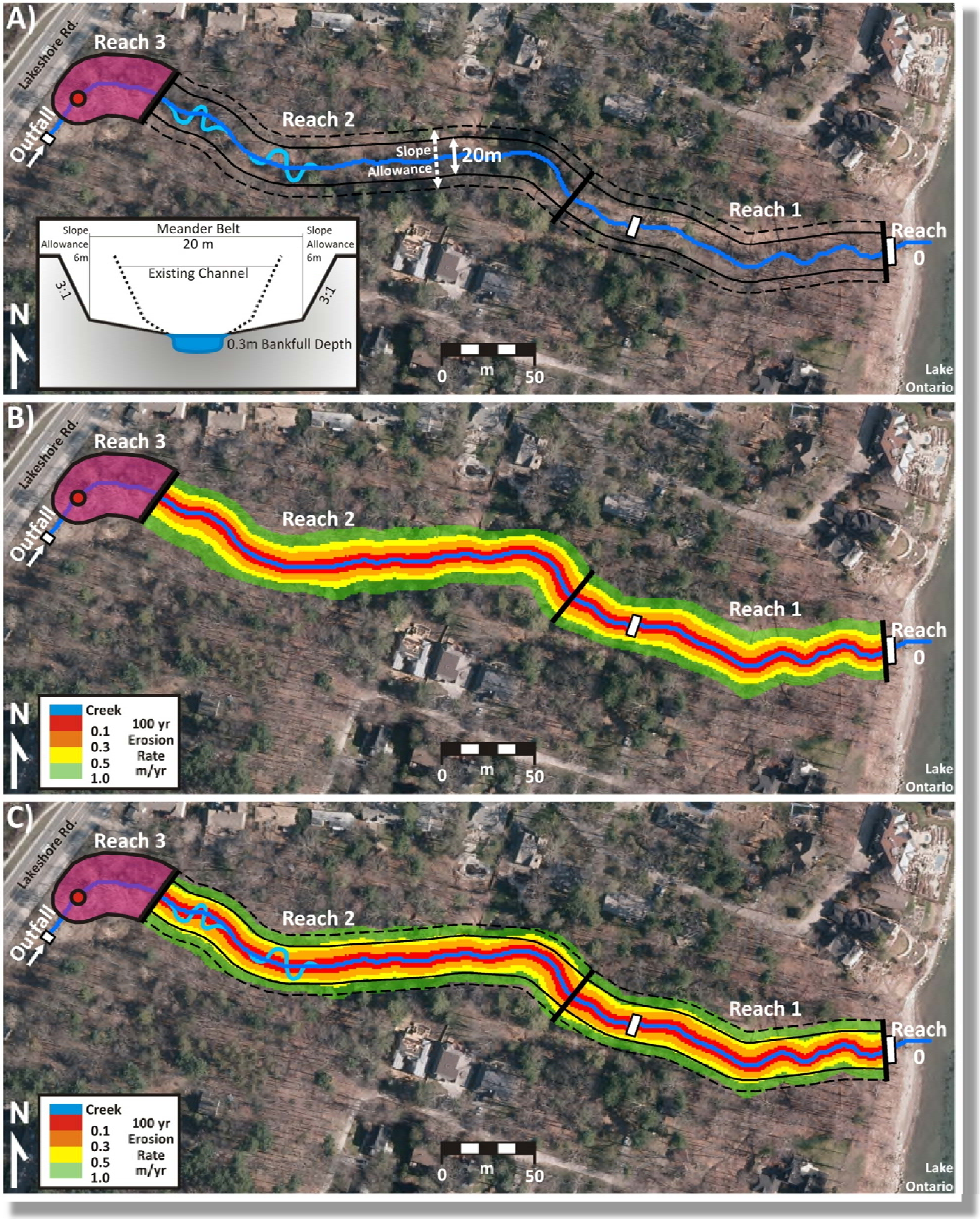



**Figure 7.2:** Erodible corridor and erosion hazard mapping for Moore Creek. **A)** Meander belt mapping of **20 m** belt-width (16 m x 1.25 factor of safety) with inset schematic cross-section of proposed **32 m** wide management corridor; **B)** Topographic Erodible Corridor (TEC) model of erosion probability (see text for details); **C)** Comparison of meander belt mapping with TEC model. **Note:** Area of Reach 3 identified for management considerations discussed in the text.

### 7.2 Sediment Supply to the Lake

Hydraulic modeling, suspended sediment sampling, and continuous discharge records provide a basis to constrain the potential quantity of sediment that Moore Creek delivers to the lake. To arrive at an estimate of sediment supply to Lake Ontario, sediment transport can be practically divided into two modes of transport based on grain-size and expected fluvial processes as summarized in **Table 7.2**.

**Table 7.2:** Modes of sediment transport for sediment supply assessment

| Mode of Transport | Description | Analysis Method |
|---|---|---|
| Suspended Sediment Load | Wash-load, mostly silt, clay, and some very fine sand | Suspended sediment rating curve indexed to discharge |
| Sand and Gravel Bedload | Bedload transport by tractive forces at threshold shear stresses and stream powers | Excess shear stress and/or stream power analysis based on continuous discharge records |

<u>*Sediment Transport Sampling*</u>

Suspended sediment concentrations ($C_{ss}$, mg/L) were sampled using a DH-48 depth-integrated sampler (**Figure 7.3A**) during discharge measurement events as summarized in **Table 5.3**. The $C_{ss}$ values for all baseflow and low-flow measurements for the first three measurements were generally between 0.1 and 0.2 g/L. For frequent storm flow events (greater than 0.03 m$^3$/s), suspended sediment measurements suggest $C_{ss}$ values are generally in greater than 10 g/L (**Table 5.3**). Although the completed 2013-2014 field sampling of $C_{ss}$ for Moore Creek is not statistically significant, the data provide a crude model estimate for the suspended sediment rating curve, where $\boldsymbol{C_{ss} = 34\ Q^{0.76}}$ ($r^2$ = 0.52). Based on this relationship, the continuous discharge data were used to estimate the total suspended sediment load ($G_{ss}$) over the 266.8 day monitoring period (where $G_{ss} = \Sigma\ C_{ss} \times Q$ for all 5 minute time intervals = 1900 kg). If this preliminary estimate is extrapolated to be representative of an entire year then the annual suspended sediment load to Lake Ontario is in the range of 2600 kg (or **~3 t/yr**).

Attempted bedload transport measurements using a standard USFS Bedload Trap (**Figure 7.3B**) were unsuccessful due to narrow time-periods of peak discharge. The bedload trap was installed for one storm flow event on October 4th, 2013; however, the 420 g of sand/silt material captured was not considered representative of sediment transport as the bedload trap had become clogged with fallen tree leaves (i.e., a limitation in fall season), thereby obstructing flow through the trap.

<u>*Excess Stream Power Bedload Sediment Transport*</u>

Two common forms of bedload transport equations are often used, either based on excess shear stress (e.g., Meyer-Peter and Muller, 1948) or based on excess stream power (e.g., Bagnold, 1980). For the purposes of this study, a modified excess stream power equation is tested based on a form given by Martin (2003):

$$i_b = a\ (\omega - \omega_o)^{1.5}\ d^{-1}\ D^{1/4} \qquad [4]$$

where $i_b$ is the specific bedload transport rate [kg/m·s],
$\omega$ is the specific stream power [W/m$^2$],
$\omega_o$ is the critical specific stream power [W/m$^2$],
$d$ is the flow depth [m], and
$D$ is the sediment grain-size [m].

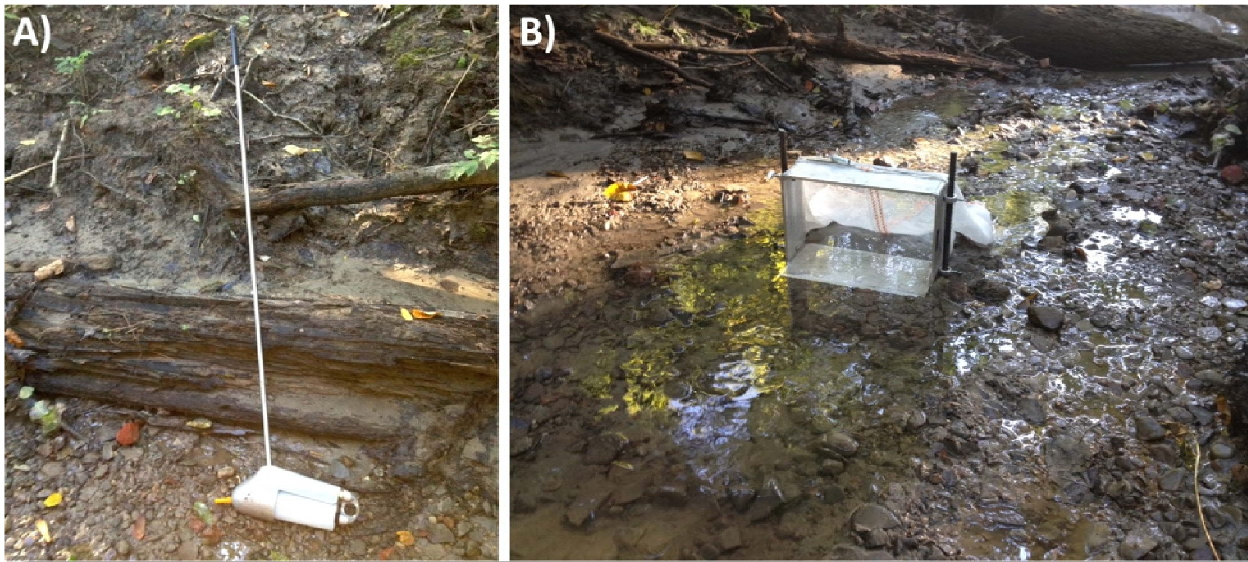



**Figure 7.3:** Sediment transport sampling devices. **A)** DH-48 depth-integrated suspended sediment sampler. **B)** US Forest Service (USFS) Bedload Trap.

A rationally-derived "*a*" coefficient for equation [4] is given as 0.0139 (Martin, 2003). The critical specific stream power ($\omega_o$) for a given grain-size ($D$) can be derived by equations such as that by Parker et al. (2011). For the purposes of this study, bedload transport of sand and gravel in Reach 1 was assessed based on the $D_{50}$ value of 12 mm (Table 4.1) and a corresponding critical specific stream power of $\omega_o = 8.17$ W/m$^2$.

Based on Equation [4], the continuous discharge data (**Figure 5.2**) was used to estimate the total sand and gravel bedload transport ($I_b$) over the 266.8 day monitoring period (where $I_b = \Sigma\, i_b$ for all 5 minute time intervals = 4100 kg). If this preliminary estimate is extrapolated to be representative of an entire year then the total annual bedload sediment supply to the lakeshore is in the range of 5.7 tonnes (i.e., average bedload transport rate of **~6 t/yr**). Based on estimated sediment bar storage in Reach 1 (**Table 4.1**), this transport rate is equivalent to a sediment turnover rate of less than 5% of the bed material stored in the active channel of Reach 1. This estimated sediment export rate also corresponds to an average channel degradation rate of less than 1 cm/yr within Reaches 2 and 3, while the actual degradation rate may be even less due to net material losses from the banks due to channel widening, lateral migration, and bank failure.

A summary of preliminary results for sediment supply to the lakeshore is provided in **Table 7.3**. The preliminary estimate of **~9 t/yr** for the total annual sediment load of Moore Creek to the lakeshore is equivalent to **~40 t/yr·km$^2$**, which is within the sediment yield range of 1 – 53 t/yr·km$^2$ for Lake Ontario tributaries as reported by Stone and Saunderson (1996).

**Table 7.3:** Preliminary analysis results for Moore Creek annual sediment supply to the lakeshore

| Mode of Transport | Constrained Range Sediment Load (t/yr) | Estimate of Sediment Load (t/yr) |
|---|---|---|
| Suspended Sediment Load | 1 – 5 | ~3 |
| Sand and Gravel Bed Load | 1 – 10 | ~6 |
| **Total:** | 1 – 15 | ~9 |

Another uncertainty in the annual sediment transport assessment is the effect of ice in the channel during winter and early spring flow conditions. During the winter, ice may tend to limit sediment erosion by shielding bed material with flows over the ice (and frozen sediments may resist erosion). However, as ice cover melts, flow under the ice may become pressurized increasing sediment transport and ultimately ice break up can accentuate sediment transport by floating debris and localized scour. Assessment of these processes on Moore Creek is only based on anecdotal evidence of stream conditions during the winter months (**Appendix A**), and a more scientific treatment would be limited by many practical constraints. As such, it is assumed in this study that the net effect of ice is neutral relative to sediment transport during the other seasons.

# 8 SUMMARY AND RECOMMENDATIONS

A fluvial geomorphic assessment of Moore Creek was completed based on field data collected in the late summer and fall seasons of 2013. The study of Moore Creek represents a supplementary component of CVC's LOISS background study completed by CVC and Aquafor Beech in 2011. Based on the results of the geomorphic assessment and hydraulic analysis, the purpose of the study was to:

- Characterize the existing conditions of Moore Creek,
- Define existing and future erosion hazards,
- Assess sediment supply to Lake Ontario; and
- Provide management recommendations with respect to restoration opportunities and considerations for replacement of two pedestrian bridges.

## 8.1 Summary and Results

A summary of the study and the key results are outlined below:

*Geomorphic Assessment of Moore Creek*

- General patterns of erosion and sediment transport have been documented based on the identification of four (4) stream reaches. These patterns are supported by detailed sediment grain-size sampling, hydraulic modeling, and tractive force calculations.
- Severe channel erosion in Reach 3 contributes sand and gravel sediments downstream.
- Bank erosion and sediment transport within Reach 2 contribute fine gravel and sand downstream.
- Reach 1 is primarily aggradational with greater storage of sand and fine gravel materials. Frequent storm flows ultimately transport sand materials in Reach 1 to the lake.
- Reach 0 is considered a relatively stable knickpoint in the channel profile at the shoreline.

*Hydrology and Hydraulics*

- Basic hydrology of Moore Creek was assessed based on empirical drainage-area relations indexed to adjacent watersheds and based on continuous water-level monitoring over the 2013-2014 hydrologic year. Discharge records have been calculated for this study of Moore Creek with stage-discharge rating curves using two empirical models.
- Basic hydraulic models were developed for select field sites in Reaches 1 and 2 of Moore Creek to calculate channel shear stress and to identify the most relevant discharges for sediment transport processes.

*Erodible Corridor and Erosion Hazards*

- The erodible corridor for Reach 1 and 2 of Moore Creek has been recommended to be **20 m** in width (including 1.25 factor of safety) plus a 6 m stable slope allowance for the entrenched channel banks on both sides of the corridor. *As such the total management corridor width is* **32 m**. Standard meander belt delineation methods are generally in agreement with a second independent Topographic Erodible Corridor approach (Phillips, 2009) based on volumetric erosion rates modeled using a high resolution digital elevation model.
- Erosion hazards in Reach 3 were not fully assessed within the scope of this study due to severe entrenchment and channel erosion which will require detailed slope stability assessments and mitigative engineering measures. This reach is within a private property outside the Lorne Park Estates boundaries, and it is expected that the existing erosion issues are to be addressed by others.

*Sediment Supply to Lake*

- The estimate of sediment supply to Lake Ontario from this study is ~**9 t/yr** from Moore Creek, which is equivalent to a sediment yield of ~**40 t/yr·km$^2$**. This sediment loading includes estimates of suspended sediment load and sand-gravel bedload (1/3 and 2/3 of total load, respectively). The discharge and sediment transport sampling results are not statistically significant, but the load estimates are reasonable with respect to the volumes of material stored in the stream system and published sediment yields for Lake Ontario tributaries from other sources.

## 8.2 Management Recommendations

♦ *Stream Corridor Enhancement and Erosion Hazards*

Erosion hazards have been delineated within a 32 m wide management corridor for a 100-year planning horizon. Based on the results of this study, **the recommended erosion hazard limit for Moore Creek is 32 m**. To enhance the long-term natural form and function of Moore Creek, and to potentially reduce long-term erosion hazard risks, it is recommended that property owners and residents limit their activities within **at least 10 m** of the nearest channel bank. Negative impacts to the creek may be associated with the following activities within the delineated stream corridor:

- Clearing or mowing of shrubs, grasses, and herbaceous vegetation;
- Dumping or piling of yard waste, including grass clippings, leaves, and branches;
- Landscaping or placement of artificial materials (even low-impact); and
- Placing and storage of materials (e.g., lumber, bricks) or other structures.

♦ *Special Considerations for Pedestrian Bridges*

In the context of the completed geomorphic assessment of Moore Creek, a number of special considerations have been identified with respect to any future repairs or replacements of the two existing pedestrian bridges over the watercourse (see locations of Px1 and Px2, **Figure 2.1A**).

- **Downstream Pedestrian Bridge at Shoreline** (Reach 0, Px1) – the existing pedestrian bridge structure includes a concrete headwall with a wooden deck span of about 8 m and a ~0.8 x 2 m orifice in the concrete over the active stream channel. Repair or replacement of the bridge structure should include the following special considerations:

- ***Grade Control*** – stability of the channel knickpoint should be maintained by preserving/retrofitting the concrete headwall or by installing other engineering measures within the channel. Channel downcutting from this location upstream into Reach 1 would result in dramatic increases in erosion and sediment release to the lake, which should be avoided.
- ***Span and Channel Materials*** – if the concrete headwall is to be removed, opportunities should be considered to restore the channel and banks using natural and environmentally sensitive engineering materials with a bridge span of at least 8 – 10 m. The existing headwall may be subject to blockages by debris and the small orifice is a constriction within the fluvial system, but the headwall may also be important for maintaining the existing grade control at this location.
- ***Aquatic Habitat*** – as Reach 0 is the key to connectivity between Moore Creek and the lake, any bridge replacement activities should consider opportunities to enhance aquatic habitat and fish passage (in consultation with CVC biologists/ecologists).
- ***Design Concept*** – to maintain grade control, channel engineering measures may include a boulder or armourstone rock weir (with possible concrete structure or grouting). For enhancement of fish passage, a boulder step-pool channel is recommended with technical criteria for stability based on fluvial hydraulics and lake shore processes. To help reduce the grade constraints, the designed channel may be extended 10 – 20 m upstream of the existing bridge structure, however this would increase the necessary earth works and impacts on mature terrestrial vegetation. Assessment of alternatives should be explored by the design consultant.

- **Upstream Pedestrian Bridge** (Reach 1, Px2) – the existing pedestrian bridge structure includes a wooden deck span of about 6 m with a recent retrofit of four 4"x4" wooden beams to brace the underside of the bridge. The recently installed wooden piers have a 2 m span over the creek which is less than the active bankfull width of 4 – 5 m. Repair or replacement of the bridge structure should include the following special considerations:
  - ***Span and Bank Materials*** – a minimum span of 8 – 10 m is recommended, with no part of the structure within a 5 m span of the active bankfull channel. Local restoration and bank regrading may be considered to enhance channel capacity and riparian vegetation, but the sandy creek bed materials should not be disturbed as when removing the existing wooden beams.
  - ***Trail Drainage*** – runoff from the trail approaching the existing bridge may contribute to local scouring and rill development on the banks adjacent to the bridge. Methods to redirect and attenuate surface runoff from the trail might also be considered to mediate future damages to the trail and creek banks.

♦ *Restoration Opportunities and Reach 3 Erosion Issues*

The overall geomorphic form and function of Moore Creek may be managed with consideration of a few priorities as outlined below, which include ecological enhancement objectives for the stream corridor. Hydrologically, it is assumed that upstream storm water inputs will not change.

- **Sediment Supply to Moore Creek** (Reach 3) – severe erosion issues in Reach 3 contribute to a considerable supply of sand and gravel to stream reaches downstream. Any technical input from CVC regarding proposed engineering measures in Reach 3 should explicitly consider sediment supply issues. While a reduction in sediment supply from Reach 3 may be necessary and beneficial, *some amount of continued sediment delivery which mimics native sources of* **fine gravel** *should be maintained*.

- **Erodible Corridor** (Reaches 1 and 2) – existing bank and channel erosion features within Reaches 1 and 2 should be preserved within the identified 32 m wide management corridor. As no infrastructure or private structures were observed to be at risk within the Lorne Park Estates, properties experiencing bank erosion may be best left to undergo natural channel adjustments. Other than possible native plantings strategically located in cleared riparian areas, no direct intervention is recommend to deal with existing bank erosion processes. As detailed above, property owners are encouraged to limit activities within the identified management corridor.
- **Surface and Sub-Surface Drainage** (Reaches 1 and 2) – sandy surface materials in the Moore Creek catchment contribute to dynamic sub-surface groundwater flow with seasonal fluctuations, storm water fluctuations, and natural background patterns (including some contribution from the surrounding septic fields of the homes within Lorne Park Estates).
  - ***Saturated Bank Failure –*** Local increases in infiltration due to redirected surface runoff or lot-level sources of water may contribute to ground saturation and bank slumping along the creek channel. In lieu of a detailed study, any efforts on the part of property owners to reduce water inputs on their lots might help to mitigate excessive bank slumping within their property and along the creek channel (e.g., grass watering, pool leaks).
  - ***Water Quality –*** a water quality study will be important to considered any aquatic habitat enhancements for Moore Creek. This might include consideration of storm water quality controls in Reach 3.
- **Aquatic Habitat Enhancements**
  - ***Reach 0*** – There may be an opportunity for enhanced habitat connectivity between Moore Creek and the lake (e.g., boulder step-pool channel design). Opportunities might be considered in conjunction with repair or replacement of the pedestrian bridge.
  - ***Reach 1*** – Due to the considerable aggradation of sand and associated low-gradient bedforms, no clear opportunities for aquatic habitat restoration are recommended for Reach 1. It is recommended that existing large woody debris be maintained to provide some limited aquatic diversity in locally scoured refuge pools. Monitoring of woody debris by CVC biology staff is recommend, and opportunities to slightly increase woody debris in the channel through natural or management activities may also provide some additional aquatic habitat benefits. Based on the results of this study, any increased erosion associated additional woody debris in Reach 1 is not expected to significantly increase net erosion or sediment delivery to the lake, however, it is unclear the degree to which fish passage might be enhanced by woody debris alone.
  - ***Reach 2*** – Maintaining gravel sediment supplies locally through bank erosion processes while reducing sand inputs (e.g., from Reach 3) may have beneficial impacts for the development of more persistent riffle-pool habitat in Reach 2.
  - ***Reach 3*** – Restoration in this reach is to be considered with respect to erosion mitigation and engineering measures by others. A source of fine gravel to downstream reaches should be maintained.

## ♦ References

Aquafor Beech Ltd. (2011). Hydrology and Hydraulics Report, Lake Ontario Integrated Shoreline Strategy.

Bagnold, R.A. (1980). An empirical correlation of bedload transport rates in flumes and natural rivers. Proceedings of the Royal Society 372A, 453-73.

Martin, Y. (2003). Evaluation of bed load transport formulae using field evidence from the Vedder River, British Columbia. *Geomorphology*, **53**: 75-95.

Meyer-Peter, E. and Müller, R. (1948). Formulas for bed load transport. Proceedings of the 2nd Meeting of the International Association of Hydraulic Structures Research, Stockholm, Sweden. Appendix 2, 39-64.

Ministry of Transportation of Ontario, MTO. (1997). Drainage Management Manual.

Ontario Ministry of the Environment, MOE. (1999). Revised Stormwater Management Guidelines. Draft Report. Ontario Ministry of the Environment.

Ontario Ministry of Natural Resources, MNR. (2002). Technical Guide – River & Stream Systems: Erosion Hazard Limit. OMNR Water Resources Section, Peterborough, Ontario.

Parker, C., Clifford, N.J., Thorne, C.R. (2011). Understanding the influence of slope on the threshold of coarse grain motion: revisiting critical stream power. *Geomorphology*, **126**: 51–65.

Phillips, R.T.J. (2009). Tightening the River Meander-Belt: Application of a Topographic Erodible Corridor Concept Using DEM Raster Analysis – A Case Study of Highland Creek, Ontario. **Presentation:** American Geophysical Union 2009 Joint Assembly, May 24 – 27, 2009. Toronto, Ontario.

Phillips, R.T.J. and Desloges, J.R. (2014). Glacially conditioned specific stream powers in low-relief river catchments of the southern Laurentian Great Lakes. *Geomorphology*, **206**: 271-287.

Piégay, H., Darby, S.E., Mosselman, E., and Surian, N. (2005). A review of techniques available for delimiting the erodible river corridor: a sustainable approach to managing bank erosion. *River Research and Applications*, **21:** 773-789.

Stone, M. and Saunderson, H.C. (1996). Regional patterns of sediment yield in the Laurentian Great Lakes basin. In *Erosion and Sediment Yield: Global and Regional Perspectives*, D.E. Walling and W. Webb (eds). (Proceedings of the Exeter Symposium, July 1996). IAHS Publication no. 236: 125-131.

Toronto and Region Conservation Authority, TRCA. (2004). Meander Belt Delineation Procedures. September 27, 2001 (Revised January 30, 2004).

## GLOSSARY OF TERMS

| | |
|---|---|
| **Aggradation** | a general increase in channel elevation due to the deposition of sediment delivered from upstream *stream reaches*. |
| **Bankfull channel** | a theoretical channel capacity which typically conveys the "dominant" discharge or average annual peak flood event.<br><br>A bankfull discharge is considered to happen at least every 1 to 2 years (i.e., the 2-year flow), where higher flow events would otherwise spill onto adjacent areas of relatively flat-lying floodplain. Application of this concept can be difficult in *entrenched channels* (see definition below). |
| **Degradation**<br>(or incision) | a general decrease in channel elevation due to the erosion of sediment to downstream *stream reaches*. |
| **Entrainment** | a threshold process in which sediment particles begin to move due to fluid forces of water flowing in a channel, an important aspect of channel bed erosion. |
| **Entrenched channel**<br>(or entrenchment ratio) | a channel which tends to be deeper (or has higher banks) compared to the *bankfull channel*.<br><br>As such, higher magnitude flow events do not tend spill onto an accessible floodplain, but are constrained within the channel and tend to accentuate erosion processes. The *entrenchment ratio* is typically defined as the <u>channel width</u> at two times the <u>bankfull depth</u> divided by the <u>bankfull channel width</u> (e.g., a ratio of < 1.4 – 2.2 for entrenched channels). |
| **Fluvial processes** | the physical interaction of flowing water in river and stream channels with the sediments, rocks, and vegetation which form the boundary of the channel.<br><br>In very general terms, fluvial processes represent how sediment is eroded, transported, and deposited within stream channels. |
| **Grade control**<br>(in fluvial geomorphology) | a natural or engineered feature of rivers and streams which prevents local *degradation* (or incision) of the channel.<br><br>As such, grade control features resist erosion (e.g., large stone or concrete) and prevent any vertical lowering of the channel bed. |

| | |
|---|---|
| **Grain size distribution** (and percent finer) | a sample of sediment particle sizes where the range of sizes is described by summary statistics, such as the average (or mean) grain size.<br><br>For sediment transport analysis, relevant grain-sizes are often summarized in terms of a few select *percent finer* statistics. For example, the median grain size ($D_{50}$) is that for which 50% of the sediment is smaller (or finer). For the $D_{95}$ grain size, 95% of the sediment smaller and for the $D_{84}$ grain size, 84% of the sediment is smaller. |
| **Hydraulic models** | As applied to open-channel stream flows, they are mathematical representations of the physical properties of water flow.<br><br>Describe how a volumetric discharge of water (in cubic metres per second) will be partitioned into flow width, depth, and velocity based on the available channel cross-section and water surface slope with consideration of flow resistance (e.g., obstacles to flow). Flow hydraulic characteristics have implications for *shear stress* and sediment transport. |
| **Knickpoint** | a sharp or abrupt change in the channel slope (or elevation).<br><br>An extreme example of a knickpoint is the Niagara Falls on the Niagara River. |
| **Return period flow** | a statistical summary of how peaks in stream discharge will reoccur at given annual frequencies (i.e., their *return period*).<br><br>For example, a 2-year flow will be equalled or exceeded, on average, at least once every two years. A 100-year flow is a very large discharge (flood) event which will, in theory, be equalled or exceeded, on average, at least once every 100 years. |
| **Riffle-pool bed morphology** | undulations in a channel bed progressing downstream where coarse sediments (e.g., gravel) impose shallow flowing “rapids” (i.e., riffles) which alternate between deeper pools.<br><br>Semi-stable riffle-pool features are often associated with more diverse types of aquatic habitat. |
| **Rill development** | rills are small cuts into the surface soil materials caused by small-scale erosion during intense rainfall events where runoff is concentrated into low areas along the ground. |
| **Riparian area** | the transitional area between stream channels and surrounding lands typically characterized by distinct vegetation with important ecological significance. |

| | |
|---|---|
| **Shear Stress** (or tractive force) | the force of flowing water acting on the channel bed materials as described by the flow *hydraulics* (e.g., water slope, flow depth, and flow velocity).<br><br>Threshold shear stress is the most commonly used approach to predict when specific sediment grain sizes will be *entrained*. |
| **Stream power** | a measure of stream energy that emphasizes the ability of stream flow to perform the geomorphic work of moving sediment. |
| **Stream reach** | a length of stream with relatively consistent characteristics of channel morphology (or shape) and *fluvial processes*. |
| **Thalweg** | the lowest elevation of a stream or river channel cross-section which is important for representing and interpreting the channel bed morphology (or shape) and the channel gradient (or slope) in a downstream direction. |

# APPENDIX A

## Photographic Inventory of Moore Creek

# Moore Creek: Reach 0 (August, 2013)

# Moore Creek: Reach 0 (August, 2013)

# Moore Creek: Reach 0 (August, 2013)

# Moore Creek: Reach 1  (August, 2013)

# Moore Creek: Reach 1 (August, 2013)

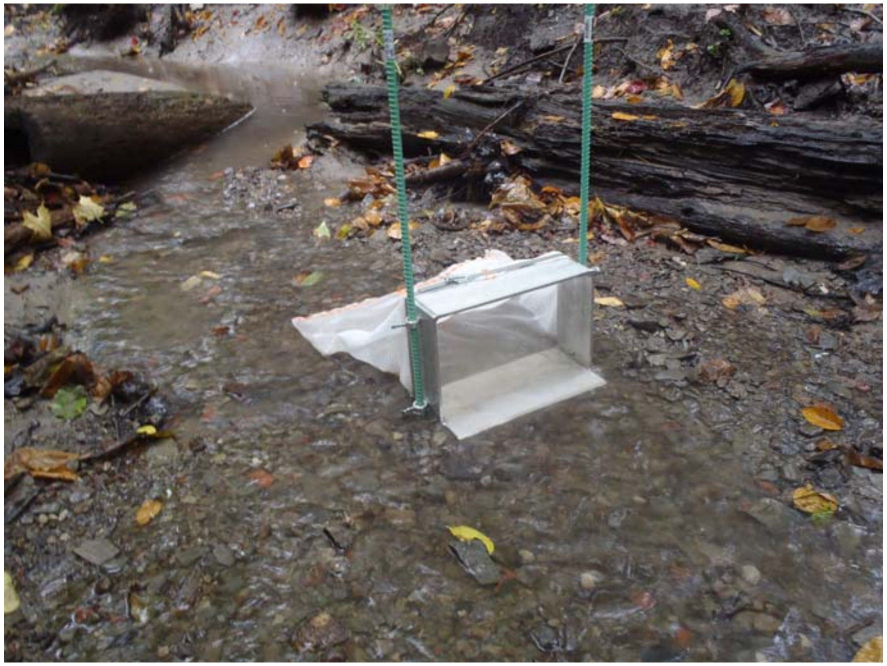
# Moore Creek: Reach 1  (August, 2013)

Moore Creek: Reach 1  (August, 2013)

# Moore Creek: Reach 2 (August, 2013)

# Moore Creek: Reach 2 (August, 2013)

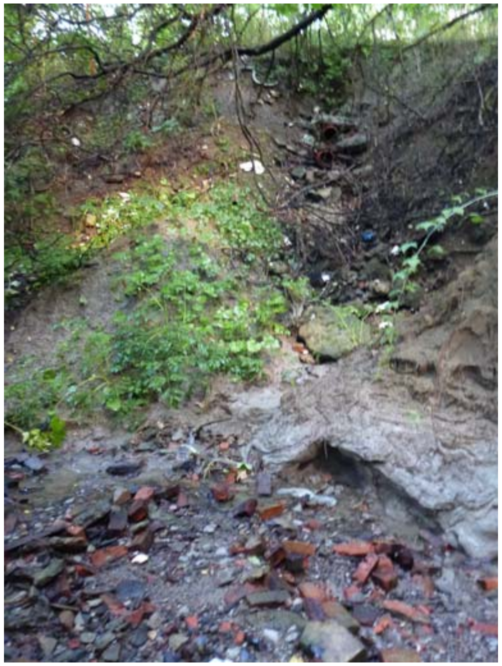
# Moore Creek: Reach 2  (August, 2013)



# Moore Creek: Reach 2  (August, 2013)

# Moore Creek: Reach 3  (August, 2013)

# Moore Creek: Reach 3  (August, 2013)



Moore Creek: Reach 3  (August, 2013)

# Moore Creek: Sediment Bar 1.1 (Reach 1) September 5, 2013

# Moore Creek: Sediment Bar 1.1 (Reach 1) September 5, 2013

# Moore Creek: Sediment Bar 1.2 (Reach 1) September 5, 2013

# Moore Creek: Sediment Bar 2.1 (Reach 2) September 5, 2013

# Moore Creek: Winter Conditions (Reaches 0 and 1) January 11, 2014

# Moore Creek: Winter Conditions (Reaches 0 and 1) January 11, 2014

# APPENDIX B

## Rapid Geomorphic Assessment Forms for Moore Creek (4 Reaches)

**Appendix B**: Rapid Geomorphic Assessment (RGA) Stability Index (SI) for Moore Creek.

| **Moore Creek** | **AI** | **DI** | **WI** | **PI** | **RGA SI-Index** |
|---|---|---|---|---|---|
| Reach 0 | 0.57 | 0.60 | 0.30 | 0 | **0.37** |
| Reach 1 | 1.0 | 0.30 | 0.30 | 0.29 | **0.47** |
| Reach 2 | 0.71 | 0.50 | 0.50 | 0.14 | **0.46** |
| Reach 3 | 0.43 | 0.90 | 0.80 | 0.29 | **0.60** |

AI = Aggradation; DI = Degradation; WI = Widening; PI = Planform Adjustment

**Stability Index Definitions from MOE (1999)**

| Stability Index Value | Stability Class | Description |
|---|---|---|
| 0 – 0.25 | Stable | Channel morphology is within the expected range of variance for stable channels of similar type. Channels are in good condition with minor adjustments that do not impact the function of the watercourse. |
| 0.25 – 0.40 | Transitional | Channel morphology is within the expected range of variance but with evidence of stress. Significant channel adjustments have occurred and additional adjustment may occur. |
| 0.40 – 1.0 | In Adjustment | Metrics are outside of the expected range of variance for channels of similar type. Significant channel adjustments have occurred and are expected to continue. |

Aquafor Beech Limited

Date 23-Aug-13

Reach 0

## RAPID GEOMORPHIC ASSESSMENT

**Watercourse:** Moore Creek Reach 0

**Reach Boundaries:**

| Form/ Process | no. | Description | Present No | Present Yes | FactorValue |
|---|---|---|---|---|---|
| Evidence of Aggradation (AI) | 1 | Lobate bar | 1 | | |
| | 2 | Coarse material in riffle embedded | | 1 | |
| | 3 | Siltation in pools | | 1 | |
| | 4 | Medial bars | 1 | | |
| | 5 | Accretion on point bars | | 1 | |
| | 6 | Poor longitudinal sorting of bed materials | 1 | | 0.57 |
| | 7 | Deposition in overbank zone | | 1 | |
| Evidence of Degradation (DI) | 1 | Exposed bridge footings | | 1 | |
| | 2 | Exposed sanitary/storm sewer/pipeline etc | 1 | | |
| | 3 | Elevated stormsewer outfall | 1 | | |
| | 4 | undermined gabion basket/concrete apron/etc | 1 | | |
| | 5 | Scour pools d/s of culverts/stormsewers | | 1 | |
| | 6 | Cut face on bar forms | 1 | | |
| | 7 | Head cutting due to knick point migration | | 1 | |
| | 8 | Terrace cut through older bar material | | 1 | |
| | 9 | Suspended armor layer visible in bank | | 1 | 0.60 |
| | 10 | Channel worn into undisturbed overburden/bedrock | | 1 | |
| Evidence of Widening (WI) | 1 | Fallen/leaning trees/fence posts/etc | | 1 | |
| | 2 | Occurrence of large organic debris | | 1 | |
| | 3 | Exposed tree roots | | 1 | |
| | 4 | Basal scour on inside meander bends | 1 | | |
| | 5 | Basal scour on both sides of channel through riffle | 1 | | |
| | 6 | Gabion baskets/concrete walls/armour stone etc. out flanked | 1 | | |
| | 7 | Length of basal scour > 50% through subject reach | 1 | | |
| | 8 | Exposed length of previously buried pipe/cable etc. | 1 | | |
| | 9 | Fracture lines along top of bank | 1 | | 0.30 |
| | 10 | Exposed building foundation | 1 | | |
| Evidence of Planimetric Form Adjustment (PI) | 1 | Formation of chute(s) | 1 | | |
| | 2 | Evolution of single thread channel to multiple channel | 1 | | |
| | 3 | Evolution of pool-riffle form to low bed relief form | 1 | | |
| | 4 | Cutoff channel(s) | 1 | | |
| | 5 | Formation of island(s) | 1 | | |
| | 6 | Thalweg alignment out of phase with meander geometry | 1 | | 0.00 |
| | 7 | Bar forms poorly formed/reworked/removed | 1 | | |
| Stability Index (SI) = (AI+DI+WI+PI)/m | | | | SI = | 0.37 |

**Reach Description:**

Aquafor Beech Limited

Date 23-Aug-13

Reach 1

## RAPID GEOMORPHIC ASSESSMENT

**Watercourse:** Moore Creek Reach 1

**Reach Boundaries:**

| Form/ Process | no. | Description | Present No | Present Yes | FactorValue |
|---|---|---|---|---|---|
| Evidence of Aggradation (AI) | 1 | Lobate bar | | 1 | |
| | 2 | Coarse material in riffle embedded | | 1 | |
| | 3 | Siltation in pools | | 1 | |
| | 4 | Medial bars | | 1 | |
| | 5 | Accretion on point bars | | 1 | |
| | 6 | Poor longitudinal sorting of bed materials | | 1 | 1.00 |
| | 7 | Deposition in overbank zone | | 1 | |
| Evidence of Degradation (DI) | 1 | Exposed bridge footings | 1 | | |
| | 2 | Exposed sanitary/storm sewer/pipeline etc | 1 | | |
| | 3 | Elevated stormsewer outfall | 1 | | |
| | 4 | undermined gabion basket/concrete apron/etc | 1 | | |
| | 5 | Scour pools d/s of culverts/stormsewers | 1 | | |
| | 6 | Cut face on bar forms | 1 | | |
| | 7 | Head cutting due to knick point migration | 1 | | |
| | 8 | Terrace cut through older bar material | | 1 | |
| | 9 | Suspended armor layer visible in bank | | 1 | 0.30 |
| | 10 | Channel worn into undisturbed overburden/bedrock | | 1 | |
| Evidence of Widening (WI) | 1 | Fallen/leaning trees/fence posts/etc | | 1 | |
| | 2 | Occurrence of large organic debris | | 1 | |
| | 3 | Exposed tree roots | | 1 | |
| | 4 | Basal scour on inside meander bends | 1 | | |
| | 5 | Basal scour on both sides of channel through riffle | 1 | | |
| | 6 | Gabion baskets/concrete walls/armour stone etc. out flanked | 1 | | |
| | 7 | Length of basal scour > 50% through subject reach | 1 | | |
| | 8 | Exposed length of previously buried pipe/cable etc. | 1 | | |
| | 9 | Fracture lines along top of bank | 1 | | 0.30 |
| | 10 | Exposed building foundation | 1 | | |
| Evidence of Planimetric Form Adjustment (PI) | 1 | Formation of chute(s) | 1 | | |
| | 2 | Evolution of single thread channel to multiple channel | 1 | | |
| | 3 | Evolution of pool-riffle form to low bed relief form | | 1 | |
| | 4 | Cutoff channel(s) | 1 | | |
| | 5 | Formation of island(s) | 1 | | |
| | 6 | Thalweg alignment out of phase with meander geometry | | 1 | 0.29 |
| | 7 | Bar forms poorly formed/reworked/removed | 1 | | |
| Stability Index (SI) = (AI+DI+WI+PI)/m | | | | SI = | 0.47 |

**Reach Description:**

Aquafor Beech Limited

Date 23-Aug-13

Reach 2

## RAPID GEOMORPHIC ASSESSMENT

**Watercourse:** Moore Creek Reach 2

**Reach Boundaries:**

| Form/ Process | Geomorphic Indicator | | Present | | FactorValue |
|---|---|---|---|---|---|
| | no. | Description | No | Yes | |
| Evidence of Aggradation (AI) | 1 | Lobate bar | | 1 | |
| | 2 | Coarse material in riffle embedded | | 1 | |
| | 3 | Siltation in pools | | 1 | |
| | 4 | Medial bars | 1 | | |
| | 5 | Accretion on point bars | | 1 | |
| | 6 | Poor longitudinal sorting of bed materials | 1 | | 0.71 |
| | 7 | Deposition in overbank zone | | 1 | |
| Evidence of Degradation (DI) | 1 | Exposed bridge footings | 1 | | |
| | 2 | Exposed sanitary/storm sewer/pipeline etc | 1 | | |
| | 3 | Elevated stormsewer outfall | 1 | | |
| | 4 | undermined gabion basket/concrete apron/etc | 1 | | |
| | 5 | Scour pools d/s of culverts/stormsewers | 1 | | |
| | 6 | Cut face on bar forms | | 1 | |
| | 7 | Head cutting due to knick point migration | | 1 | |
| | 8 | Terrace cut through older bar material | | 1 | |
| | 9 | Suspended armor layer visible in bank | | 1 | 0.50 |
| | 10 | Channel worn into undisturbed overburden/bedrock | | 1 | |
| Evidence of Widening (WI) | 1 | Fallen/leaning trees/fence posts/etc | | 1 | |
| | 2 | Occurrence of large organic debris | | 1 | |
| | 3 | Exposed tree roots | | 1 | |
| | 4 | Basal scour on inside meander bends | 1 | | |
| | 5 | Basal scour on both sides of channel through riffle | | 1 | |
| | 6 | Gabion baskets/concrete walls/armour stone etc. out flanked | 1 | | |
| | 7 | Length of basal scour > 50% through subject reach | 1 | | |
| | 8 | Exposed length of previously buried pipe/cable etc. | 1 | | |
| | 9 | Fracture lines along top of bank | | 1 | 0.50 |
| | 10 | Exposed building foundation | 1 | | |
| Evidence of Planimetric Form Adjustment (PI) | 1 | Formation of chute(s) | 1 | | |
| | 2 | Evolution of single thread channel to multiple channel | 1 | | |
| | 3 | Evolution of pool-riffle form to low bed relief form | 1 | | |
| | 4 | Cutoff channel(s) | 1 | | |
| | 5 | Formation of island(s) | 1 | | |
| | 6 | Thalweg alignment out of phase with meander geometry | | 1 | 0.14 |
| | 7 | Bar forms poorly formed/reworked/removed | 1 | | |
| Stability Index (SI) = (AI+DI+WI+PI)/m | | | | SI = | 0.46 |

**Reach Description:**

Aquafor Beech Limited

Date 23-Aug-13

Reach 3

## RAPID GEOMORPHIC ASSESSMENT

**Watercourse:** Moore Creek Reach 3

**Reach Boundaries:**

| Form/ Process | Geomorphic Indicator | | Present | | FactorValue |
|---|---|---|---|---|---|
| | no. | Description | No | Yes | |
| Evidence of Aggradation (AI) | 1 | Lobate bar | | 1 | |
| | 2 | Coarse material in riffle embedded | 1 | | |
| | 3 | Siltation in pools | 1 | | |
| | 4 | Medial bars | 1 | | |
| | 5 | Accretion on point bars | | 1 | |
| | 6 | Poor longitudinal sorting of bed materials | | 1 | 0.43 |
| | 7 | Deposition in overbank zone | 1 | | |
| Evidence of Degradation (DI) | 1 | Exposed bridge footings | 1 | | |
| | 2 | Exposed sanitary/storm sewer/pipeline etc | | 1 | |
| | 3 | Elevated stormsewer outfall | | 1 | |
| | 4 | undermined gabion basket/concrete apron/etc | | 1 | |
| | 5 | Scour pools d/s of culverts/stormsewers | | 1 | |
| | 6 | Cut face on bar forms | | 1 | |
| | 7 | Head cutting due to knick point migration | | 1 | |
| | 8 | Terrace cut through older bar material | | 1 | |
| | 9 | Suspended armor layer visible in bank | | 1 | 0.90 |
| | 10 | Channel worn into undisturbed overburden/bedrock | | 1 | |
| Evidence of Widening (WI) | 1 | Fallen/leaning trees/fence posts/etc | | 1 | |
| | 2 | Occurrence of large organic debris | | 1 | |
| | 3 | Exposed tree roots | | 1 | |
| | 4 | Basal scour on inside meander bends | | 1 | |
| | 5 | Basal scour on both sides of channel through riffle | | 1 | |
| | 6 | Gabion baskets/concrete walls/armour stone etc. out flanked | 1 | | |
| | 7 | Length of basal scour > 50% through subject reach | | 1 | |
| | 8 | Exposed length of previously buried pipe/cable etc. | | 1 | |
| | 9 | Fracture lines along top of bank | | 1 | 0.80 |
| | 10 | Exposed building foundation | 1 | | |
| Evidence of Planimetric Form Adjustment (PI) | 1 | Formation of chute(s) | 1 | | |
| | 2 | Evolution of single thread channel to multiple channel | 1 | | |
| | 3 | Evolution of pool-riffle form to low bed relief form | 1 | | |
| | 4 | Cutoff channel(s) | 1 | | |
| | 5 | Formation of island(s) | 1 | | |
| | 6 | Thalweg alignment out of phase with meander geometry | | 1 | 0.29 |
| | 7 | Bar forms poorly formed/reworked/removed | | 1 | |
| Stability Index (SI) = (AI+DI+WI+PI)/m | | | | SI = | 0.60 |

**Reach Description:**

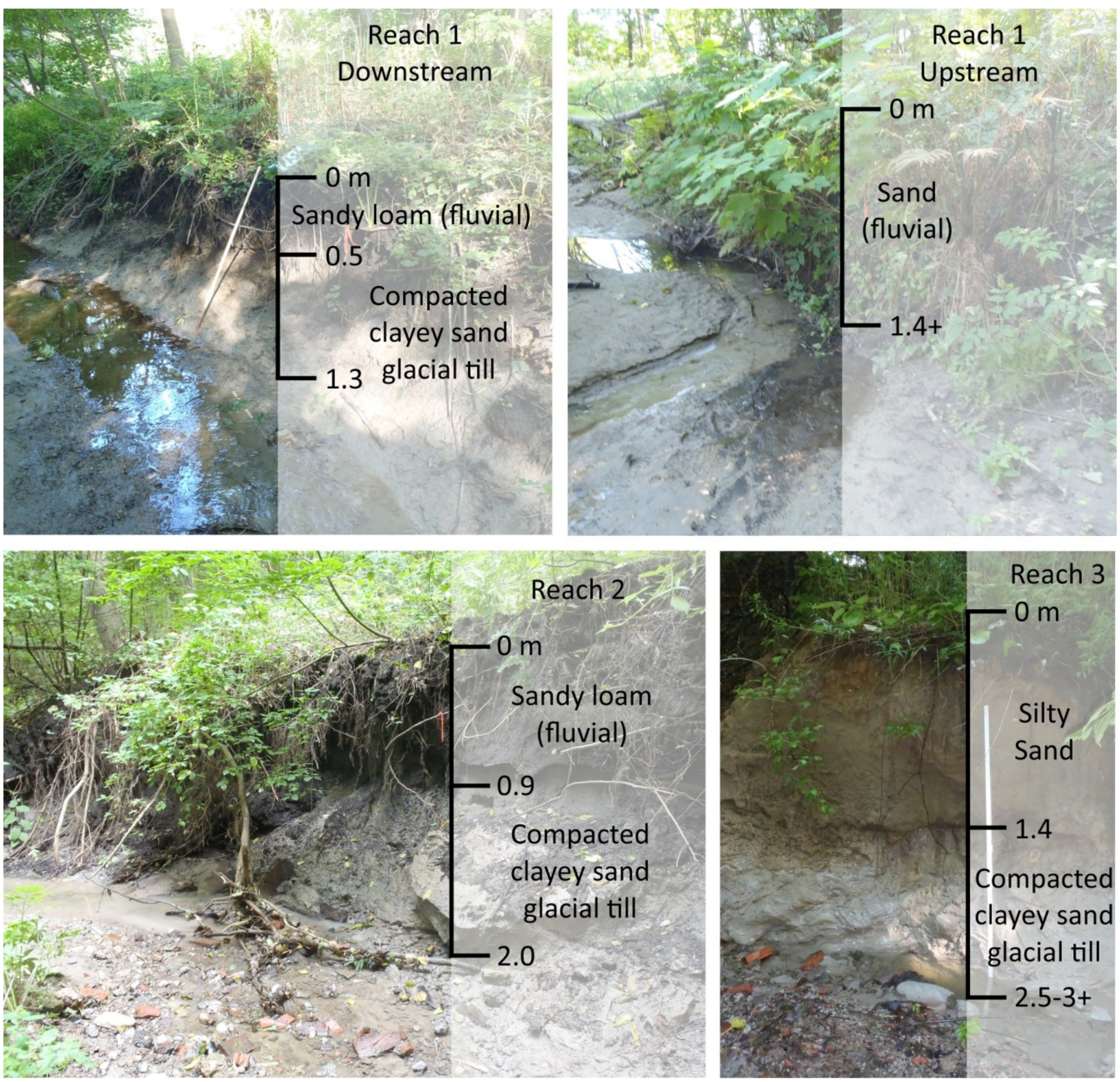
**Appendix B:** General observations of bank materials and vegetation.

Bank materials of Moore Creek were observed to be very sand rich, with upper layers generally consisting of sandy loam fluvial deposits and with lower layers of compacted glacial materials frequently exposed (clayey sand glacial till). *Given the sandy texture and observed field evidence of erosion, the banks of Moore Creek were considered* ***highly erodible****.* Moore Creek was considered entrenched as the bankfull depth ranged from 0.3 to 0.5, while the bank heights ranged from 1.3 to greater than 3.0 m.

Upstream sections of Reach 1 with greater than 1 m of sand were the most laterally stable, likely due to the low-energy gradient and consequent establishment of herbaceous ground cover along the banks. Local bank scour was observed around large woody debris and downstream sections showed increased evidence of bank erosion approaching the lake shore (with exposure of alluvial and glacial deposits).

Sandy loam banks and compacted glacial deposits were frequently exposed throughout the upstream sections of Reach 2, particularly in active cutbanks (2.0+ m in height). Some bank sections of Reach 2 were stable with rooted trees on the banks, however local instabilities were also observed due to bank saturation from high groundwater conditions.

Bank materials and slopes in Reach 3 consisted of thick exposures of sandy glacial material topped with massive unconsolidated silty sands (minor gravel lenses). Bank exposures were typically greater than 2.5 m, with some failing slopes in the range of 3 – 4 m in height.



# APPENDIX C

## Topographic Survey Summary Results (Plan, Cross-Sections, Profile)

**Table C.1:** Channel geometrics from topographic survey and hydraulic modeling of Moore Creek

| Field Site | Survey Bankfull Parameters | | | $Q_2 = 0.7\ m^3/s$ Hydraulic Model* | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Width (m)** | **Depth (m) max [avg]** | **XS Area ($m^2$)** | $w$ **(m)** | $d_{max}$ **(m)** | $s$ **(m/m)** | $v$ **(m/s)** | $\tau$ **($N/m^2$)** | $\omega$ **($W/m^2$)** |
| Downstream (Reach 1) | 4.8 | 0.53 [0.32] | 1.5 | 4.2 | 0.43 | 0.0050 | 0.75 | 11 | 8 |
| Upstream (Reach 2) | 2.8 | 0.51 [0.35] | 1.0 | 2.7 | 0.41 | 0.0086 | 0.99 | 20 | 22 |

* Hydraulic modeling results in Appendix D.

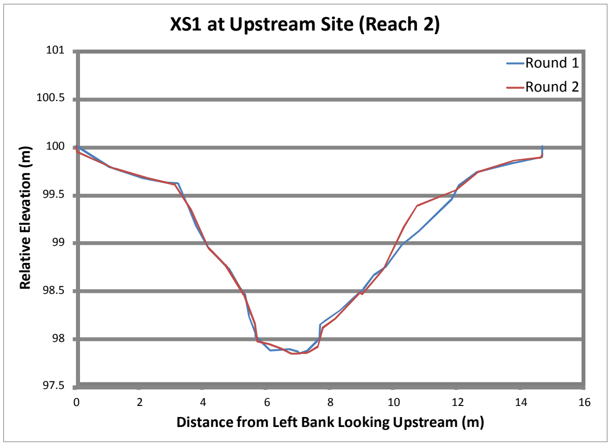



Figure C1: XS1, Upstream Site

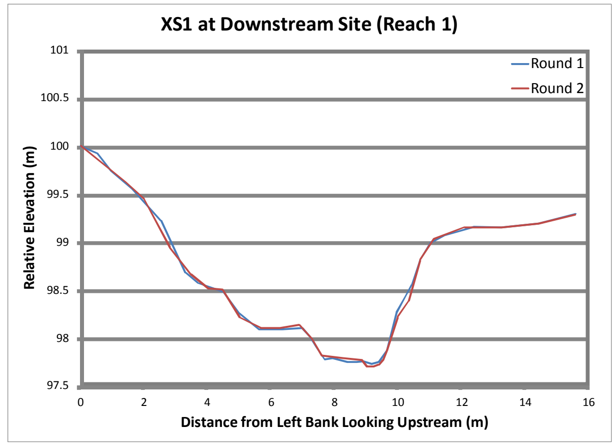



Figure C4: XS4, Downstream Site

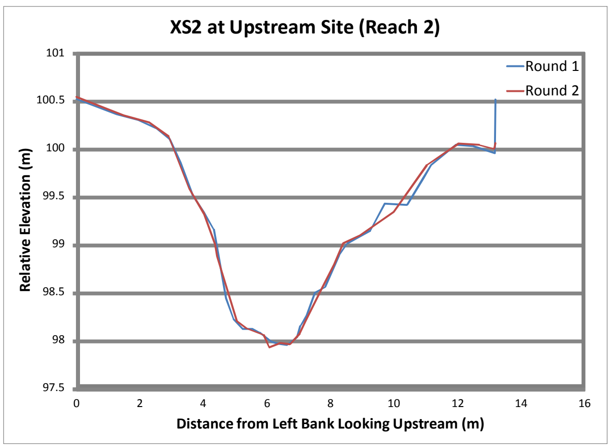



Figure C2: XS2, Upstream Site

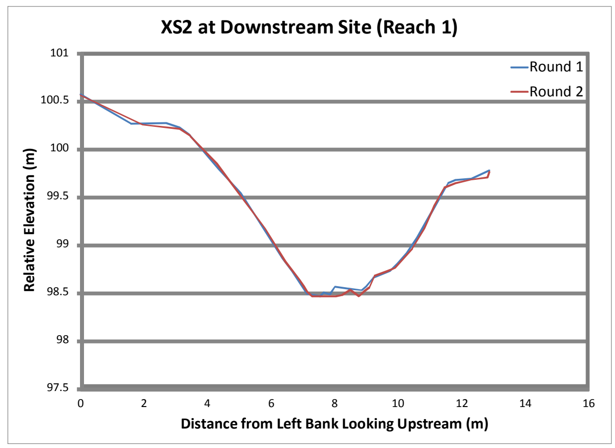



Figure C5: XS2, Downstream Site

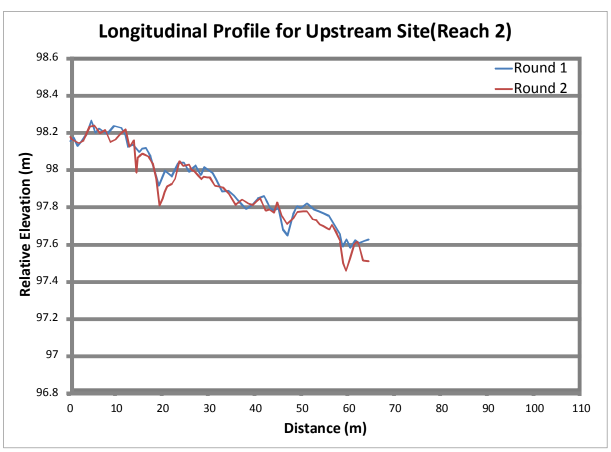



Figure C3: Profile, Upstream Site

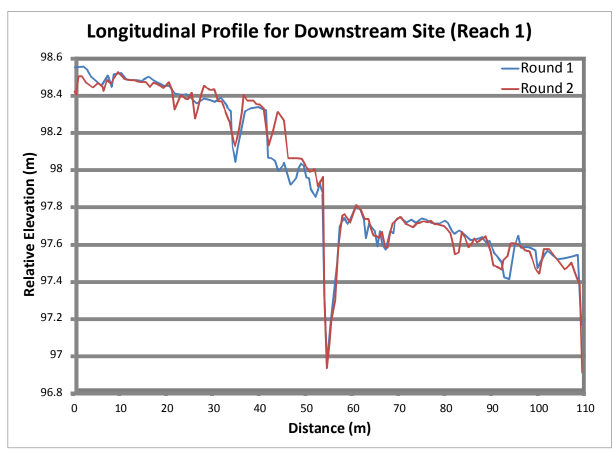



Figure C6: Profile, Downstream Site

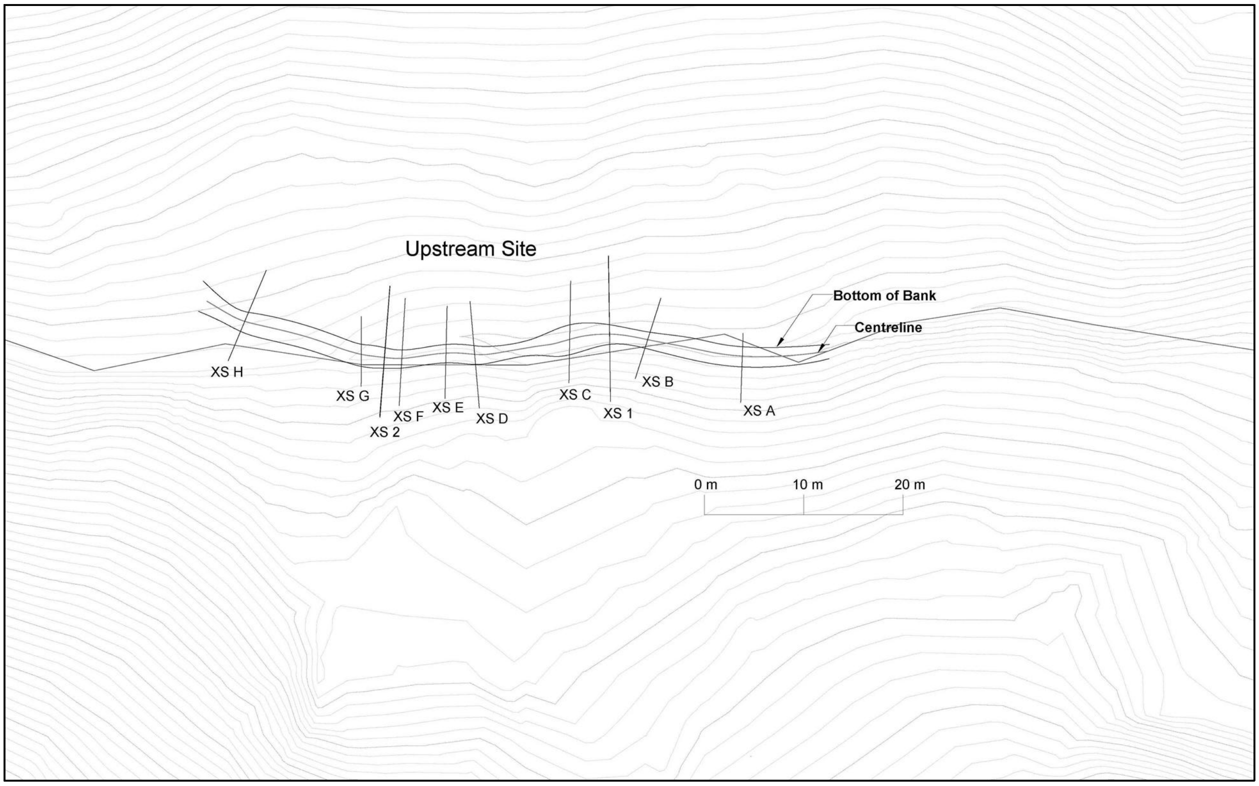



**Figure C7: Planform for Upstream Site**

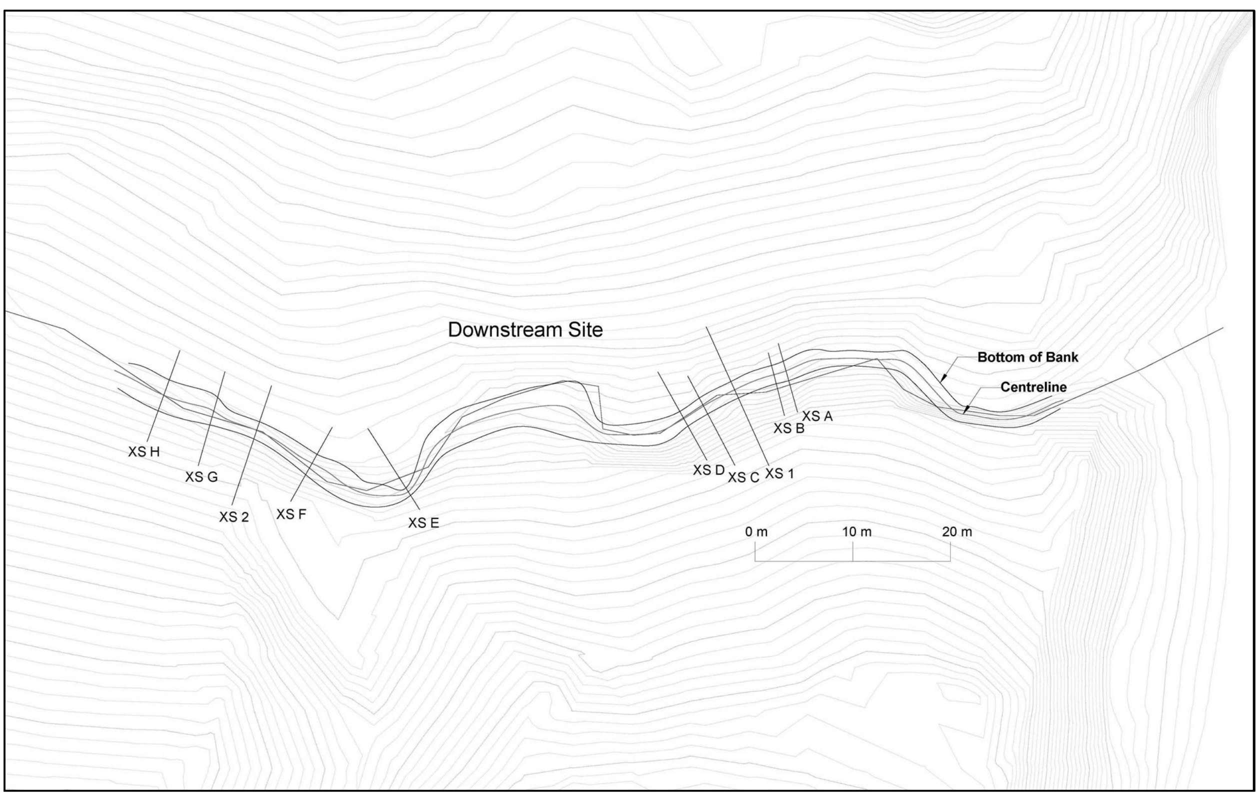
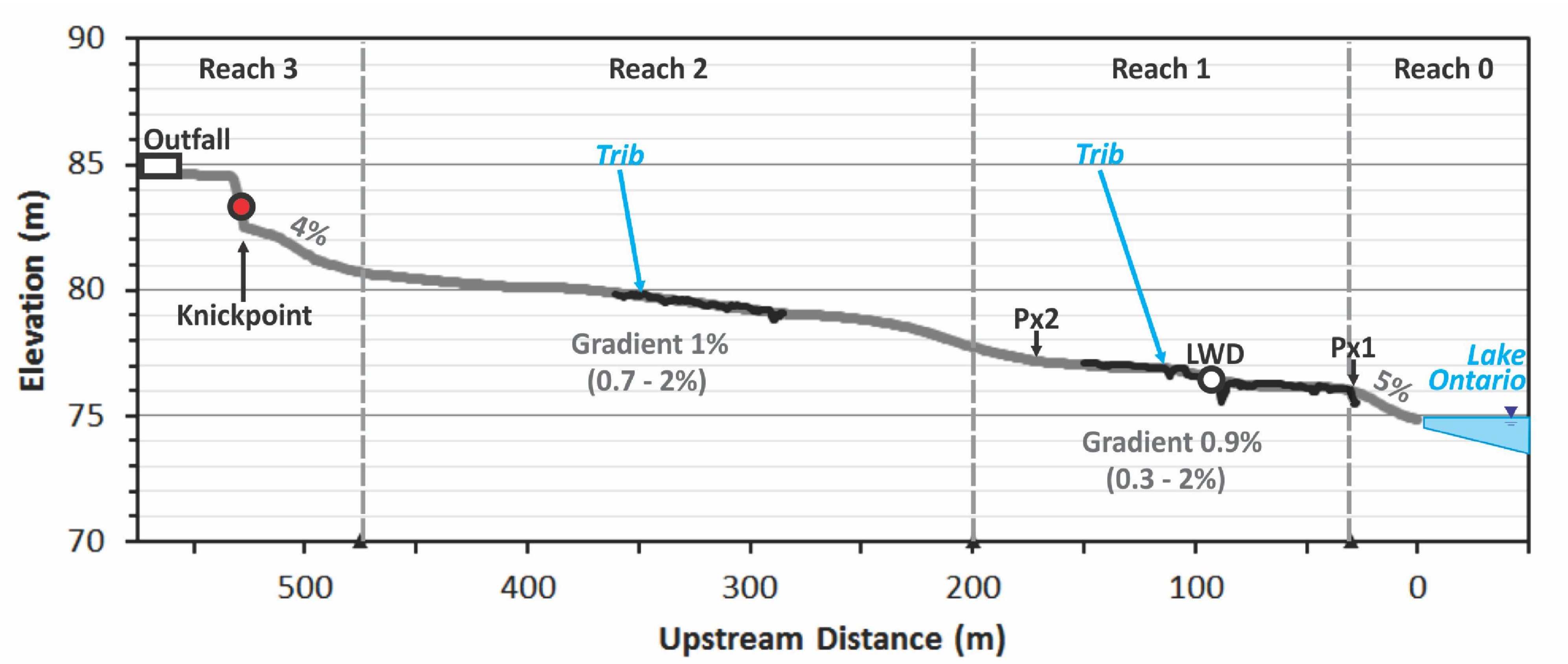



**Figure C8: Planform for Downstream Site**




**Appendix C (Figure 2.1C revised):** Updated longitudinal profile (generalized in grey) based on DEM data with interpreted channel gradients for each stream reach (Vertical Exaggeration x10) with overlay of field surveyed profiles for Reaches 1 and 2 (black lines). Notes: Px1 and Px2 are the pedestrian bridges; LWD = large woody debris.

# APPENDIX D

## Hydraulic Modeling (HEC-RAS) Output Tables

**Table D1: HEC-RAS Model Output for Upstream Site (Reach 2)**

| River Station | Profile | Q Total ($m^3/s$) | Shear Chan ($N/m^2$) | Shear Total ($N/m^2$) | Shear LOB ($N/m^2$) | Shear ROB ($N/m^2$) | W.S. Elev (m) | E.G. Slope (m/m) | Vel Chnl (m/s) | Max Chl Dpth (m) | Power Chan (N/m s) | Power LOB (N/m s) | Power ROB (N/m s) | Power Total (N/m s) | Top Wdth Act (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 50.9 | 2-Year | 0.7 | 23.71 | 23.71 | | | 98.53 | 0.010648 | 1.1 | 0.37 | 26.02 | | | 26.02 | 2.66 |
| 50.9 | Regional | 4.25 | 41.75 | 41.75 | | | 99.08 | 0.008128 | 1.67 | 0.91 | 69.89 | | | 69.89 | 4.36 |
| 50.9 | Gravel Ent. | 0.15 | 7.43 | 7.43 | | | 98.38 | 0.006202 | 0.55 | 0.21 | 4.12 | | | 4.12 | 2.15 |
| 50.9 | Larger Gravel En | 0.45 | 18.63 | 18.63 | | | 98.47 | 0.010226 | 0.94 | 0.3 | 17.52 | | | 17.52 | 2.46 |
| | | | | | | | | | | | | | | | |
| 38.8 | 2-Year | 0.7 | 17.66 | 17.66 | | | 98.44 | 0.007602 | 0.95 | 0.33 | 16.84 | | | 16.84 | 2.91 |
| 38.8 | Regional | 4.25 | 34.31 | 34.31 | | | 99.01 | 0.00603 | 1.54 | 0.9 | 52.95 | | | 52.95 | 4.07 |
| 38.8 | Gravel Ent. | 0.15 | 19.41 | 19.41 | | | 98.23 | 0.025608 | 0.83 | 0.12 | 16.1 | | | 16.1 | 2.29 |
| 38.8 | Larger Gravel En | 0.45 | 16.18 | 16.18 | | | 98.36 | 0.009142 | 0.87 | 0.25 | 14.12 | | | 14.12 | 2.72 |
| | | | | | | | | | | | | | | | |
| 36.5 | 2-Year | 0.7 | 10.28 | 10.28 | | | 98.44 | 0.003444 | 0.76 | 0.5 | 7.8 | | | 7.8 | 2.74 |
| 36.5 | Regional | 4.25 | 31.04 | 31.04 | | | 99 | 0.005382 | 1.47 | 1.06 | 45.66 | | | 45.66 | 4.11 |
| 36.5 | Gravel Ent. | 0.15 | 2.96 | 2.96 | | | 98.23 | 0.001802 | 0.37 | 0.29 | 1.09 | | | 1.09 | 2.29 |
| 36.5 | Larger Gravel En | 0.45 | 7.37 | 7.37 | | | 98.36 | 0.002931 | 0.62 | 0.42 | 4.6 | | | 4.6 | 2.58 |
| | | | | | | | | | | | | | | | |
| 34.7 | 2-Year | 0.7 | 15.01 | 15.01 | | | 98.42 | 0.00596 | 0.89 | 0.46 | 13.38 | | | 13.38 | 2.76 |
| 34.7 | Regional | 4.25 | 29.44 | 29.44 | | | 99 | 0.005527 | 1.41 | 1.04 | 41.64 | | | 41.64 | 4.85 |
| 34.7 | Gravel Ent. | 0.15 | 6.41 | 6.41 | | | 98.22 | 0.005381 | 0.51 | 0.26 | 3.29 | | | 3.29 | 2.26 |
| 34.7 | Larger Gravel En | 0.45 | 11.81 | 11.81 | | | 98.34 | 0.005751 | 0.76 | 0.39 | 9.02 | | | 9.02 | 2.57 |
| | | | | | | | | | | | | | | | |
| 30.2 | 2-Year | 0.7 | 20.84 | 20.84 | | | 98.37 | 0.009163 | 1.03 | 0.36 | 21.52 | | | 21.52 | 2.78 |
| 30.2 | Regional | 4.25 | 31.16 | 31.16 | | | 98.97 | 0.005485 | 1.47 | 0.95 | 45.83 | | | 45.83 | 4.43 |
| 30.2 | Gravel Ent. | 0.15 | 11.75 | 11.75 | | | 98.18 | 0.010952 | 0.68 | 0.16 | 8.04 | | | 8.04 | 1.94 |
| 30.2 | Larger Gravel En | 0.45 | 18.82 | 18.82 | | | 98.29 | 0.010346 | 0.95 | 0.28 | 17.79 | | | 17.79 | 2.45 |
| | | | | | | | | | | | | | | | |
| 27.3 | 2-Year | 0.7 | 44.41 | 44.41 | | | 98.27 | 0.022149 | 1.48 | 0.27 | 65.55 | | | 65.55 | 2.07 |

| River Station | Profile | Q Total ($m^3/s$) | Shear Chan ($N/m^2$) | Shear Total ($N/m^2$) | Shear LOB ($N/m^2$) | Shear ROB ($N/m^2$) | W.S. Elev (m) | E.G. Slope (m/m) | Vel Chnl (m/s) | Max Chl Dpth (m) | Power Chan (N/m s) | Power LOB (N/m s) | Power ROB (N/m s) | Power Total (N/m s) | Top Wdth Act (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 27.3 | Regional | 4.25 | 39.22 | 39.22 | | | 98.92 | 0.00774 | 1.62 | 0.93 | 63.47 | | | 63.47 | 4.46 |
| 27.3 | Gravel Ent. | 0.15 | 23.79 | 23.79 | | | 98.11 | 0.028409 | 0.93 | 0.11 | 22.21 | | | 22.21 | 1.84 |
| 27.3 | Larger Gravel En | 0.45 | 38.43 | 38.43 | | | 98.2 | 0.024132 | 1.32 | 0.21 | 50.78 | | | 50.78 | 1.92 |
| | | | | | | | | | | | | | | | |
| 17.6 | 2-Year | 0.7 | 6.82 | 6.82 | | | 98.28 | 0.002336 | 0.62 | 0.5 | 4.2 | | | 4.2 | 3.51 |
| 17.6 | Regional | 4.25 | 13.57 | 13.57 | | | 98.94 | 0.002222 | 0.98 | 1.16 | 13.33 | | | 13.33 | 6.08 |
| 17.6 | Gravel Ent. | 0.15 | 3.78 | 3.78 | | | 98.05 | 0.003013 | 0.4 | 0.27 | 1.51 | | | 1.51 | 2.86 |
| 17.6 | Larger Gravel En | 0.45 | 5.66 | 5.66 | | | 98.19 | 0.00249 | 0.54 | 0.41 | 3.04 | | | 3.04 | 3.4 |
| | | | | | | | | | | | | | | | |
| 13.6 | 2-Year | 0.7 | 18.46 | 18.46 | | | 98.23 | 0.007673 | 0.98 | 0.39 | 18.1 | | | 18.1 | 2.62 |
| 13.6 | Regional | 4.25 | 21.53 | 21.53 | | | 98.9 | 0.004043 | 1.21 | 1.07 | 26.03 | | | 26.03 | 5.84 |
| 13.6 | Gravel Ent. | 0.15 | 9.6 | 9.6 | | | 98.02 | 0.008465 | 0.62 | 0.18 | 5.99 | | | 5.99 | 2.01 |
| 13.6 | Larger Gravel En | 0.45 | 15.02 | 15.02 | | | 98.15 | 0.007195 | 0.86 | 0.31 | 12.98 | | | 12.98 | 2.2 |
| | | | | | | | | | | | | | | | |
| 9.7 | 2-Year | 0.7 | 19.14 | 19.14 | | | 98.2 | 0.007052 | 1.02 | 0.52 | 19.5 | | | 19.5 | 2.07 |
| 9.7 | Regional | 4.25 | 83.7 | 83.7 | | | 98.66 | 0.018502 | 2.32 | 0.98 | 194.22 | | | 194.22 | 3.17 |
| 9.7 | Gravel Ent. | 0.15 | 5.69 | 5.69 | | | 98 | 0.003811 | 0.5 | 0.33 | 2.86 | | | 2.86 | 1.8 |
| 9.7 | Larger Gravel En | 0.45 | 13.21 | 13.21 | | | 98.13 | 0.005707 | 0.82 | 0.45 | 10.89 | | | 10.89 | 1.99 |
| | | | | | | | | | | | | | | | |
| 0 | 2-Year | 0.7 | 22.01 | 22.01 | | | 98.11 | 0.010002 | 1.06 | 0.36 | 23.23 | | | 23.23 | 2.78 |
| 0 | Regional | 4.25 | 49.02 | 49.02 | | | 98.6 | 0.010005 | 1.8 | 0.85 | 88.2 | | | 88.2 | 4.19 |
| 0 | Gravel Ent. | 0.15 | 10.66 | 10.66 | | | 97.93 | 0.010003 | 0.65 | 0.18 | 6.94 | | | 6.94 | 2.05 |
| 0 | Larger Gravel En | 0.45 | 18 | 18 | | | 98.05 | 0.01001 | 0.92 | 0.3 | 16.61 | | | 16.61 | 2.52 |

**Table D2: HEC-RAS Model Output for Downstream Site 1 (Reach 1)**

| River Station | Profile | Q Total ($m^3/s$) | Shear Chan ($N/m^2$) | Shear Total ($N/m^2$) | Shear LOB ($N/m^2$) | Shear ROB ($N/m^2$) | W.S. Elev (m) | E.G. Slope (m/m) | Vel Chnl (m/s) | Max Chl Dpth (m) | Power Chan (N/m s) | Power LOB (N/m s) | Power ROB (N/m s) | Power Total (N/m s) | Top Wdth Act (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | |
| 11.6 | 2-Year | 0.7 | 11.28 | 11.06 | | | 98.15 | 0.004446 | 0.77 | 0.59 | 8.73 | | | 8.55 | 3.29 |
| 11.6 | Regional | 4.25 | 42.49 | 29.67 | 15.57 | 14.42 | 98.54 | 0.00712 | 1.73 | 0.98 | 73.57 | 8.78 | 7.73 | 43.05 | 6.49 |
| 11.6 | Gravel Ent. | 0.15 | 3.66 | 3.66 | | | 97.94 | 0.002208 | 0.41 | 0.38 | 1.5 | | | 1.5 | 1.95 |
| 11.6 | Larger Gravel En | 0.45 | 9.19 | 9.19 | | | 98.07 | 0.004257 | 0.68 | 0.5 | 6.24 | | | 6.24 | 2.76 |
| | | | | | | | | | | | | | | | |
| 9.2 | 2-Year | 0.7 | 11.2 | 11.2 | | | 98.14 | 0.00416 | 0.78 | 0.49 | 8.72 | | | 8.72 | 3.05 |
| 9.2 | Regional | 4.25 | 33.63 | 23.64 | 16.59 | 9.49 | 98.55 | 0.005454 | 1.55 | 0.9 | 52.07 | 10.21 | 4.02 | 28.95 | 7.48 |
| 9.2 | Gravel Ent. | 0.15 | 3.52 | 3.52 | | | 97.94 | 0.002278 | 0.4 | 0.28 | 1.4 | | | 1.4 | 2.28 |
| 9.2 | Larger Gravel En | 0.45 | 8.59 | 8.59 | | | 98.06 | 0.003656 | 0.67 | 0.41 | 5.72 | | | 5.72 | 2.63 |
| | | | | | | | | | | | | | | | |
| 5.6 | 2-Year | 0.7 | 13.06 | 13.06 | | | 98.12 | 0.006879 | 0.79 | 0.39 | 10.36 | | | 10.36 | 4.33 |
| 5.6 | Regional | 4.25 | 30.15 | 26.48 | 1.46 | 6.67 | 98.53 | 0.006018 | 1.42 | 0.81 | 42.72 | 0.18 | 2.2 | 36.84 | 6.36 |
| 5.6 | Gravel Ent. | 0.15 | 4.27 | 4.27 | | | 97.93 | 0.00302 | 0.43 | 0.2 | 1.84 | | | 1.84 | 2.32 |
| 5.6 | Larger Gravel En | 0.45 | 10.12 | 10.12 | | | 98.04 | 0.004616 | 0.71 | 0.31 | 7.23 | | | 7.23 | 2.64 |
| | | | | | | | | | | | | | | | |
| 1.3 | 2-Year | 0.7 | 9.73 | 9.73 | | | 98.1 | 0.004477 | 0.7 | 0.4 | 6.82 | | | 6.82 | 4.35 |
| 1.3 | Regional | 4.25 | 31.18 | 31.18 | | | 98.5 | 0.006165 | 1.44 | 0.8 | 44.98 | | | 44.98 | 5.06 |
| 1.3 | Gravel Ent. | 0.15 | 5.57 | 5.57 | | | 97.91 | 0.004927 | 0.48 | 0.21 | 2.65 | | | 2.65 | 2.65 |
| 1.3 | Larger Gravel En | 0.45 | 9.64 | 9.64 | | | 98.02 | 0.005852 | 0.67 | 0.32 | 6.41 | | | 6.41 | 3.9 |
| | | | | | | | | | | | | | | | |
| 0 | 2-Year | 0.7 | 13.18 | 13.18 | | | 98.08 | 0.007007 | 0.8 | 0.36 | 10.48 | | | 10.48 | 4.43 |
| 0 | Regional | 4.25 | 33.82 | 33.82 | | | 98.49 | 0.007001 | 1.49 | 0.76 | 50.43 | | | 50.43 | 5.12 |
| 0 | Gravel Ent. | 0.15 | 7.22 | 7.22 | | | 97.9 | 0.007005 | 0.53 | 0.17 | 3.85 | | | 3.85 | 2.62 |
| 0 | Larger Gravel En | 0.45 | 12.33 | 12.33 | | | 98 | 0.007012 | 0.76 | 0.28 | 9.38 | | | 9.38 | 3.2 |

## Table D3: HEC-RAS Model Output for Downstream Site 2 (Reach 1)

| River Station | Profile | Q Total ($m^3/s$) | Shear Chan ($N/m^2$) | Shear Total ($N/m^2$) | Shear LOB ($N/m^2$) | Shear ROB ($N/m^2$) | W.S. Elev (m) | E.G. Slope (m/m) | Vel Chnl (m/s) | Max Chl Dpth (m) | Power Chan (N/m s) | Power LOB (N/m s) | Power ROB (N/m s) | Power Total (N/m s) | Top Wdth Act (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | |
| 27.2 | 2-Year | 0.7 | 9.07 | 9.07 | | | 98.9 | 0.004017 | 0.68 | 0.45 | 6.17 | | | 6.17 | 4.25 |
| 27.2 | Regional | 4.25 | 19.77 | 19.77 | | | 99.38 | 0.00406 | 1.14 | 0.94 | 22.57 | | | 22.57 | 7.1 |
| 27.2 | Gravel Ent. | 0.15 | 7.88 | 7.88 | | | 98.7 | 0.008459 | 0.55 | 0.25 | 4.31 | | | 4.31 | 2.74 |
| 27.2 | Larger Gravel En | 0.45 | 7.55 | 7.55 | | | 98.83 | 0.004208 | 0.6 | 0.39 | 4.51 | | | 4.51 | 3.93 |
| | | | | | | | | | | | | | | | |
| 21.8 | 2-Year | 0.7 | 7.07 | 7.07 | | | 98.89 | 0.00285 | 0.61 | 0.39 | 4.32 | | | 4.32 | 4.4 |
| 21.8 | Regional | 4.25 | 20.54 | 20.54 | | | 99.36 | 0.003694 | 1.19 | 0.87 | 24.43 | | | 24.43 | 5.86 |
| 21.8 | Gravel Ent. | 0.15 | 4.5 | 4.5 | | | 98.67 | 0.003842 | 0.43 | 0.18 | 1.93 | | | 1.93 | 2.88 |
| 21.8 | Larger Gravel En | 0.45 | 5.65 | 5.65 | | | 98.82 | 0.002841 | 0.53 | 0.33 | 2.97 | | | 2.97 | 4.13 |
| | | | | | | | | | | | | | | | |
| 17 | 2-Year | 0.7 | 9.62 | 9.62 | | | 98.86 | 0.003965 | 0.71 | 0.41 | 6.83 | | | 6.83 | 3.82 |
| 17 | Regional | 4.25 | 28.01 | 28.01 | | | 99.31 | 0.005466 | 1.37 | 0.86 | 38.4 | | | 38.4 | 5.54 |
| 17 | Gravel Ent. | 0.15 | 7 | 7 | | | 98.64 | 0.006258 | 0.53 | 0.19 | 3.72 | | | 3.72 | 2.38 |
| 17 | Larger Gravel En | 0.45 | 7.31 | 7.31 | | | 98.8 | 0.003617 | 0.6 | 0.34 | 4.38 | | | 4.38 | 3.5 |
| | | | | | | | | | | | | | | | |
| 10.4 | 2-Year | 0.7 | 10 | 9.74 | | 1.15 | 98.83 | 0.004201 | 0.72 | 0.42 | 7.2 | | 0.13 | 7 | 3.87 |
| 10.4 | Regional | 4.25 | 38.45 | 33.25 | | 10.78 | 99.23 | 0.007053 | 1.62 | 0.82 | 62.38 | | 4.77 | 51.54 | 5.2 |
| 10.4 | Gravel Ent. | 0.15 | 5.33 | 5.33 | | | 98.61 | 0.003975 | 0.48 | 0.2 | 2.55 | | | 2.55 | 2.15 |
| 10.4 | Larger Gravel En | 0.45 | 7.78 | 7.76 | | | 98.77 | 0.00416 | 0.61 | 0.36 | 4.75 | | | 4.74 | 3.66 |
| | | | | | | | | | | | | | | | |
| 0 | 2-Year | 0.7 | 16.58 | 11.23 | | 4.69 | 98.76 | 0.007001 | 0.93 | 0.44 | 15.37 | | 1.19 | 9 | 4.97 |
| 0 | Regional | 4.25 | 37.04 | 29.61 | | 24.3 | 99.19 | 0.007004 | 1.58 | 0.86 | 58.69 | | 18.5 | 35.23 | 7.65 |
| 0 | Gravel Ent. | 0.15 | 8.58 | 8.58 | | | 98.55 | 0.00701 | 0.6 | 0.23 | 5.12 | | | 5.12 | 1.81 |
| 0 | Larger Gravel En | 0.45 | 13.56 | 8.67 | | 1.07 | 98.7 | 0.007008 | 0.81 | 0.38 | 10.99 | | 0.1 | 6.73 | 4.27 |

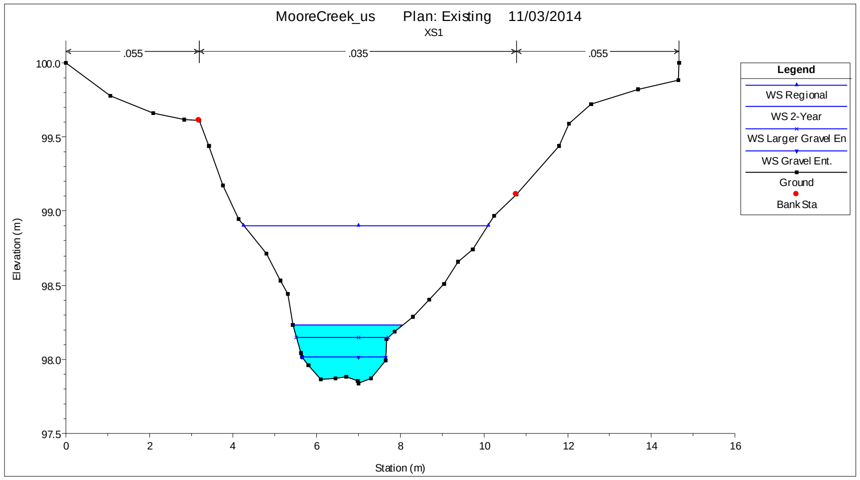



Figure D1: Cross-Section 1 at Upstream Site (Reach 2)

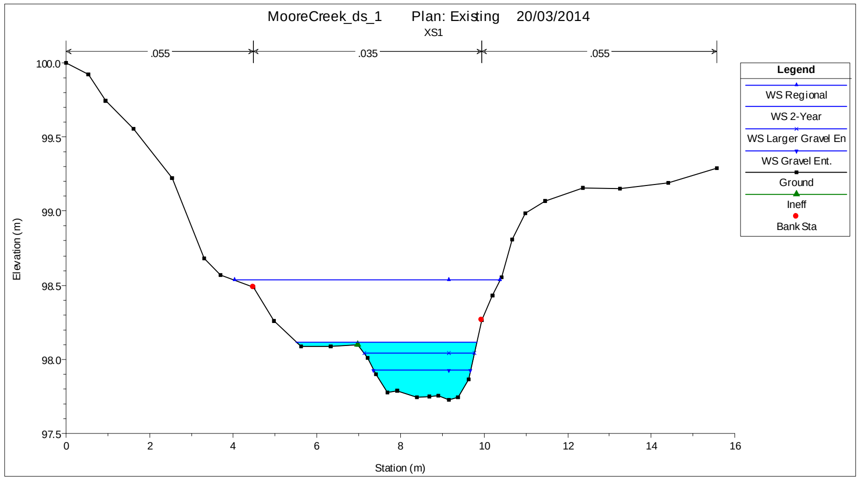



Figure D3: Cross-Section 1 at Downstream Site (Reach 1)

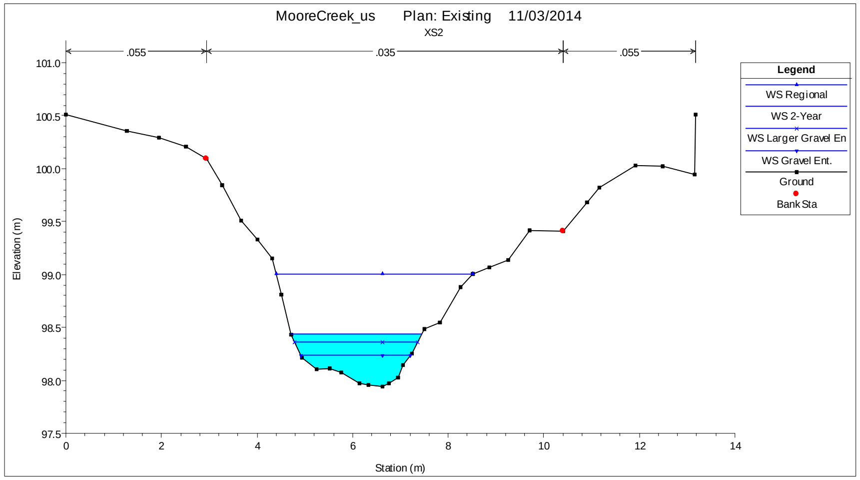



Figure D2: Cross-Section 2 at Upstream Site (Reach 2)

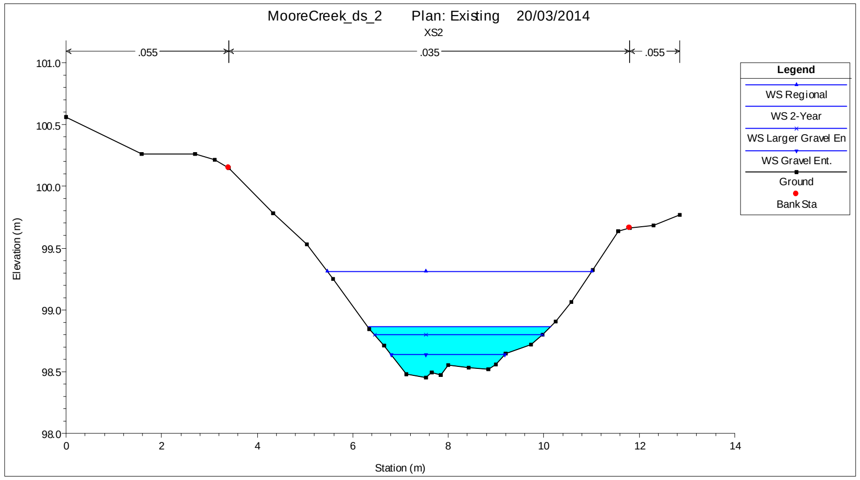



Figure D4: Cross-Section 2 at Downstream Site (Reach 1)