Appendix C - Fluvial Geomorphological Assessment Report

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West Aldershot Creek Erosion EA – Fluvial Geomorphological Assessment



PECG Project # 1400326

Prepared For
Associated Engineering (Ont.) Ltd

September 17, 2019

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Appendix A. Grain Size Distribution

1. Introduction

Palmer Environmental Consulting Group Inc. (PECG) is pleased to provide Associated Engineering (AE), on behalf of the City of Burlington (the City), the results of our fluvial geomorphological assessment of West Aldershot Creek, in Burlington. The baseline fluvial geomorphological information included in this report informs the development and evaluation of alternatives for erosion control in association with completion of a Schedule B Municipal Class Environmental Assessment (EA).

1.1 Background

West Aldershot Creek exhibits the effects of an urbanized hydrologic regime, largely without the benefit of stormwater management controls throughout the watershed. Its watershed is covered by a high proportion of impervious surfaces, so it is predisposed to rapid routing of surface runoff and floodwater during even modest rainstorms. The unnaturally rapid, or 'flashy,' hydrologic response has accelerated erosion along the bed and banks of the creek. Anomalous accumulations of sediment at the mouth of West Aldershot Creek, which the City has had to dredge to maintain boat access, are a testament to the severity of erosion.

Erosion is most severe along the upstream portion of the study corridor, where the channel is confined along the bottom of a nearly V-shaped ravine with little to no floodplain to attenuate flow energy. Significant bed scour and down-cutting has occurred, which in turn has led to undercutting and collapse of the banks. Several small slope failures have occurred recently along the lower valley walls in response to the fluvial erosion. Trees have fallen into the channel once their root masses are sufficiently undermined, which, in turn, has exacerbated erosion by forcing flows over, under and around the woody debris jams that form. Without intervention, the channel will continue to erode through incremental fluvial scour and mass wastage until it re-equilibrates with its new hydrologic regime. The downstream portion of the creek, where the valley bottom is wider and a narrow floodplain is more accessible, exhibits fewer, less severe erosion sites.

The City retained AE, which in turn retained PECG, to complete a comprehensive study of observed instability and environmental conditions along the West Aldershot Creek valley as a basis for developing and evaluating erosion control solutions through a Municipal Class EA process. Our team will follow through to complete detailed designs of the preferred alternative selected through the multi-stakeholder evaluation. This report presents the results of a baseline characterization of fluvial geomorphological conditions along West Aldershot Creek, with a focus on erosional processes, in support of the Municipal Class EA process.

2. Methods

Fluvial and related slope erosion processes along West Aldershot Creek were assessed through a combination of desktop and field investigations. We reviewed pertinent background information for the study area, including Conservation Halton's North Shore Watershed Study (2006) and existing Ontario Geological Survey bedrock and surficial geology mapping (Ontario Geological Survey, 2010a, b). Historical aerial photography from 1934, 1960, 1962, 1998, and recent imagery from 2008 and 2017 accessed via the City's online map viewer, provided a basis for delineating and comparing historical channel planforms and identifying important natural and anthropogenic changes within the valley and adjacent tableland.

Three distinct reaches preliminarily delineated in association with proposal preparation were confirmed through desktop review of available imagery and subsequent field observations. Reaches can be defined as lengths of channel that display similar physical characteristics and have a setting that remains nearly constant along their length. Reaches display relative homogeneity in channel form, functions and process, and are influenced by similar controlling (discharge, slope) and modifying factors (bank treatments, vegetation).

Initial field reconnaissance was completed by our senior fluvial geomorphologist in association with proposal preparation on April 18, 2018. Field investigations involving detailed data collection were completed by a PECG fluvial processes specialist and aquatic biologist during low-flow conditions on August 23, 2018. Additional field reconnaissance was completed by our senior fluvial geomorphologist on November 12, 2018, to observe the study corridor during leave-off conditions. The purpose of the field work was to observe channel conditions, examine patterns and processes of local erosion, ground truth aerial photograph-based interpretations, distinguish the stability and modes of channel adjustment along each reach, and map the type and relative severity of bed and bank erosion. Geomorphic data collected at representative sites along the three reaches included: pool and riffle cross-sections; substrate characteristics, including grain size distribution estimates based on modified Wolman (1954) pebble counts representative of bed material; and a description of bank morphology and composition. Bankfull dimensions assumed to represent 'channel-forming' flow conditions were estimated based on field indicators defining the maximum limit of scour, including abrupt changes in bank vegetation, material, steepness and undercut (Harrelson et al., 1994). A reach-scale longitudinal profile was generated from a high-resolution bare earth digital elevation model (DEM) derived from an airborne LiDAR survey of the valley conducted by Groma Technical Services (Groma) using an Unmanned Aerial Vehicle (UAV). As such, the profile represents the approximate water surface along the channel centerline. To facilitate meaningful interpretation and eliminate 'noise' in the raster-based profile, an inferred profile was smoothed from the raw data. Cross-sections were extracted from the survey data to support the development of conceptual designs.

An inventory of the type and relative severity of bed and bank erosion was completed based on the detailed topographic survey and field observations to help prioritize follow-up investigations and ultimate mitigation. Erosion was classified according to one of three (3) characterizations: bank erosion, bank undercutting (more specific than bank erosion) and bed degradation (down-cutting). Also, the severity of erosion was categorized based on a relative scale of 'severe', 'moderate' and 'low or negligible'. Severe bank erosion is generally characterized by extensive scour (and typically pronounced (>0.5 m) undercutting) of the bank, with freshly exposed sediments and leaning or fallen trees. Moderate bank erosion is generally characterized by discontinuous bank scour, possibly limited to the lower portions of the banks, and exposed

tree roots; small (<0.5 m) undercuts may or may not be present. Low or negligible erosion is generally characterized by little to no evidence of erosion (including deposition). Bed degradation is generally classified based on the degree of entrenchment and exposure of in situ (non-alluvial) substrates along the bed and perched (former bed) armour layers along the banks. Sections of channel characterized by severe bed degradation tend to exhibit evidence of continuous bed scour, commonly representing >0.5 m of down-cutting, with little to no alluvial cover. Moderate bed degradation is reserved for sections of channel that appear to have down-cut <0.5 m. Low or negligible degradation represents depositional areas or neutrality. Undercut banks are distinguished as severe (>0.5 m) or moderate (<0.5 m). Isolated areas of bed scour (e.g. pools and plunge pools) have not been recorded as bed degradation.

Estimates of bankfull discharge were made based on field indicators, measured channel geometry and visual approximation of channel roughness (Manning's n), as a basis for informing design discharges for channel works proposed in association with erosion control solutions. Reliable estimates could not be made along deeply entrenched sections of channel, where unnatural bank characteristics, severe undercuts and/or active bank failures obscured typical field indicators of bankfull depth. As such, estimates for such sections of channel were approximated based on sites yielding reliable results and the ratio of their bankfull discharge to 2-year flows modelled by AE.

3. Existing Conditions

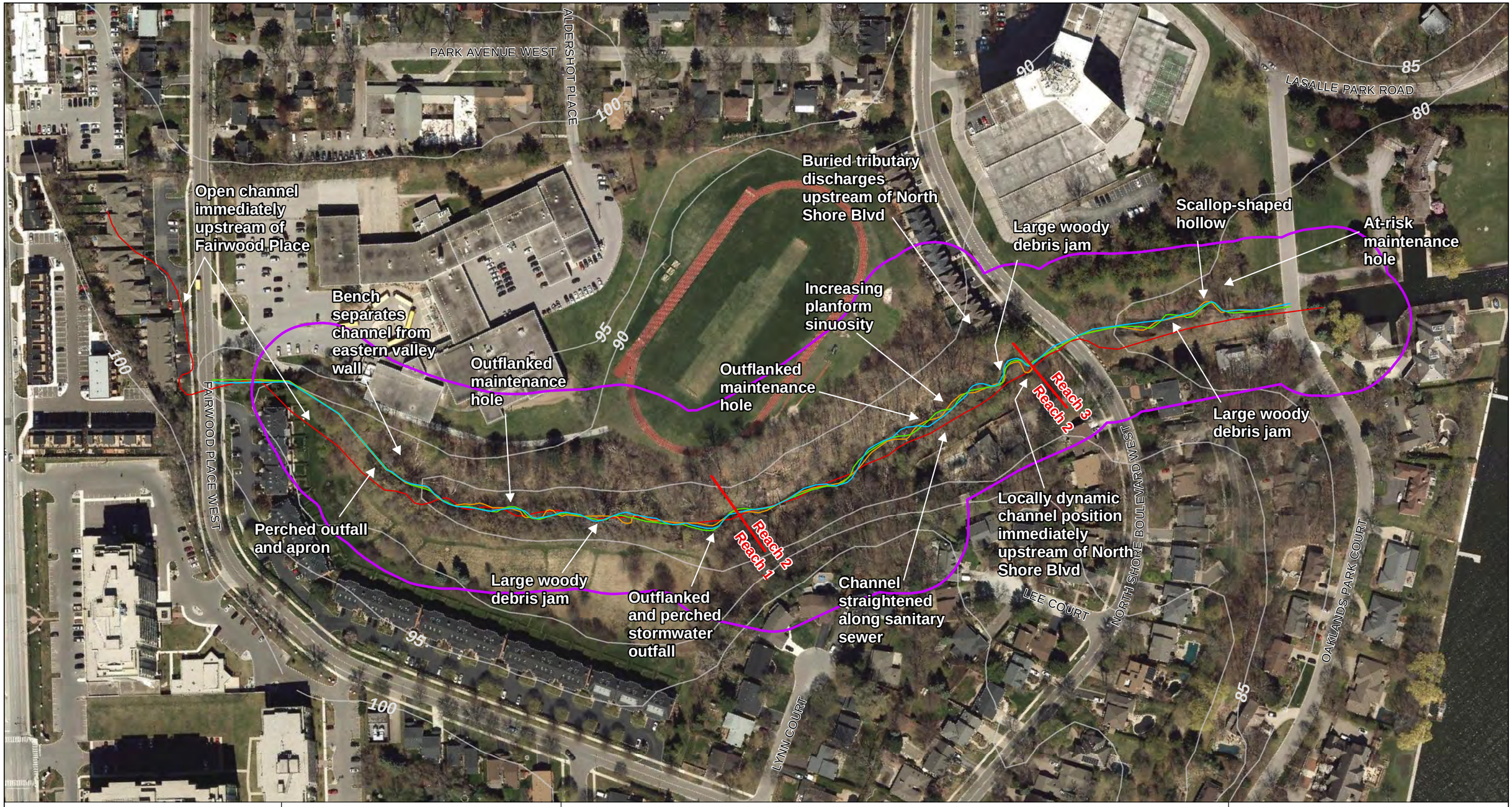
The study area has been divided into three distinct reaches, based on channel and valley characteristics, for descriptive purposes and consistency with other disciplines' reports (**Figure 1**). References are made to these reaches throughout the sections that follow.

3.1 Physical Setting and Historical Changes

West Aldershot Creek originates below the Niagara Escarpment and Highway 403 corridor and flows south through the Iroquois Plain physiographic region before emptying into Lake Ontario (Chapman and Putnam, 2007). The creek has a small drainage area 0.63 km^2 (MNRF, 2019) and is largely fed by two storm sewers. Both storm sewers, a 750 mm-diameter pipe and a 1430 mm-diameter pipe, drain urbanized catchments and discharge into the creek at the perched outfall. The surficial geology within the study area is dominated by coarse- to fine-textured glaciolacustrine sediments, deposited downslope of the former shoreline bluff of Glacial Lake Iroquois along what is now the Plains Road West corridor (OGS, 2010a). The underlying bedrock is the Queenston Formation shale (OGS, 2010b).

Land use surrounding West Aldershot Creek has changed from agricultural and rural residential to commercial and urban residential development over the historic record (1934 to 2018). Tableland along the western and eastern edge of the West Aldershot Creek ravine was cleared and graded before 1960. Aldershot High School was constructed immediately east of the valley between 1960 and 1962. A construction access road was present in 1960 along the edge of the channel in Reach 2 (**Figure 1**) for installation of linear infrastructure (presumably the Region-owned sanitary sewer). West Aldershot Creek flowed within a ravine beneath and immediately upstream of what is now Fairwood Place West until it was backfilled after the 1960s to accommodate road construction and residential development. A small tributary flowing from the northeast into Aldershot Creek near North Shore Boulevard was modified in preparation for residential development between the high school field and North Shore Boulevard between 1962 and 1995. Planform instability immediately upstream of North Shore Boulevard reflects the installation of an undersized culvert beneath the road (**Figure 1**). Riparian vegetation has consisted of moderately dense forest cover alongside Reaches 1 and 2 throughout the historic record, with Reach 3 being cleared after 1934 and slowly re-establishing sparse tree cover along the channel edge. The outlet into Lake Ontario has been unnatural since 1960.

West Aldershot Creek exhibits the effects of an urbanized hydrologic regime, largely without the benefit of stormwater management controls throughout the watershed. Its watershed is covered by a high proportion of impervious surfaces, so it is predisposed to rapid routing of surface runoff and floodwater during even modest rainstorms. The unnaturally rapid, or 'flashy,' hydrologic response has accelerated erosion along the bed and banks of the creek.



Prepared by:

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

CLIENT: Associated Engineering
PROJECT: Aldershot Creek Erosion EA

0 25 50 75
metres

DRAWN: S. Feist
CHECKED: M. Brierley
PROJECT: 140326
DATE: Apr 24, 2019

Scale 1:2000
UTM Zone 17N
NAD 1983

Study Area
Reach Breaks
Contour (5 m)

Historic Channel Centerlines
2017
2008
1998
1962

Note: Imagery (2017 - Halton Region) provided by Esri basemap service.
Contains information licensed under the Open Government License - Ontario.

Associated Engineering

Study Area and Historical Changes

FIGURE 1

Document Path: C:\Egnyte\Shared\Projects\Active\14003 - Associated Engineering\1400326 - Aldershot Creek Erosion EA\Mapping\Fluvial\Figures\Draft\mxd\140326_Fig_Fluvial.mxd

3.2 Channel Morphology

Erosion is extensive and locally severe along West Aldershot Creek, particularly where the channel is confined along the bottom of a nearly V-shaped ravine, with little to no floodplain to attenuate flow energy. Significant degradation (down-cutting) along the bed paired with continuous scour along the banks has led to the development of severe undercuts (up to 2 m) along the base of the confining terraces and valley walls themselves (**Photo 1**). Several mass movement failures have occurred recently along the lower valley walls in response to the fluvial erosion. Trees have fallen into the channel once their root masses are sufficiently undermined, which, in turn, has exacerbated erosion by forcing flows over, under and around the woody debris jams that form (**Photo 1**).

West Aldershot Creek can be described according to three reaches (**Figure 1**), as described in the following sub-sections. **Figure 2** presents a longitudinal profile, derived from the LiDAR survey data, along the channel centreline. Conspicuous slope-breaks along the profile, at reach breaks and large woody debris jams, are identified. Based on the available 0.25 m contour topographic mapping, the longitudinal profile (**Figure 2**), reach breaks are located at distinct changes in bed profile. Reach 1 has a relatively steep gradient of 3.3% compared to Reach 2 (1.1%) and Reach 3 (0.4%). There are two notable and abrupt drops in energy gradient located at large woody debris jams in Reach 2 and 3.

Bed material consists of a discontinuous veneer of gravel and cobble (including some dispersed gabion stone) overlying glaciolacustrine deposits (clay to fine sand). The proportion of sand, which locally embeds the alluvial gravel-cobble material, increases downstream. Reach 3 exhibits near-continuous embedment of underlying gravels with sand from upstream erosion. The median grain (D_{50}) size was estimated to be 30 mm from the Wolman pebble count (Appendix A) and is representative of the distribution along Reaches 1 and 2, where most channel works are warranted.



Photo 1. Upstream view of severe degradation (down-cutting) along the bed and continuous scour along the banks, with a large woody debris jam in the foreground (Reach 1)

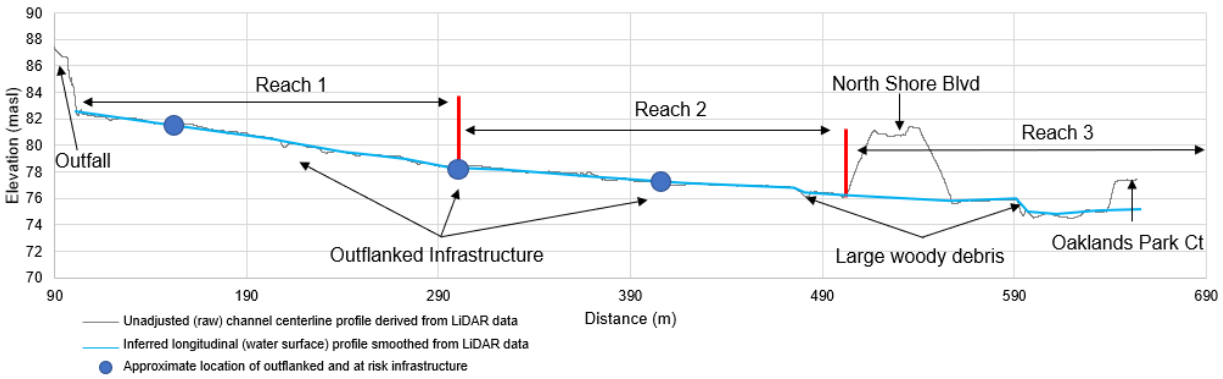


Figure 2. Longitudinal profile derived from LiDAR data provided by Groma

3.2.1 Reach 1

Reach 1 originates at the outfall south of Fairwood Place and extends 200 m downstream to the outflanked outfall that projects into the channel from the west bank (**Figure 1**). The reach is confined along both banks by high terraces or valley walls, punctuated by gullies and erosion scars where affected by fluvial erosion. The channel has become entrenched due to active degradation and is disconnected from what little floodplain once existed (**Photo 1**). This entrenchment concentrates shear stresses along the channel boundary during high flow events, which in turn leads to further degradation and instability. Bed degradation, undercut banks (up to 1 m), and localized channel widening have created an anomalously deep and narrow cross-sectional shape. The average channel depth is 1.5 m (measured from the bottom of the undercut to the bed) and width is 5.3 m (including undercut). These dimensions yield an anomalously low width:depth ratio of 3.5. The average bankfull discharge for Reach 1, estimated from the reliable Reach 2 value (5.8 m^3/s) and its proportion of AE's modelled 2-year flow for Reach 2 (5.8 $m^3s/6.2$ m^3/s = 94%), is 4.0 m^3/s (94% of the 4.3 m^3/s 2-year flow for Reach 1).

Bed material consists of a transient gravel-cobble veneer with near-continuous exposure of glaciolacustrine deposits (clay to fine sand) (**Photo 2**). Winnowing of fines and sands has coarsened the bed material. Localized bank collapses triggered by undercutting of the high terrace scarps and valley walls is also introducing coarse sediment into the channel.

Pool-riffle morphology is poorly defined, as expected based on the relative steep channel gradient (3.3%) (Montgomery and Buffington, 1997). Widening and failure of the terraces and valley walls have resulted in extensive exposure of root mats and an abundance of straight-trunked leaning and fallen trees that span or partly obstruct the channel (**Photo 3**). The introduction of large wood into the channel has resulted in two jams along Reach 1. Erosion has been exacerbated by flows forced over, under and around the jams.



Photo 2. Downstream view of gravels and cobbles with exposure of clayey to fine sandy glaciolacustrine deposits (light grey colour along lower banks) (Reach 1)



Photo 3. Upstream view of leaning and fallen trees and extensive exposure of root mats along the western (left) valley wall

A number of anthropogenic disturbances in addition to watershed urbanization influence channel morphology along Reach 1. Large concrete rubble has been historically placed along portions of the channel bed, but has since been displaced and dispersed by high-velocity storm flows. Several small, corrugated steel pipe (CSP) culverts, mostly draining immediately adjacent land (if at all still functional), discharge into the channel.

Infrastructure owned by the City and the Region of Peel (the Region) is at risk at a number of locations along Reach 1. Stormwater discharged from the main outfall at the head of West Aldershot Creek (i.e. upstream limit of Reach 1) plunges over a concrete apron into a pool immediately below. The apron has been undermined and become perched 2 m above the pool bottom (**Photo 4**). A sanitary maintenance hole is nearly exposed along the outer (east) bank approximately 100 m downstream of the main outfall; immediately opposite, another maintenance hole is at risk of impact due to severe (~2 m) bank undercutting (**Photo 5**). Depending on its depth, the sanitary sewer crossing may also be at risk of exposure due to degradation. Near the downstream end of the reach (180 m from the main outfall), an outfall has been outflanked along the west (right) bank and now projects well into the channel, with a slight perch above the bed (**Photo 6**).



Photo 4. Upstream view of the severely perched outfall and apron, 2 m above the channel bed, at the head of West Aldershot Creek (Reach 1)



Photo 5. Looking east along a sanitary sewer crossing with a maintenance hole nearly exposed along the outer (east) bank and at risk of exposure along the opposite (west) bank (Reach 1)



Photo 6. Downstream view of outflanked and slightly perched stormwater outfall along the west (right) bank at the downstream extent of Reach 1

3.2.2 Reach 2

Reach 2 extends from an outflanked and perched outfall to the crossing of North Shore Boulevard (**Figure 1**, **Photo 6**). The upstream limit of Reach 2 is marked by an abrupt transition from the ravine-like channel of Reach 1 to a more typical, sinuous channel along the bottom of a broad valley (Reach 2). The valley walls are commonly set back from the channel. The reach exhibits evidence of anthropogenic modification (i.e. straightening) with a low embankment along the west bank creating a discontinuous and moderately accessible floodplain. Channel sinuosity increases downstream, with bank erosion commonly following the criss-crossing thalweg pattern. Lateral migration is the dominant erosional process along Reach 2. Erosive energy is more effectively distributed across the wider channel cross-section and floodplain, such that erosion is less extensive and severe than along Reach 1. The average bankfull width and depth are approximately 6 m and 0.4 m, respectively. Average bankfull discharge along Reach 2 was estimated at 5.8 m^3/s, based on back-calculation from field measurements and topographic survey data.

The channel exhibits a natural, roughly rectangular cross-section along its riffles and an asymmetric cross-section deepest along its outer bank within pools. Pool-riffle morphology is generally well developed along the reach, which has an average gradient of 1.1%, with shallow pools separated by small riffles. Bed materials are dominated by gravels and cobbles with a transient veneer of sands in pools. The gravel-cobble bed is susceptible to transport during moderate to high flows. Banks are generally composed of sand, gravels and fill material.

Riparian vegetation was historically cleared along the western bank in association with installation of linear infrastructure (i.e. sanitary sewer). Riparian vegetation is now nearly continuous along the banks and valley walls. It is dominated by mixed forest with shrubby and herbaceous species dominating the understorey. There are numerous instances of straight-trunked and ‘pistol-butt’ fallen or leaning trees along the channel (**Photo 7**). A large woody debris jam was noted upstream of North Shore Boulevard resulting in a temporary, but significant grade control (**Figure 2**). The 1 m-high jam has resulted in the deposition of sand along the bed for approximately 60 m upstream, and severe erosion downstream (**Photo 8**).

Anthropogenic influences on channel morphology include several small, corrugated steel pipe (CSP) culverts, mostly draining immediately adjacent land (if at all still functional), discharge into the channel. A maintenance hole is outflanked along the outer (west) bank, now located within the channel approximately 115 m upstream of North Shore Boulevard (**Photo 7**). Severe erosion along the outer bank of a meander immediately upstream of North Shore Boulevard risks outflanking the inlet of the CSP culvert beneath the road. Flow is now deflected across the culvert inlet, eroding the opposite bank (**Photo 9**). The culvert is undersized from a fluvial geomorphological perspective, impeding the conveyance of water and sediment downstream. The concrete foundation of a chain-link fence post has been exposed by fluvial scour along the east bank of a slight meander approximately 40 m upstream of North Shore Boulevard.



Photo 7. Upstream view of fallen and leaning trees across the channel with the outflanked maintenance hole along the outer (west) bank (Reach 2)



Photo 8. Downstream view of large woody debris jam and resulting deposition upstream and severe erosion downstream (Reach 2)



Photo 9. Downstream view of the outflanked culvert with flow deflected across the inlet, eroding the opposite bank (Reach 2)

3.2.3 Reach 3

Reach 3 extends from North Shore Boulevard to the culvert outlet into Lake Ontario beneath Oaklands Park Court (**Figure 1**). The channel was historically straightened and entrenched within the fill-mantled ground, which is readily eroded (**Photo 10**). The entrenched channel prevents flow from overtopping the physical top of bank, concentrating erosive energy within the channel. The floodplain is not readily accessible to flood flows. The channel cross-section is distinctly trapezoidal and uniform along its entire length, except for a large, scallop-shaped erosional hollow (**Photo 11**). The hollow has formed along the east bank where flows have been deflected around a large woody debris jam complex.

Pool-riffle morphology is poorly defined along the entire length of the low-gradient (average 0.4%) reach. Bed materials consist of gravels overlain by a thick layer (0.2 m) of deposited sand. The large woody debris jam has created a temporary, but influential, grade control, altering the longitudinal profile of the reach (**Figure 2**, **Photo 12**). The ~1 m-high step formed by the debris jam impedes sediment transport and upstream fish passage. The average bankfull width and depth are approximately 5.5 m and 0.4 m, respectively. Average bankfull discharge was estimated at 6.7 m^3/s (94% of 7.1 m^3/s, 2-year flow).

Riparian vegetation was historically cleared along the eastern bank. Riparian vegetation is dense and nearly continuous along a narrow strip along both banks. It is dominated by deciduous stands along the tops of bank with the slopes dominated by shrubby and herbaceous meadow species.

The channel was historically straightened and entrenched between North Shore Road and Oaklands Park Court. Both road culverts are undersized from a fluvial geomorphological perspective, impeding the conveyance of water and sediment downstream. Concrete rubble is scattered along the reach. Several small outfalls discharge into the channel. A maintenance hole 15 m downstream from the anomalous scour of the left (east) bank approximately matches the setback (4.5 m) of the sanitary/water main from the top of bank. The sanitary/water main is potentially at risk if erosion were to continue along its current trajectory.



Photo 10. Upstream view of readily eroded fill-mantled ground along the west (right) bank, immediately downstream of the culvert beneath North Shore Boulevard (Reach 3)



Photo 11. Downstream view of the large, scallop-shaped erosional hollow immediately downstream of the large woody debris jam (Reach 3)



Photo 12. Upstream view of the large woody debris and plunge pool creating a significant grade control (Reach 3)

3.3 Erosion Inventory

As described above, erosion is widespread along West Aldershot Creek, although its severity generally decreases downstream from the head of the channel (Reach 1) to its mouth (Reach 3). A map-based inventory of the type and relative severity of bed and bank erosion was completed (**Figure 3**) to help identify drivers of channel instability and ultimately guide the development of erosion control solutions.

Reach 1 exhibits vertical to undercut banks and extensive scour along the bed. Instability has initiated slope failures, toppling riparian trees and has left stormwater and sanitary infrastructure at risk from near-continuous, severe erosion. Reach 1 is the primary erosion zone and the principal source of fine-grained sediment transported along West Aldershot Creek.

Along Reach 2, erosive energy is more effectively distributed across the wider channel cross-section and floodplain. As a result, erosion is discontinuous and less severe. Severe erosion is isolated to the outer (east) bank of a meander, downstream of a large woody debris jam, and immediately upstream of North Shore Boulevard. Reach 2 is a transport zone along which sediment eroded from the high, unstable banks of Reach 1 and, to a lesser extent, the low, locally scoured banks of Reach 2 is transported.

As in Reach 1, flow and erosive energy along Reach 3 are confined within a deep channel. However, oversizing of its cross-section and bank grading when the channel was historically straightened and excavated (post-1962) has moderated bed and bank erosion. The only severe erosion has occurred along the left (east) bank, where flows deflected over and around a large complex of woody debris jams have scoured a scallop-shaped hollow. Significant accumulation has occurred along portions of Reach 3, in the backwater area upstream of the woody debris jam complex and more broadly in association with backwater from high levels of Lake Ontario. Reach 3 is transitional between a transport and depositional zone, along which sediment eroded and transported along reaches 1 and 2 begins to deposit. The only significant source of (eroded) sediment along Reach 3 is the anomalous bank hollow formed in association with the woody debris jam.

Virtually all sediment eroded from the bed and banks of West Aldershot Creek is deposited abruptly at its mouth once it exits the culvert beneath Oakland Parks Court, at the shore of Lake Ontario. The recessed, anthropogenic shoreline punctuated by boat slips inhibits wave erosion and longshore drift, such that fluvial sediments locally accumulate at rates above those typical of a natural shoreline. Such accumulation of sediment, which required dredging, provided an initial impetus for the City to conduct this study and advance erosion control solutions.



Prepared by:

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

CLIENT: Associated Engineering
PROJECT: Aldershot Creel Erosion EA

0 25 50
metres

DRAWN: B.Elder
CHECKED: M. Brierley
PROJECT: 140326
DATE: Nov 27, 2018

Scale 1:1300
UTM Zone 17N
NAD 1983

Legend

- Reach break
- Contour (1 m)
- Contour (0.25 m)

Bank Erosion
- Severe
- Moderate
- Low or Negligible

Bed Degradation
- Severe
- Moderate
- Low or Negligible

Undercut Bank
- Severe
- Moderate

Note: Imagery (2017 - Halton Region) provided by Esri basemap service.

Associated Engineering

Severity of Bed and Bank Erosion

FIGURE 1

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4. Considerations for Erosion Control

A synthesis of the reach- to site-scale findings from this study reveals that West Aldershot Creek is still responding geomorphologically to watershed urbanization and historic alteration. Bed and bank erosion are widespread and locally severe (**Figure 3**). Ravine-like Reach 1 is the principal source of sediment that ultimately gets deposited at the creek mouth, so erosion control measures should focus on naturalized stabilization of this section of channel. The City should also intervene along Reaches 2 and 3, where natural channel adjustments cannot be accommodated without placing private property or infrastructure at risk.

One challenge facing the City is the management of in-stream (and riparian) woody debris. In natural watercourses, woody debris can help stabilize channels through its role in providing structure to the bed (e.g. steps) and protection of banks. In urbanized West Aldershot Creek, however, woody debris is being introduced into the channel at rates that exceed the recurrence of flows capable of dispersing and rafting it downstream. As a result, jams form that partly or wholly obstruct flows along the channel, forcing anomalous bed and/or bank scours. Regular inspections and strategic removal of in-stream woody debris by City crews will likely help mitigate anomalous bed and bank erosion now and in the future.

Establishment of appropriate design flows for proposed channel works requires consideration of field-based estimates of bankfull (~channel-forming) discharge and modelled flows, as well as reach-specific characteristics. Natural channel designs are typically sized according to estimates of bankfull or 2-year flow, which is appropriate for any channel works proposed along Reach 2, where flows greater than the bankfull or 2-year flow spill onto a floodplain and attenuate energy. Along the entrenched reaches 1 and 3, however, little to no floodplain is available to attenuate energy. As such, flows will remain confined to the channel and shear stresses may be disproportionately high. Consideration will need to be given to designing erosion control treatments along reaches 1 and 3 to withstand at least the 5-year flow, in order to meet the City's expectations for stability. The 5-year flow was modelled by AE as 5.3 m^3/s along Reach 1 and 8.8 m^3/s along Reach 3.

Key considerations for the development of erosion control solutions are highlighted below for each of the three reaches.

4.1 Reach 1

Entrenchment – The channel has become entrenched due to active degradation and is poorly connected to its floodplain. Flows are unnaturally deep and fast within the entrenched channel, and shear stresses are correspondingly high. Erosion mitigation along Reach 1 should prioritize creation of a wider, shallower cross-section, to the extent possible within the constraints of the ravine-like valley bottom, to more broadly distribute erosive forces and, in turn, reduce the propensity for bed degradation and bank erosion. Increasing the channel width:depth ratio, and incorporating at least narrow floodplain benches, would help moderate erosive energy.

Bed gradient – The average gradient of this reach was notably steeper when the outfall at the head of the channel was constructed. Discharge from the outflow would have rapidly scoured bed material, especially immediately downstream where the channel is most confined, and led to the reach-scale degradation that now characterizes this reach. Consideration was initially given to restoring a channel profile closer to its

pre-existing, natural form, given that floodplain accessibility would also be improved, but such an approach has been abandoned in favour of solutions that largely accommodate the existing profile. Maintenance of the existing channel profile takes advantage of the significant energy dissipation achieved by plunging of flows over the apron of the outfall into a deep pool.

Grade control – Vertical adjustments drive channel instability (and self-stabilization) along ravine-like reaches such as this. The outfall structure at the head of the creek is perched well above the bed (approximately 2 m), with the channel now isolated from the former floodplain bench along its east bank. Erosion control solutions should incorporate grade control, such as would occur along natural, steep ravine channels through the formation of self-stabilizing stony or woody steps, in order to mitigate further degradation and reduce the risk of bank protection measures being undermined and failing. A proposal for erosion control along the banks further underscores the need for grade control, given the increased energy that will be available to erode unprotected channel boundary materials.

Undercut banks – The reach is entrenched, with the bankfull elevation below the physical top of bank and erosive energy concentrated along the confined channel. Undercut banks have developed along the reach, as a consequence of channel entrenchment. Undercut banks are inherently unstable, their existence only possible due to temporary stabilization by root networks. They are prone to collapse through gradual settlement or small mass movement failures (e.g. slumps, slides), all of which are observed along this reach. Erosion control solutions should incorporate regrading (cutting) of banks to attain more stable angles, preferably at least 2H:1V. Such a reduction in bank steepness would decrease the potential for erosion through scour (fluvial) and mass movement (geotechnical) processes. The protection of regraded banks using hard albeit natural material (e.g. boulders, armourstone) cannot be avoided due to the relative inaccessibility of any appreciable floodplain and the concentration of flood water along the channel. In accordance with the City's expectations, erosion protection materials should be sized to at least remain stable up to 5-year flows.

Slope failure – Several factors independent of fluvial erosion contribute to instability along Reach 1, including surface water runoff and groundwater seepage. Concentrated surface runoff, whether designed or unintended, has formed a number of gullies along the eastern valley wall. Zones of groundwater seepage along the valley wall inherently exhibit greater instability due to reduced effective shear strength of the material. Erosion control strategies should account for the general distribution and relative rate of surface runoff and groundwater seepage, where applicable, to avoid impacts to erosion control structures (e.g. settlement or erosion in behind).

Downstream energy transfer – Erosion control measures that focus solely on armouring the channel bed and banks risk transferring erosive potential downstream to unprotected channel boundaries. Downstream energy transfer is best managed and moderated through the incorporation of roughness elements to the maximum extent possible, especially in steeper sections of channel. Reach 1 erosion control efforts should incorporate large stone for stability and enhanced bed roughness and riparian plantings. Vegetated (brush layering and live stakes) boulder revetments, which exhibit surface irregularities, should be prioritized over armourstone. To reduce the potential for energy transfer from Reach 1 to Reach 2, enhancement efforts should attempt to accommodate an increase in channel width (cross-sectional area) and increase floodplain interaction (benching) to dissipate energy. In addition, increased vegetation planting (i.e. brush layering and live stakes) could make banks more resistant to erosion. The City is further advised to maintain some opportunities for erosion to reduce downstream energy transfer. The total prevention of bank erosion would

otherwise create additional long-term problems and impact downstream infrastructure (i.e. sanitary sewer or road crossings). A key driver of excessive erosion along Reach 1 is the paucity of sediment entering it from the stormwater outfall.

4.2 Reach 2

Lateral adjustments – Bank erosion predominates along Reach 2 and results in lateral adjustments of channel planform. Such adjustments are driven by deflection of flows by woody debris and infrastructure (e.g. sanitary maintenance hole) and localized aggradation (sediment accumulation along the bed) that promotes spillage of flows onto the adjacent floodplain. The channel is gradually readopting a meandering pattern since its straightening several decades ago. The City should allow such adjustments and the corresponding increase in channel sinuosity, thereby (i) reducing channel gradient and, in turn, flow velocities and shear stresses; and (ii) naturalizing energy expenditure and balancing sediment sources (erosion) and storage (deposition) along the valley. Bed or bank stabilization measures should be avoided unless necessary to protect adjacent private property or infrastructure (e.g., sanitary sewer maintenance hole).

Longitudinal profile – Pool and riffle bed morphology is generally well developed along this previously straightened reach, although the riffles are smaller (lower) and pools are shallower than would be expected along a natural channel with this morphology. Historical straightening has slightly lowered average bed elevation and reduced floodplain accessibility. Consideration should be given to slightly increasing riffle size (height and length) to restore a more natural degree of floodplain connectivity, better attenuate flood flows and help dissipate any energy transferred from upstream (especially if extensive erosion protection is implemented), and enhance aquatic habitat through diversification of low-flow hydraulics and substrates.

4.3 Reach 3

Flood attenuation – Apart from localized widenings and benches along the bottom of the trapezoidal channel, few opportunities exist for flood attenuation along the reach. The establishment of floodplain benching would promote the attenuation of flood flows, naturally dissipating erosive energy along the reach. Also, benching would positively influence hydraulic capacity by creating a wider, shallow cross-section to more evenly distribute erosive forces, thereby reducing bed degradation and bank instability.

Bed morphology – Pool and riffle bed morphology is poorly defined along the reach with gravels embedded with sand. Establishing a defined pool and riffle bed morphology would improve longitudinal stability, restore natural fluvial form and function, and enhance aquatic habitat.

Channel planform - The channel has been anthropogenically modified, based on its straightness in 1962 aerial photography and the uniformity of its trapezoidal cross-section. The development of a natural, sinuous planform would increase the channel length, reducing channel gradient and, in turn, flow velocities and shear stresses. It would also optimize the balance of energy expenditure by creating natural areas of sediment storage (i.e. point bars and flood benches).

5. Conclusions

A comprehensive fluvial geomorphic assessment was completed along West Aldershot Creek, in Burlington, in order to inform the development of erosion control solutions in association with the West Aldershot Creek Erosion Control EA. The creek exhibits the effects of an urbanized hydrologic regime, without stormwater management controls. Rapid routing of surface runoff has increased the frequency and magnitude of high flows, which in turn has accelerated erosion along the bed and banks of the creek.

The upstream portion of the creek flows along the bottom of a steep, V-shaped ravine, with minimal sinuosity and no appreciable floodplain (Reach 1). As a result, the channel has become deeply entrenched. Flows are unnaturally deep and fast, which has led to as much as 1.5 m of bed degradation (down-cutting) and the scour and undercutting of confining banks. The severity of erosion along Reach 1 poses a risk to stormwater and sanitary infrastructure. Reach 1 is the predominant source of sediment that is transported along West Aldershot Creek and ultimately accumulates at its mouth.

The valley through which West Aldershot Creek flows widens abruptly at the transition from Reach 1 to Reach 2. Reach 2 exhibits a sinuous channel planform, in the process of re-establishing a meandering pattern following historical straightening to accommodate installation of linear (i.e. sanitary) infrastructure along its west side. A discontinuous, but accessible floodplain helps moderate erosion along Reach 2. Most erosion is concentrated along the outer banks of bends, which is expected. Erosion has also occurred where woody debris rafted downstream from Reach 1 accumulates and forms in-stream obstructions to flow, sediment transport and fish passage. The severity of erosion is moderate negligible, although some infrastructure is at risk. Relatively little sediment is sourced from bed and bank erosion along Reach 2, at least in comparison to Reach 1, and all is readily transported downstream at least into Reach 3.

Reach 3 is characterized by an unnaturally straight and uniformly trapezoidal channel excavated several decades ago presumably in association with infrastructure installation or land development. The channel exhibits a low gradient, except where it drops abruptly over steps formed by woody debris jams, and is prone to backwatering during high water levels in Lake Ontario. A large scallop-shaped erosional hollow has formed along the left bank, where flows have accelerated over and around a woody debris jam complex. A maintenance hole set back a short distance from this erosional hollow is the main site of at-risk infrastructure along Reach 3. The only noteworthy erosional source of sediment along Reach 3 is the erosional hollow; sediments tend to accumulate and persist along this reach before ultimately being flushed into Lake Ontario.

A synthesis of reach- to site-scale findings of the fluvial geomorphological study described herein underscores the importance of several considerations for the development of erosion control measures along Reach 1:

- Accounting for, accommodating and reducing channel entrenchment;
- Maintaining the existing, overall bed profile, thereby taking advantage of the energy dissipation achieved by the plunging of flows discharged from the outfall at the head of the creek;
- Implementing grade control into design solutions to inhibit further down-cutting and mitigate risk of undermining of bank protection measures;

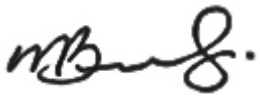
- Incorporating erosion control measures along both banks in anticipation of unavoidable, high-velocity flows;
- Managing surface runoff and seepage on the valley walls in such a way that the stability of creek erosion control measures is not compromised; and
- Introducing roughness elements into erosion control, to the extent possible, so that downstream energy transfer is minimized.

Along Reaches 2 and 3, erosion control solutions can likely be more localized. Efforts should be made to improve floodplain connectivity, through benching and/or raising of existing riffles, and accommodate the observed readoption of a more natural, meandering pattern. Regular inspections and strategic removal of in-stream woody debris by City crews will likely help mitigate anomalous bed and bank erosion now and in the future.

6. Certification

This report was prepared and reviewed by the undersigned:

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Appendix A

Grain Size Distribution

Representative bed material grain size distribution

