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Fluvial Geomorphological Assessment of Oshawa Creek and Evaluation of Erosion Mitigation Strategies at Prioritized Sites

Thomas Street to Wentworth Street West

Palmer Project #
1510206

Prepared For
City of Oshawa

October 8, 2021

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Tel: 647-795-8153 | www.pecg.ca

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Patrick Lee, M.Sc., P.Eng.
Manager, Professional Services
City of Oshawa
50 Centre Street South
Oshawa, ON L1H 3Z7

cc: Harshad Patel, M. Eng., P.Eng.

Dear Patrick Lee:

Re: Fluvial Geomorphological Assessment of Oshawa Creek and Evaluation of Erosion Mitigation Strategies at Prioritized Sites
Project #: 1510206

Palmer is pleased to provide the City of Oshawa with the results of our fluvial geomorphological assessment of Oshawa Creek between Thomas Street and Wentworth Street West, in Oshawa, as a basis for inventorying, evaluating, and recommending actions to address erosion risks.

Through geomorphological field investigations and desktop analyses, we identified eight erosion hazard sites, three of which were prioritized for more detailed follow-up assessment due to the potential risk to City property, private property and/or infrastructure (i.e., Sites 3, 4 and 6). An additional erosion hazard site (Site 8) is encompassed in the Site 6 assessment due to its close proximity.

Two alternatives for mitigating erosion, in addition to the ‘do nothing’ option, were developed and evaluated for each site to address unacceptable risk. Each preferred alternative, which is recommended for implementation at Sites 3, 4 and 6/8 (subject to findings of a geotechnical assessment), represents the best compromise among hydraulic, geomorphological, ecological, permitting and cost considerations.

Should you have any questions, please do not hesitate to contact Robin McKillop at 647-795-8153 (ext. 106) or robin.mckillop@pecg.ca.

Yours truly,
Palmer

Vice President, Principal Geomorphologist

Executive Summary

The fluvial geomorphology of Oshawa Creek, between Thomas Street and Wentworth Street West, reflects a history of watershed urbanization and local channel modifications (e.g., road and pedestrian crossings, localized stabilization). The City of Oshawa retained Palmer to complete a fluvial geomorphological assessment along this study corridor as a basis for inventorying and evaluating erosion hazard sites prior to developing concepts that mitigate risk at prioritized sites.

The study corridor of Oshawa Creek is situated within a broad, well-defined valley. Dynamic planform adjustment along the valley highlights a combination of natural meander migration and channel morphology that is not fully adapted to the urbanized hydrologic regime. Multiple meander bends are locally confined by valley walls and a high fill terrace. The channel is well connected to its floodplain as evidenced by low banks and overbank deposition. Three in-channel erosion control structures (rip-rap bank revetments) help mitigate risk at bridge crossings along the study corridor. All erosion control structures currently mitigate risk but are vulnerable to outflanking at their upstream ends.

Erosion along the study corridor is most pronounced along unprotected meanders where the channel is eroding into the channel banks and/or along the valley wall. A total of eight erosion hazard sites were identified and characterized. Of these, three sites were prioritized for more detailed follow-up investigation and the development of conceptual strategies to mitigate erosion-related risks to City property, private property and/or infrastructure (i.e., Sites 3, 4 and 6). Site 8 was also included as part of the detailed assessment and mitigative concepts for Site 6, due to its close proximity.

Site 3 was prioritized for follow-up assessment based on potential risks to private property at 124 and 124A Thomas Street and a City-owned pedestrian bridge along the Joseph Kolodzie Oshawa Creek Bike Path. Site 3 encompasses the outer bank of a meander and a pedestrian bridge immediately downstream of a historically straightened section of channel. Concentration of erosive energy at the meander apex has formed a near-vertical toe slope along the eastern valley wall, which could lead to future instability and pose a risk to private property at the edge of adjacent tableland. Bank erosion has also begun to outflank the boulder riprap revetment that protects the left abutment of the misaligned pedestrian bridge. The City should consider replacing the existing pedestrian bridge and updating its bi-annual municipal inspection report accordingly. Bridge span and siting Bridge span and siting we re-examined at preliminary design stage.

Site 4 includes a 50 m-long section of Oshawa Creek beneath and immediately downstream of the pedestrian bridge, where a sanitary sewer diagonally crosses beneath the channel. Bifurcation of flow around a large medial bar has promoted bed and bank erosion along the two, smaller channels. The buried sanitary sewer is within the envelope of scour potential between the upstream and downstream pools and is potentially at risk of exposure and damage.

At Site 6, severe erosion along the outer bank of a meander is responsible for decades of undercutting and mass movements along the lower half of the western valley wall. Private property (204 Thomas Street) at the edge of adjacent tableland is located within the stable slope allowance and may be at risk from continued slope recession.

At Site 8, the upstream extent of the boulder revetment that protects the Bike Path and left abutment of the Thomas Street bridge exhibits precursory signs of failure due to channel planform adjustment and local concentration of surface runoff from the adjacent parking lot and Bike Path.

Two of the three prioritized erosion hazard sites warrant immediate attention, based on apparent risks posed to the pedestrian bridge (Site 3) and private properties at 204 Thomas Street and 1125 to 1139 Valley Court and Thomas Street bridge (Site 6/8). Site 4 is situated so close to Site 3 that we recommend coordination of preferred concepts to include protection of the sanitary sewer crossing. Two conceptual alternatives for erosion mitigation were developed for comparison to the ‘do nothing’ alternative for each of the prioritised sites:

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Summary of Erosion Mitigation Alternatives and Recommended Actions at the Prioritized Sites

Site	'Do Nothing'	Concept 1	Concept 2	Recommended Action(s)
3	Without intervention, fluvial/valley wall interaction will continue to over-steepen the slope toe, further compromising valley wall stability and potentially posing a risk to the property at 124 and 124A Thomas Street. Localized concentration of energy will continue to outflank the boulder riprap protecting the left bridge abutment.	Slight realignment of the channel upstream of the pedestrian bridge crossing will create additional separation between the channel and valley wall, while also yielding a more favorable planform geometry that better mitigates the risk of outflanking of the left bridge abutment.	A vegetated boulder revetment with embedded large wood would protect the over-steepened toe of the valley wall from further undercutting and better mitigate the risk of outflanking of the left bridge abutment.	Design and implement the preferred alternative, Concept 1, following completion of a geotechnical assessment to refine the stable slope allowance and associated risk to private property, thereby confirming that additional slope stabilization measures are not required.
4	Without intervention, the Region-owned sanitary sewer that crosses diagonally beneath a medial bar may be at risk of exposure and damage if the bar were to erode and migrate downstream without replacement by bed material from upstream, or if the deep pool immediately downstream begins to headcut toward the sewer.	A reinforced riffle with armourstone ribs would inhibit degradation and upstream knickpoint migration over the sanitary sewer.	The enhancement of the existing riffle with a well graded cobble and boulder mixture would provide additional cover over the sanitary sewer. A second riffle downstream of the deep pool at the meander apex would add redundancy for bed stabilization (better mitigating the risk of headcutting). Embedded wood would limit potential for outflanking of the second riffle.	Coordinate the design and implementation of the preferred alternative for Site 4, Concept 1, with the preferred alternative for Site 3, Concept 1, even if risk to the sewer may not be imminent, to avoid potential for repeated disturbance by a patchwork of mitigative solutions, reduce costs and streamline permitting.
6/8	Without intervention, fluvial scour will continue to drive valley wall instability and increase risk to private properties that extend to the crest of the western valley wall (Site 6). Planform adjustment and concentration of surface runoff from the parking lot and Bike Path continue to outflank and winnow material from boulder revetment protecting the left abutment of the Thomas Street bridge (Site 8).	A low floodplain bench protected by a vegetated boulder revetment along the outer bank of the meander would create separation and mitigate continued fluvial undercutting and associated mass movements along the western valley wall. Compensatory inner-bank cut would maintain bankfull geometry and flood conveyance/storage. Existing deteriorated protection at Site 8 would be replaced with vegetated boulder revetment.	Creek realignment that locally mirrors the meander would position the channel well away from the western valley wall. The new alignment would also accommodate a straighter approach to the Thomas Street bridge.	Conduct a geotechnical assessment to more precisely establish the extent and nature of risks to private properties at the edge of adjacent tableland. Design and implement the preferred alternative, Concept 1, assuming the results of the geotechnical assessment do not justify more extensive toe protection and/or incorporation of additional slope stabilization measures.

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1. Introduction

Palmer is pleased to provide the City of Oshawa (the City) with our fluvial geomorphological assessment of Oshawa Creek between Thomas Street and Wentworth Street West (Wentworth Street), in Oshawa. This assessment supports the City's objective of identifying and evaluating erosion hazards and developing strategies to mitigate corresponding unacceptable risks at prioritized sites. Our team identified eight erosion hazard sites, three of which were prioritized for more detailed investigations due to the potential risks to City property, private property and/or infrastructure. Cost-effective strategies for mitigating risk at each of these prioritized sites (including a proximal site of only moderate priority), while also minimizing ecological impacts, have been identified and evaluated for the City's consideration.

Following provision of introductory background information (Section 1), we outline desktop and field methods used in this study (Section 2). Section 3 provides an overview of the physical setting and influential historical changes. Section 4 describes channel morphology and fluvial processes along the study corridor of Oshawa Creek, and details conditions at each of the prioritized erosion hazard sites. In Section 5, we identify and evaluate alternative strategies for mitigating erosion risks at the prioritized sites. Our conclusions and recommendations are provided in Section 6.

Surveyed channel cross-sections are included in **Appendix A**. Standardized summary characterizations of each of the eight inventoried sites, including hazard, risk and recommended action(s), are provided in **Appendix B**. Erosion mitigation concepts for prioritized sites are presented in **Appendix C**. An example calculation of critical discharge is summarized in **Appendix D**. Geomorphic Assessment and Rapid Stream Assessment Technique results are provided in **Appendix E**. Ontario Stream Assessment Protocol (OSAP) fish habitat mapping is provided in **Appendix F**. An Adobe Accessibility Check Report is included in **Appendix G**. A tabulated summary of responses to comments from the City and CLOCA on the draft versions of this report is provided in **Appendix H**.

2. Methods

Fluvial and associated slope erosion processes along Oshawa Creek were assessed through a combination of desktop and field investigations. We reviewed pertinent background information for the study area, including Central Lake Ontario Conservation Authority's (CLOCA's) Oshawa Creek Watershed Aquatic Resource Management Plan (2002), Fisheries Management Plan (2007), Oshawa Creek Watershed Plan (2013), Oshawa Creek 2020 Watershed Plan Update (2020), and regulatory floodplain mapping and hydraulic model (HEC-RAS) data, as well as Ontario Geological Survey (OGS) bedrock and surficial geology mapping (OGS, 2006, 2010a,b). We also reviewed 0.5 m topographic contours and 2019 LiDAR survey data provided by CLOCA.

Historical aerial photography provided by CLOCA from 1927, 1954, 1967, 1974, and recent orthophotography from CLOCA (2005, 2012, 2018), provided a basis for delineating and qualitatively comparing historical channel planforms and identifying important natural and anthropogenic changes within the valley and in adjacent tableland. Delineated historical channel planforms were used for quantitative overlay analysis. Systematic trends in lateral or down-valley migration were identified and measured. The measurements were then used to calculate time-averaged channel migration rates. Estimates of time-averaged migration rates were established based on channel positions between 1974 and 2018, except at one site where systematic migration began in 2005.

The meander belt of Oshawa Creek was delineated as context for understanding broad trends in channel position and to inform the conceptual design of possible channel realignments by outlining predictions of future erosion. Meander belt delineation was completed according to a combination of protocols for both *confined* and *unconfined* systems (Ontario Ministry of Natural Resources, 2002; Parish Geomorphic, 2004), because some of the meanders abut valley walls along the study corridor. The meander belt was preliminarily established by delineating and then buffering the meander belt axis until the outer banks of meander bends were encompassed (except where historically filled), following the valley trend. The final meander belt was determined as the existing belt width plus a 20% Factor of Safety (FoS). The meander belt boundaries were then locally shifted to the midpoint of valley walls, in accordance with the Toronto and Region Conservation Authority protocol (Parish Geomorphic, 2004), such that the belt width varies in width in concert with transitions in valley wall confinement.

Palmer's in-house ecologists prepared a baseline characterization of existing aquatic and terrestrial conditions based on CLOCA's field data and available background information (e.g., fish community records, Ecological Land Classification (ELC) mapping, Natural Heritage Information Centre (NHIC) records, Department of Fisheries and Oceans (DFO) Aquatic Species at Risk tool) in addition to scoped field investigations to address any data gaps and enable refinement of existing CLOCA data, as necessary. Fish habitat mapping was completed in accordance with established protocols (Ontario Stream Assessment Protocol (OSAP) habitat mapping), with particular attention given to the identification of any fish passage barriers and opportunities for habitat restoration and enhancement. ELC mapping was compiled for each of the prioritized sites to support development and evaluation of conceptual designs. Any wetlands and vegetation supported by groundwater seepage were highlighted. Baseline information to characterize ecological features and functions was prepared for each prioritized site, to include assessment of vegetation communities, potential Species at Risk (SAR), significant natural heritage features, wetland communities, and aquatic and terrestrial habitat. An ecologist from Palmer, specializing in both aquatic and terrestrial ecology, visited the site on April 28, 2021, to document existing in-stream and riparian conditions as they relate to fish and fish habitat, and to confirm and update the ELC mapping for the surrounding terrestrial lands.

Palmer gained initial impressions of channel conditions through observations made by our senior fluvial geomorphologist and fluvial processes specialist during a site-reconnaissance visit, during low-flow conditions, on April 16, 2021. The purpose of this reconnaissance was to observe channel conditions, examine patterns and processes of local erosion, ground truth aerial photograph-based interpretations, and produce an inventory of erosion hazard sites. As part of this, a Rapid Geomorphic Assessment (RGA; Ontario Ministry of the Environment, 2003) was completed along the study reach to document evidence of channel aggradation, degradation, widening and/or planimetric form adjustment. The RGA tool provides a useful checklist of evidence to consider, but its results are dependent on the presence or absence of a set number of specific features within a reach and thus must be interpreted carefully to ensure accuracy (McKillop, 2016). The Rapid Stream Assessment Technique (RSAT; Galli, 1996) field method was also applied along the study corridor to gain a general understanding of stream characteristics and overall health.

Palmer, in consultation with the City, prioritized three of the inventoried sites for more detailed, follow-up investigation, on the basis of potential risks posed to City property, private property, and/or infrastructure (including a proximal site of only moderate priority). Additional field reconnaissance and detailed data collection were completed by Palmer's fluvial processes specialists on April 29, 2021, during low-flow conditions, at each of the three sites confirmed for prioritization by the City. The following site-specific data were collected at sites 3, 4, and 6: representative pool and riffle cross-sections; a local longitudinal bed and water surface profile (to approximate the local energy gradient); substrate characteristics, including grain size distribution estimates based on modified Wolman (1954) pebble counts representative of bed material at each prioritized site; and a description of bank morphology and composition. Bankfull dimensions, assumed to represent 'channel-forming' flow conditions, were based on field indicators defining the principal limit of scour, including abrupt changes in bank vegetation, material, and steepness (Harrelson et al., 1994). Bed erosion threshold analyses were completed at select locations using the collected field data based on Shields (1936), using an approach consistent with Church (2006):

- Critical shear stress (using Shield's (1936) equation): $\tau_{cr} = \theta g(\rho_s - \rho)D$
- Actual (average) shear stress: $\tau_o = \rho g d S$
- Average velocity (using Manning's equation, with depth substituted for hydraulic radius): $v = 1.49(d^{2/3}S^{1/2})/n$
- Discharge (using the continuity equation): $Q = vA$

  where τ_{cr} is the critical shear stress (N/m^2), θ is Shield's parameter (typically ~0.06 along this creek), g is the acceleration of gravity (9.81 m/s^2), ρ_s is the density of sediment (~2,650 kg/m^3), ρ is the density of water (~1,000 kg/m^3), d is the flow depth (m), τ_o is the average shear stress (N/m^2), D is the grain size to be moved (m), S is the slope (m/m), v is the average velocity (m/s), n is Manning's n (typically ~0.035 along this creek), Q is the discharge (m^3/s), and A is the cross-sectional flow area (m^2).

Each erosion hazard site along the study reach was photographed and characterized according to standardized criteria. Bankfull channel dimensions were estimated at each site in order to detect potentially anomalous dimensions (e.g., pinch-point) and provide guidance to any channel realignment considerations. Site-specific channel dimensions were also reviewed in the context of existing hydrological and hydraulic data, in order to evaluate the role of watershed urbanization in observed instabilities. Each of the inventoried erosion hazard sites was assigned a relative erosion hazard risk rating of high, moderate, or low considering the severity and rapidity of erosion and the general site context. Recommended actions for each site were highlighted for the City's consideration at the bottom of the standardized site characterization pages in **Appendix B.**

3. Physical Setting and Historical Changes

3.1 Watershed and Valley Form

Oshawa Creek originates in agricultural lands on the southern flank of the Oak Ridges Moraine and flows generally southward over the till plains of the South Slope and the former Glacial Lake Iroquois Plain before entering Lake Ontario (Chapman and Putnam, 1984). The entire Oshawa Creek watershed has a drainage area of 120 km^2 (CLOCA, 2013). The southern portion of the Oshawa Creek watershed, especially south of Highway 407, is fully built-out with mostly residential and commercial development. As of 2007, the entire watershed had a recorded rural land use of 60% (CLOCA, 2007); however, this proportion is likely now smaller, based on changes observed in recent orthophotography provided by CLOCA. Land use directly upstream of, and adjacent to, the study corridor has been residential since 1954, before which the area was mixed residential and agricultural. Much of this development dates back to the mid-1900s, well before the incorporation of stormwater management (SWM) practices. Urbanization has altered the natural hydrology of the lower reaches of Oshawa Creek by accelerating surface runoff and flood routing, thereby increasing peak flows. Channel morphology has not fully adapted to the urbanized hydrologic regime, and the upcoming northward expansion of development in response to continued population growth, and recent eastward extension of Highway 407 will only further stress the system.

Within the Oshawa Main subwatershed, Oshawa Creek has a moderate gradient (average of 0.5%; CLOCA, 2007). Within the study corridor, along which the creek has a slightly gentler gradient of 0.44% as it approaches its mouth at Lake Ontario, Oshawa Creek meanders along the bottom of a well-defined valley. Surficial deposits of adjacent tableland consist of sandy silt to silty sand-textured till locally overlain by glaciolacustrine clay, silt, and sand deposits (OGS, 2010a,b). The valley bottom is generally filled with silty to cobbly alluvium, underlain by till, reflecting a history of lateral and vertical channel adjustment. Erosion-resistant till is commonly exposed along the bed and banks where the channel is in contact with the valley walls. Erosion protection measures (i.e., boulder revetments and armourstone walls) occur locally along the study corridor, typically adjacent to infrastructure.

3.2 Historical Assessment

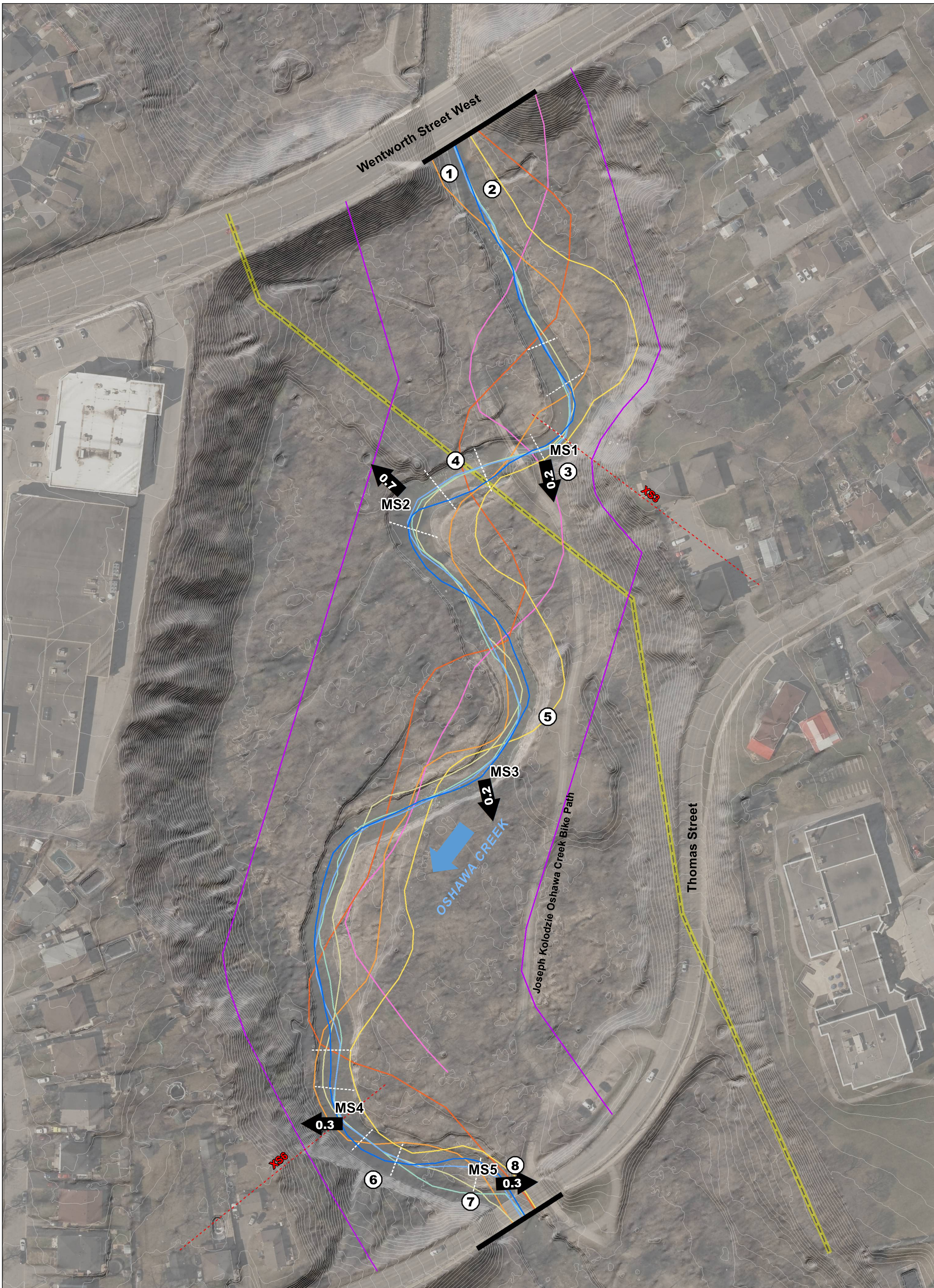
In 1927, the study corridor of Oshawa Creek was surrounded by undeveloped, agricultural land to the west, rural land use to the east, and a small urban development to the north. The valley walls were sparsely vegetated with young trees and shrubs.

The Wentworth Street and Thomas Street bridge crossings define the upstream and downstream extent of the study corridor, respectively (**Figure 1**). The Thomas Street crossing was constructed before 1927 but was moved approximately 250 m downstream sometime between 1927 and 1954. The Wentworth Street crossing was constructed sometime between 1954 and 1967. Additionally, a pedestrian bridge, constructed in the 1990s or early 2000s, crosses the channel approximately 150 m downstream of the Wentworth Street bridge crossing. A sanitary main, constructed before 1954, crosses beneath the watercourse immediately downstream of the pedestrian crossing.

Natural recolonization of the valley bottom by a variety of shrub and tree species in recent decades has re-established a functional riparian zone. Once dominated by meadow landscapes (e.g., 1927), the valley has since been colonized by a dense deciduous tree canopy.

Residential development within the Oshawa Creek watershed intensified in 1967, continuing through the early 2000s. Ongoing urbanization in the upper portions of the Oshawa Creek watershed continues to modify the hydrological response (‘flashiness’), which is inferred to be contributing to recent channel and planform adjustment. These adjustments pose a risk to development that has encroached to the valley edge and to infrastructure that crosses beneath the channel.

Between 2005 and 2010, the outer bank of Oshawa Creek, just upstream of the Thomas Street crossing and pedestrian crossing, was reinforced with boulder and armourstone revetments to prevent lateral erosion and subsequent outflanking of bridge footings.



LEGEND:

- Migration Site (MS) *rate in m/year*
- Meander Belt
- Cross Section *(white dashed line)*
- LiDAR Cross Section *(red dashed line)*
- Study Corridor Limits
- Sanitary Sewer
- Contours (50 cm)
- Erosion Hazard Site
- Flow Direction

Channel Centre Line (Year)

2020	1974
2018	1967
2012	1954
2005	1927

TITLE:

Historic Changes and Meander Belt

METRE SCALE: 0 5 10 20 30 40

NORTH:

CLIENT: City of Oshawa

PRINT SCALE: 1:1400	PRINT SIZE: 11 x 17 "		
DATUM: NAD 1983	PROJECTION: UTM Zone 17		
DATE: Aug 23, 2021	DRAWN: KG	CHECKED: AS	

PROJECT: Oshawa Creek Geomorphological Assessment and Erosion Mitigation

PREPARED BY: Palmer™

FIGURE NO.	REVISION:	PROJECT NO.
1	1-2	1510206

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Imagery (2020) provided by the City of Oshawa

3.3 Aquatic Ecology

The study corridor is classified as a fifth-order stream, as characterized by the Strahler method (CLOCA, 2007). It contains no impediments (partial or complete barriers) to fish passage. Oshawa Creek is predominantly a cold- and cool-water system, with warm-water sites found in the lower reaches of the main branch, as indicated by temperature loggers (CLOCA, 2007). The study area occurs within this warm-water reach. The warm water timing window for construction is July 1 to March 31 (DFO, CLOCA 2007). Oshawa Creek is a migratory corridor for spring and fall spawning runs of anadromous trout and Pacific Salmon from Lake Ontario. As such, any works must not block fish passage as migratory species are usually staging early in the lower parts of Oshawa Creek. The construction timing window should be confirmed with the local Ontario Ministry of Natural Resources and Forestry (MNRF) office before any in-water works are scheduled.

The following aquatic habitat descriptions interpret the aquatic habitat mapping provided in **Appendix F.** Along the study corridor, the creek is characterized by well-developed riffle-run-pool stream morphology. Undercut banks and overhanging woody debris are found throughout the reach and provide in-stream cover. Well defined pools and riffle were present along the study corridor. Substrates within the watercourse vary among morphological habitat units, with pools primarily featuring silt and sands, and gravel and cobbles predominant within riffles and runs.

The riparian area is densely vegetated and includes overhanging woody plants and grasses. In some areas, large Willow *(Salix spp.)* trees overhang the watercourse and provide significant in-water cover. Despite the urban location of the study corridor, the riparian area is highly functional due to its protection within a well-defined valley. Riparian function is reduced by a clearing, with mowed lawn, at the pedestrian bridge crossing between Sites 3 and 4. A clearing with mowed grass is also present at Site 5. Immediately downstream of Wentworth Street, the west bank of Oshawa Creek features the elevated concrete footpath of the Joseph Kolodzie Oshawa Creek Bike Path (hereafter referred to simply as “the Bike Path”). This section of the reach offers minimal fish habitat value as it is a run with limited riparian area or refuge. Despite the densely vegetated riparian area throughout the majority of the reach, vegetation is mostly absent from the wetted width of the creek, limited to some Creeping Bentgrass *(Agrostis stolonifera)* and Reed Canary Grass *(Phalaris arundinacaea)* emerging from sandy bars at the edges of pools. This is a testament to the frequency and extent of flood flows, which inhibit in-stream vegetation survival. The sections of the watercourse that feature significant erosion and steep slopes, primarily the outer banks of the pools at the apices of meanders, currently provide limited fish habitat due to the lack of riparian cover and high-velocity runs within the study corridor. Gravel bars occur within the stream and locally bifurcate flow, potentially providing habitat for small fish in portions of the side channels.

3.4 Terrestrial Ecology

The study corridor is located within a naturalized system, which predominantly exhibits a deciduous tree canopy with small areas of thicket and meadow (CLOCA, 2007). The presence of small open meadow areas within the deciduous forest community indicates that this area has been subject to environmental disturbances in the past. The restriction of development from the main portion of the valley has allowed vegetation and forest succession to occur since land clearing associated with European settlement of the region. Based on available ELC mapping and related information provided by CLOCA and the NHIC, no wetland communities of significant size have been mapped in the area (CLOCA, 2019). The MNRF's Land Information Ontario (LIO) database identifies several polygons of Oshawa Creek Coastal Wetland complex along the banks of Oshawa Creek, downstream of Thomas Street, but none of these features occurs within the study corridor.

Screening for any SAR will be required through Ontario Ministry of the Environment, Conservation and Parks in advance of, and to inform, any proposed works along the Oshawa Creek valley. Butternut (*Juglans cinerea*) and certain species of bats are at risk and may be present, for example, although neither was observed during Palmer's ecological field reconnaissance.

CLOCA's ELC data is high-level and indicates two community types occurring within the study corridor: Fresh-Moist Hemlock Mixed Forest and Fresh-Moist Lowland Deciduous Forest. The study area is dominated primarily by two forest types, upland and lowland deciduous forest, divided primarily by topographic position within the valley (**Figure 2**). Eastern Hemlock *(Tsuga canadensis)* is present within the upland forest, but such coniferous species are uncommon within the canopy. No wetlands were identified within the study area, corroborating information from LIO, but some small inclusion wetland vegetation communities are associated with the riparian area of Oshawa Creek. The following ELC communities were identified within the study area:

Dry – Fresh Sugar Maple Hemlock Deciduous Forest (FOD5)
This forest type occupies the upper valley walls of Oshawa Creek, and is dominated by Sugar Maple *(Acer saccharum)*, with other upland hardwood species including Black Cherry *(Prunus serotina)*, White Ash *(Fraxinus americana)*, Basswood *(Tilia americana)* and occasional White Pine *(Pinus strobus)* and Eastern Hemlock in the canopy. The subcanopy includes younger individuals of the canopy species and Ironwood *(Ostrya virginiana)*. The understory, which is primarily sparse due to dense hardwood canopy cover, includes Trout Lily *(Erythronium americanum),* Long-stalked Sedge *(Carex pedunculata)*, sapling Sugar Maple, and Intermediate Wood Fern *(Dryopteris intermedia)*.

Fresh – Moist Willow Lowland Deciduous Forest (FOD7-3)
This forest type primarily occurs on the lowlands along the valley bottom of Oshawa Creek, with a canopy that is primarily dominated by non-native Willow species, indicating historical clearing or disturbance. Canopy trees include Crack Willow *(Salix fragilis)*, Weeping Willow *(Salix babylonica)* and Manitoba Maple *(Acer negundo)*, with an understory of Urban Avens *(Geum urbanum)*, Broad-leaved Dock *(Rumex crispus)*, Common Self-heal *(Prunella vulgaris)*, Creeping Bellflower *(Campanula rapunculoides)* and Great Willlow-herb *(Epilobium hirsutum)*.

LEGEND:

Ecological Land Classification (ELC)

Flow Direction

Imagery (2020) provided by the City of Oshawa

TITLE: **Existing Environmental Conditions**

METRE SCALE: 0 5 10 20 30 40

NORTH:

CLIENT: City of Oshawa

PRINT SCALE: 1:1400 | PRINT SIZE: 11 x 17 "

DATUM: NAD 1983 | PROJECTION: UTM Zone 17

DATE: Aug 23, 2021 | DRAWN: KG | CHECKED: AS

PROJECT: Oshawa Creek Geomorphological Assessment and Erosion Mitigation

PREPARED BY: Palmer™

FIGURE NO. 2 | REVISION: 1-1 | PROJECT NO. 1510206

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4. Description of Channel Morphology and Fluvial Processes

A description of channel morphology and fluvial processes, with an emphasis on bed and bank erosion, is provided below (Section 4.1). The study corridor includes eight inventoried erosion hazard sites, each of which is identified and characterized in **Figure 3** and **Appendix B**, respectively. The three prioritized sites (3, 4 and 6/8) are further described below in Section 4.3. Section 4.4 highlights the overall implications of the reach- to site-scale findings for the City's management of Oshawa Creek within the study corridor.

4.1 Study Corridor

Oshawa Creek exhibits evidence of historical modification (Section 3) along the study corridor. Dynamic planform adjustment along the valley bottom (**Figure 1**) likely highlights that channel morphology has not fully adopted to the urbanized hydrologic regime. The channel generally exhibits broad, irregularly shaped meanders that have increased in sinuosity and gradually migrated downstream, as indicated by the presence of inner-bank scroll (point) bars. Some meanders are now locally confined by valley walls (Sites3 and 6) and/or a high fill terrace (Site 5) (**Photo 1**). The construction of Wentworth Street and Thomas Street on high, valley-spanning road embankments has locally fixed the channel planform in place, limiting planform departures within, and immediately upstream and downstream of, the study corridor.

The channel is generally well connected to its floodplain as evidenced by low banks and overbank deposition. Average bed gradient is 0.44% along the entire study corridor, with no overall concavity/convexity in the longitudinal profile (**Figure 4**). Bed gradient is gentler than average between Sites 5 and 6 (0.2%) and steeper than average from Site 6 to the downstream end of the study corridor (0.6%). This difference may be explained by the original Thomas Street Bridge crossing, situated at approximately the same location as the change in gradient before its removal sometime between 1927 and 1954 (**Figure 5**). Sediment deposition upstream of the crossing, and subsequent erosion downstream of the crossing, could explain this abrupt change in gradient.

LEGEND:

- Erosion Hazard Site
- Photo Location and Direction
- Flow Direction
- 2020 Channel Centreline
- Cross Section (*white dashed line*)
- Study Corridor Limit
- Sanitary Sewer

Existing Erosion Control Structures

- Rip-Rap Bank Revetment

Imagery (2020) provided by the City of Oshawa

TITLE:

Inventoried and Prioritized Erosion Hazard Sites

METRE SCALE: 0 5 10 20 30 40 50

NORTH:

CLIENT: City of Oshawa

PRINT SCALE:	1:1750	PRINT SIZE:	11 x 17 "
DATUM:	NAD 1983	PROJECTION:	UTM Zone 17
DATE:	Aug 23, 2021	DRAWN: BE	CHECKED: AS

TITLE: Oshawa Creek Geomorphological Assessment and Erosion Mitigation

PREPARED BY: Palmer™

FIGURE NO.	REVISION:	PROJECT NO.
3	1-2	1510206

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Photo 1. Channel eroding high, fill-formed terrace along the outer bank of a meander (Site 5). Upstream view.

Channel gradient along the study corridor is consistent with those typically associated with pool-riffle morphology (**Photo 2**) (e.g., Buffington and Montgomery, 1997). Riffles are typically situated at the inflection points between successive meanders, and pools generally occur at and immediately downstream of meander apices. Local bed scouring has resulted in a maximum pool bankfull depth of 1.8 m. The average of all surveyed maximum bankfull depths for pools is 1.6 m. The average of all surveyed maximum bankfull depths for riffles is 1.1 m, with the deepest reaching 1.2 m (**Table 1**). The average of all surveyed maximum bankfull depths for the entire study reach is 1.3 m. Average bankfull width is 16.9 m, and average width-to-depth ratio is 23.0 m. Average width-to-depth ratio within the study corridor is notably higher than what is common for channels with similar morphologies to Oshawa Creek (i.e., 15 – 20 m). This likely reflects differential erodibility of alluvial banks (readily eroded) and underlying till substrate (erosion-resistant), as well as stresses introduced by urbanization (i.e., hydrologic regime change). Outer-bank erosion and subsequent lateral channel migration has resulted in valley wall contact at Sites 3 (**Photo 3**) and 6 (**Photo 4**). Medial bars at Site 4 and between Sites 6 and 7 bifurcate low flows and have concentrated erosive energy along adjacent bank areas (**Photo 2**). A low berm that diagonals across the western floodplain, parallel to and just southwest of the sanitary sewer as it approaches the left channel bank, is likely excess material following installation of the sewer. Average bankfull discharge is 27.6 m^3/s (**Table** 1).

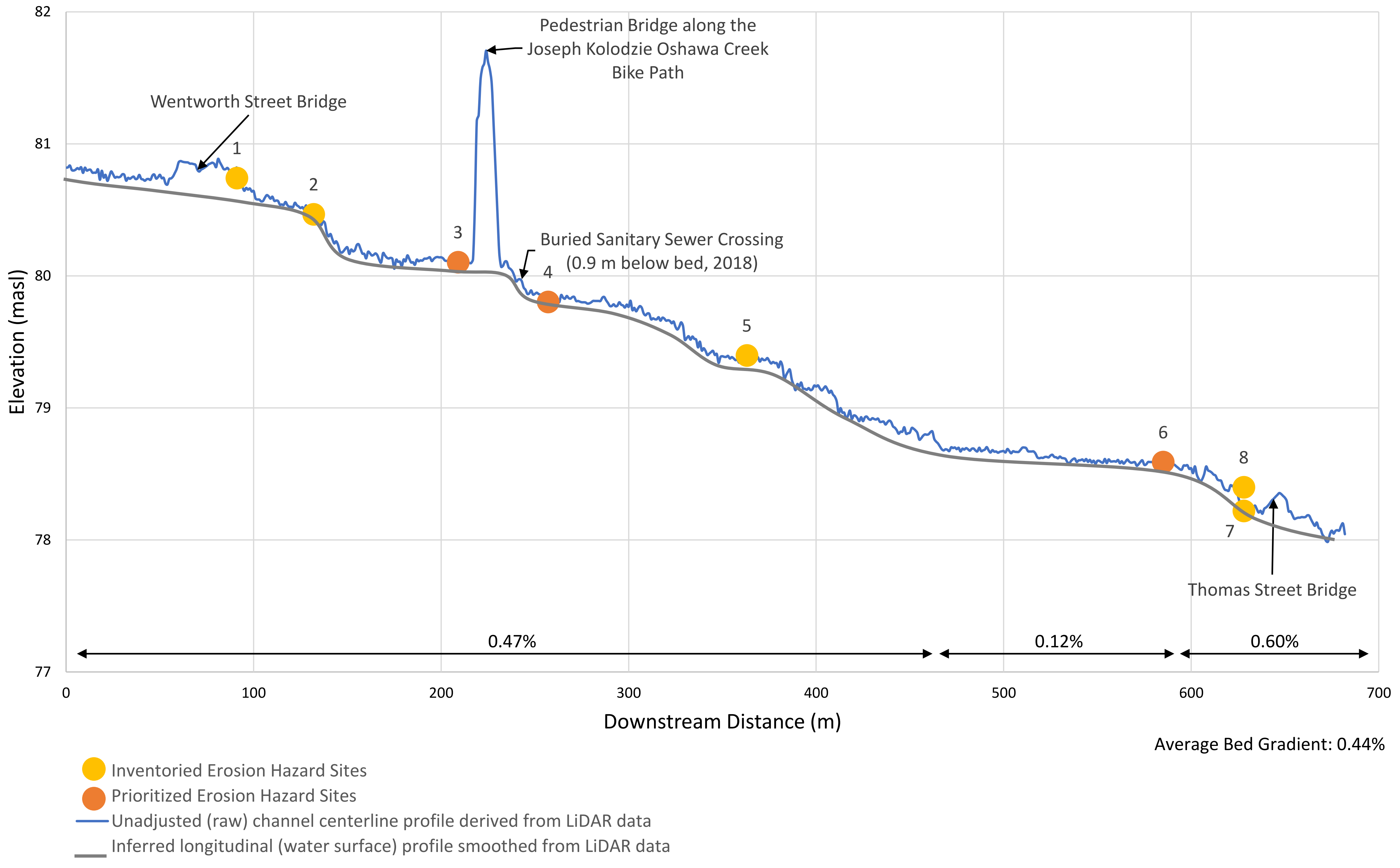

Figure 4. LiDAR-derived longitudinal profile of Oshawa Creek.

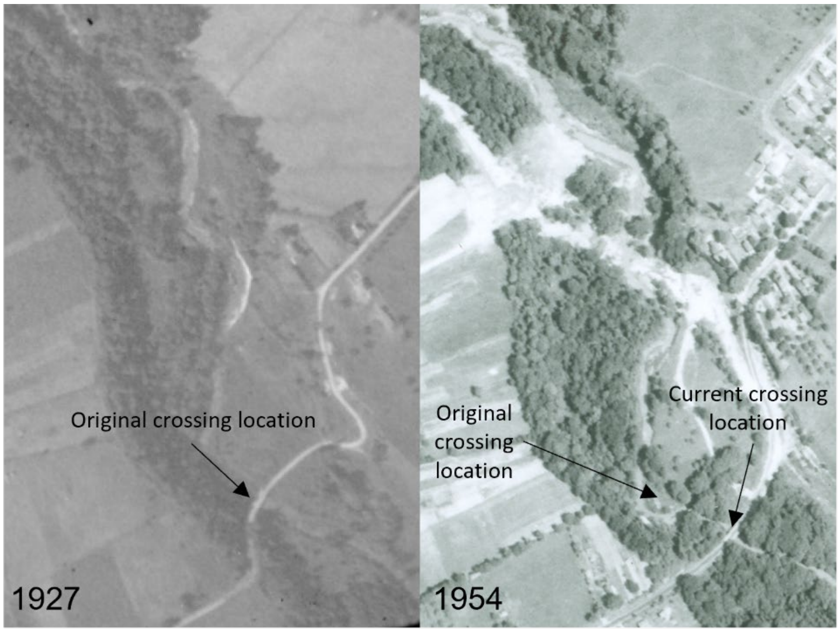

Figure 5. Location of original and current Thomas Street Bridge crossing in 1927 and 1954 aerial photography. Original crossing was removed between 1927 and 1954.

Photo 2. A riffle at Site 4 formed by a medial bar that bifurcates flow toward a pool immediately downstream at the apex of a meander. Downstream view.

Table 1. Estimated bankfull flow conditions and erosion thresholds at surveyed cross-sections.

Site	XS	Type	Bankfull Hydraulics						Erosion Threshold
			Q_{bfl} (m³/s)	W_{bfl} (m)	D_{bflA} (m)	D_{bflM} (m)	W_{bfl}:D_{bflA}	V_{bfl} (m/s)	Q_{cr} (m³/s)
Site 3/4	3-1	Riffle	16.5	20.9	0.6	1.0	34.6	1.1	15.3
	3-2	Riffle	19.9	18.0	0.6	0.9	29.4	1.1	22.2[9]
	3-3	Pool	25.7	17.3	0.8	1.4	22.1	1.4	13.6
	3-4	Pool	26.9	13.9	1.0	1.8	14.5	1.5	6.3
	4-1	Riffle	28.1	19.3	0.7	1.2	26.9	1.3	20.5
Site 3/4 Average			**23.4**	**17.9**	**0.7**	**1.3**	**25.5**	**1.3**	**15.6**
Site 6/8	6-1	Riffle	24.9	16.3	0.7	1.0	22.9	1.4	23.6
	6-2	Riffle	31.5	15.6	0.8	1.2	19.2	1.6	22.3
	6-3	Pool	26.1	13.5	0.7	1.4	18.3	1.5	10.1
	6-4	Riffle	21.1	15.3	0.6	1.2	24.3	1.2	18.0
	6-5	Pool	55.1	19.0	1.1	1.8	17.4	2.1	26.7
Site 6/8 Average			**31.7**	**15.9**	**0.8**	**1.3**	**20.4**	**1.6**	**20.1**
Study Corridor Average			**27.6**	**16.9**	**0.8**	**1.3**	**23.0**	**1.4**	**17.9**

Notes:

1. Abbreviations: XS: cross-section, Q_{bfl}: bankfull discharge, W_{bfl}: bankfull width, D_{bflA}: average bankfull depth, D_{bflM}: maximum bankfull depth, V_{bfl}: average bankfull velocity, D_{cr}: critical depth.
2. Width-to-depth ratio (e.g., 34.6) calculated simply as the bankfull width (e.g., 20.9 m) divided by the average bankfull depth (e.g., 0.6 m). The reach-average ratio is calculated as the average of the column values as opposed to the average of the quotient of the reach-average widths and depths. Width-to-depth ratios can give an indication of channel stability, as values in the range of 15 – 20 are common for in-regime channels with morphologies similar to Oshawa Creek.
3. Average velocity corresponds to the discharge back-calculated from site-specific channel geometry (cross-section and slope) and roughness (Manning's n), using Manning's equation.
4. Critical discharge is calculated using a combination of shear stress, Manning's and continuity equations, as outlined in Section 2.
5. Based on surveyed cross-sections, local water surface slopes, and Manning's n values of 0.035.
6. Bankfull discharge and velocity estimates are most reliable for riffle cross-sections situated along straight portions of channel free of obstructions.
7. Cross-sections at each erosion hazard site ordered from upstream to downstream.
8. An example calculation of critical discharge for Site 3, Cross-section 1, is provided in **Appendix D**.
9. Critical discharges above bankfull, such as those included for certain cross-sections indicate that the channel lacks competence to mobilize the bed material at bankfull flow. The specific values that exceed bankfull importantly convey the relative erosional sensitivity (or lack thereof) of the channel, but should be considered conservative given that they were estimated without detailed overbank topographic information. The energy required to mobilize sediment is instead dispersed into the floodplain.

Photo 3. Valley wall contact along the outer bank of the meander at Site 3. Upstream view.

Photo 4. Valley wall contact along the outer bank of the meander at Site 6. Upstream view. Person for scale.

Bed materials within Oshawa Creek are relatively well sorted, ranging from coarse sand to cobbles, and are dominated by gravels and small cobbles (**Figure 6**). Extensive fine-grained deposits blanket pool bottoms and a thin veneer of sand embeds larger particles in pools and riffles, potentially sourced from eroding valley walls or transported from former headpond deposits from the Cedardale Dam, upstream of the study corridor (Palmer, 2020). The representative median grain size (D_{50}) of Oshawa Creek, within the study corridor, is approximately 50 mm (5 cm). There are several locations along the study corridor where underlying till is exposed on the bed (e.g., downstream of Site 4 and Site 6). Abundant woody debris has accumulated along the channel, derived mainly from downstream rafting of trees that have fallen into the channel following erosion and undercutting of adjacent banks. Conspicuous traces of organic matter in overbank areas demarcate the limits of recent flood inundation (**Photo 5**). Long sections of undercut bank expose elevated armoured (cobbly) layers, providing at least localized evidence of historic degradation (down-cutting) from a former (higher) channel bed (**Photo 6**).

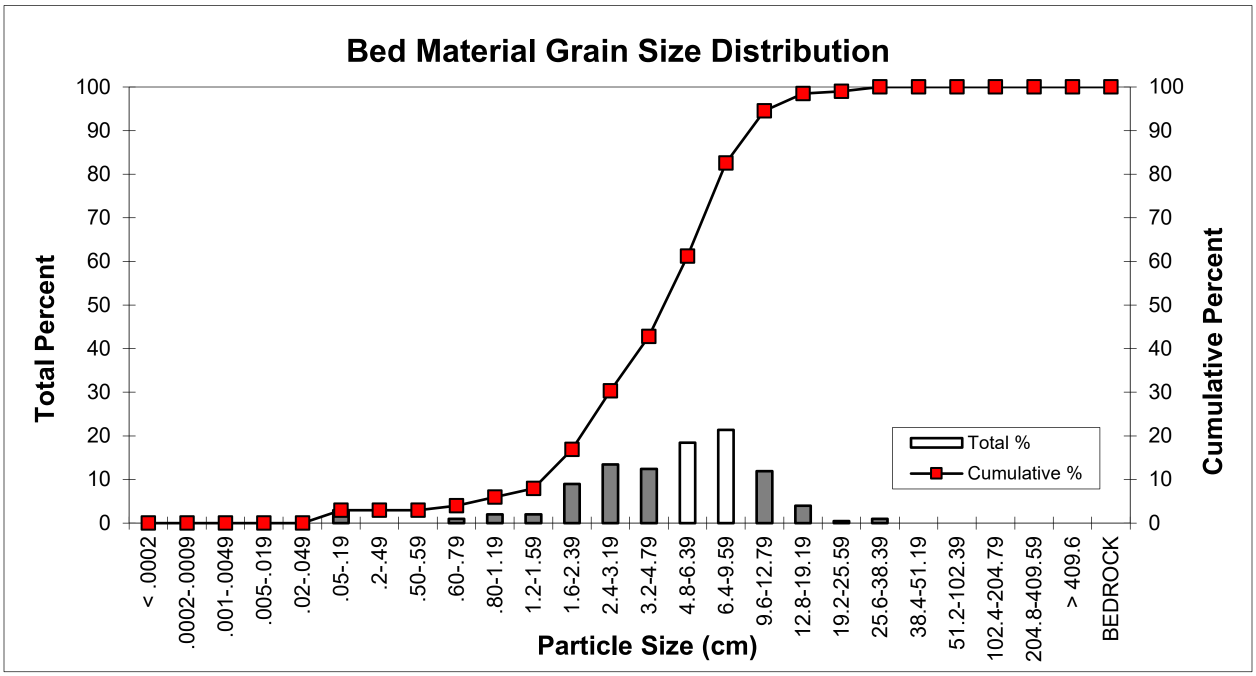

Figure 6. ***Integrated grain size distribution of bed material from pebble counts (100 count at Site 3/4 and 100 count at Site 6) conducted along Oshawa Creek.***

Photo 5. Woody debris in the channel and overbank deposition of organic debris near Site 3. View of left (east) bank.

Photo 6. Low, undercut bank exposing an elevated armoured layer at Site 4. Flow from left to right.

The results of the RGA suggest the study corridor is currently “transitional” due to dominant modes of adjustment being aggradation and channel widening (**Table 2**). The results of the RSAT indicate the study corridor has ‘Fair’ quality based on good in-stream and riparian habitat conditions, fair channel stability and sediment scouring/deposition, and poor water quality (**Table 3**).

Table 2. Summary results of RGA for Oshawa Creek between Thomas Street and Wentworth Street.

Form/Process	**Index**
Aggradation	0.43
Degradation	0.17
Widening	0.44
Planimetric Form Adjustment	0.17
Stability Index	**0.30**
Classification	**Transitional**

Table 3. Summary results of RSAT for Oshawa Creek between Thomas Street and Wentworth Street.

Evaluation Category	**Index**
Channel Stability	5
Channel Scouring/Sediment Deposition	4
Physical In-stream Habitat	5
Water Quality*	2
Riparian Habitat Conditions	5
Biological Indicators	4
Total:	**25**
Verbal Ranking:	**Fair**

* Water quality score is based on CLOCA’s watershed report card.

4.1.1 Existing Erosion Control Structures

A total of three erosion control structures was inventoried along the study corridor (**Table 4**). The structures are riprap bank revetments, all protecting bridge abutments from being outflanked.

Table 4. Summary of erosion control structures along the study corridor.

ID	Type	Length (m)	Current Condition	Description	Mechanism(s) of Failure
A	Riprap Bank Revetment	7.5	Erosion observed around structure. Boulders founded on bed and appeared stable and functional	Riprap bank revetment protecting the left pedestrian bridge abutment	Outflanking at the upstream extent
B	Riprap and Armourstone Bank Revetment	30	Erosion observed with some displacement of stone at upstream extent. Remaining structure appears stable and functional	Riprap revetment and Armourstone bank protecting the right Thomas Street bridge abutment	Outflanking at the upstream extent
C	Riprap Bank Revetment	10	Erosion observed upstream and behind structure. Stone founded on bed and keyed into bank. Structure deteriorating but appears stable and functional	Riprap bank revetment protecting the left Thomas Street bridge abutment	Outflanking and winnowing of fines

The erosion control structures, so far, are functioning as designed despite initiation of outflanking at their upstream ends. The bottom row (toe) of each revetment is founded on or below the bed, inhibiting undermining at the time of the field reconnaissance. The presence of sub-angular boulders allows stone to 'lock' together, increasing the revetments shear strength. The revetments are designed with stable, engineered slopes that prevent slipping and/or sliding failures resulting from fluvial interaction. Boulder revetments are 'flexible' erosion mitigation solutions that can move and readjust to movement (e.g., settling) and scour, increasing their design lifespan. Despite observed erosion at each erosion control structure, they are stable and offer long-term stability. However, outflanking suggests that their upstream limits were not keyed into the bank and/or extended far enough upstream to prevent erosion. Precursory evidence of outflanking is incorporated into the site-scale descriptions below (Section 4.3).

4.2 Meander Belt and Migration Rates

The meander belt was delineated by considering historical meander migration and the local confinement by valley walls. The existing meander belt is 90 m where it is unconfined, then widens to 110 m for the final version to account for the 20% FoS. The final meander belt was further refined (narrowed) to the midpoints of valley walls to better reflect localized confinements (**Figure 1**). At migration measurement locations 1, 2, 4, and 5, systematic migration was documented between 1974 and 2020 (**Figure 1**). At location 3, systematic down-valley migration is predominant (**Table 5; Figure 1)**. The migration rates range from 0.2 m/year to 0.7 m/year. Such rapid rates of migration largely reflect the low, erodible (alluvial) banks and flashy peak flows that typify this study corridor.

Table 5. Meander migration rate calculation table based on comparative analysis of historical channel bank delineation.

Migration Measurement Location	Start (Year)	End (Year)	Period (Years)	Cardinal Direction	Distance (m)	Rate (m/year)
1	1974	2020	46	SE	8	0.2
2	1974	2020	46	W	30	0.7
3*	1974	2020	46	SSE	9	0.2
4	1974	2020	46	SW	12	0.3
5	2005	2020	15	ENE	5	0.3

*Migration is dominantly down-valley.

4.3 Site-Scale

A total of eight erosion hazard sites were inventoried through the desktop review and field reconnaissance completed in the first phase of this study (**Figure 3**). Standardized, summary characterizations of each erosion hazard site are included in **Appendix B**. More detailed, site-scale descriptions are provided in the following sub-sections for Sites 3/4 and 6/8, which were prioritized based on potential risk to City property, private property, and/or infrastructure. The site-scale characterizations focus on local-scale geomorphic processes. Both hazard site pairings exhibit outer-bank erosion along meanders in combination with valley wall erosional processes (e.g., mass wasting) and at least precursory outflanking of boulder revetments that protect bridge abutments.

4.3.1 Site 3/4 – Pedestrian Bridge and Sanitary Sewer Crossing

A pedestrian bridge, a buried sanitary sewer, and private property at the edge of adjacent tableland (124 and 124A Thomas Street) are potentially at risk due to fluvial and valley wall erosion within the channel segment encompassing Sites 3 and 4. Sites 3 and 4 are located approximately 150 m downstream of the Wentworth Street bridge, in association with a pedestrian bridge crossing along the Bike Path. Site 3 encompasses the outer bank of a meander and a pedestrian bridge, built sometime between 1981 and 2005, immediately downstream. A private dwelling within the property at 124 and 124A Thomas Street is set back approximately 9 m from the crest of the adjacent valley wall, roughly 14 m high. The historical realignment of Oshawa Creek through the narrow gap between the high road embankments, along which Wentworth Street is situated, has formed an anomalously straight approach toward the valley wall. Although the position of the valley wall has remained largely unchanged over the historical record, concentration of erosive energy around the bend has created a near-vertical toe slope (**Photo 7**), which could lead to future instability.

According to the MNRF (MNR, 2002), in the absence of site-specific geotechnical information, the stable slope allowance (3H:1V) extends well into adjacent tableland (**Figure 7**). Two buildings are located within the sum of the toe erosion allowance (6 m), based on dense till exposed along the slope toe and MNRF's (2002) Table 3, and the 42 m stable slope allowance, highlighting future risk.

Downstream transfer of energy from the erosion-resistant valley wall has started to outflank and undermine the boulder revetment protecting the bridge abutment **(Figure 1; Photo 7**). The bridge is located immediately downstream of the meander apex, where erosive energy is naturally concentrated, with its left (outer bank) abutment set back much closer to the thalweg than its right (inner bank) abutment. The siting and skew of the bridge abutments exacerbate erosion along the outer bank. The bridge abutment along the outer bank projects into the channel, creating a point of erosion concentration. If bridge abutments were shifted approximately 10 m to the south, erosion risk to the bridge would have been significantly reduced. A deep scour pool has formed along the outside of the meander, exacerbated by a point bar that has formed along the inner bank. The scour pool extends downstream, beneath the pedestrian bridge, the left abutment of which is at risk of being undermined.

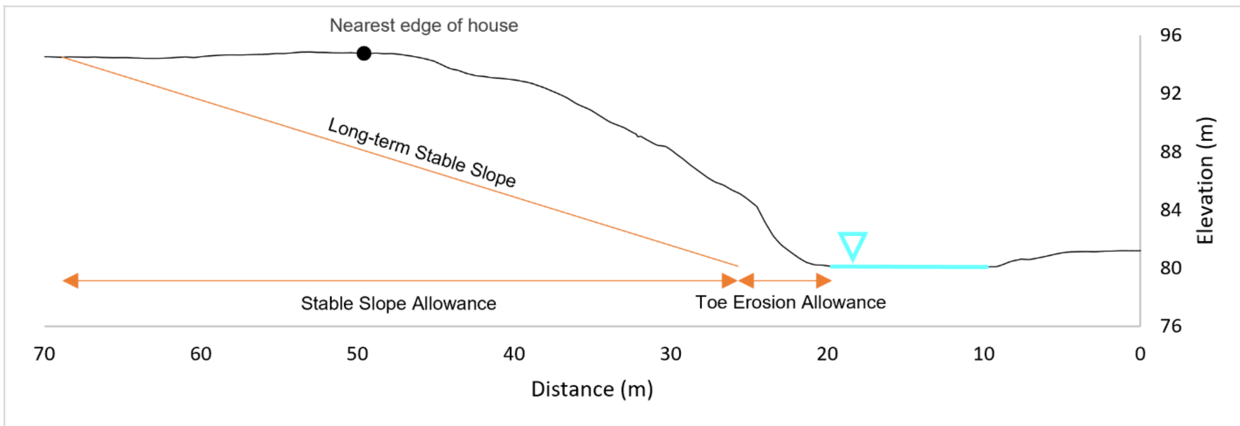

Figure 7. Downstream view of LiDAR-derived cross-section of east side of valley at Site 3, showing the toe erosion allowance (6 m) and the stable slope allowance (42m) projected into tableland with a private residence.

Photo 7. Bank revetment upstream of pedestrian bridge being outflanked at the downstream limit of an erosive scarp, along the Site 3 valley wall contact. Downstream view.

Site 4 encompasses the 50 m-long section of Oshawa Creek beneath, and immediately downstream of, the pedestrian bridge (**Figure 3**). Three parallel sanitary sewers (254 mm to 610 mm in diameter) cross diagonally beneath the creek, approximately 18 m downstream of the bridge, and only 0.9 m below the bed, in 2019, as inferred from 1953 as-built drawings provided by the City and 2019 LiDAR data provided by CLOCA (**Figure 8**). As-built drawings indicate the sewer is not encased in concrete. The large medial gravel bar that has formed over the sewer crossing bifurcates low to moderate flows, promoting scour of both banks and the channel bed (**Photo 8**). Scouring forces localized widening and deepening of the channel. Widening of the channel has increased the length of sanitary sewer at risk from erosion and has left the bridge footing projecting into the channel.

The gradient at Site 4 is 0.62%, notably steeper than at other sites, and the reach-scale average (0.44%). Two deep pools define the upstream (1.66 m deep) and downstream (1.40 m deep) limits of Site 4. A reasonable approximation of typical bed scour potential along this particular section of channel is the grade-line tangent to the bottoms of the deepest pools. Longitudinal adjustments are likely to occur at least within the envelope between the channel bed and this maximum pool depth grade line. The grade-line tangent to the bottoms of the pools is currently 0.16 m below the bottom of the sanitary pipe, such that the sanitary pipe is within the area of scour potential and potentially at risk of exposure and damage (**Figure 8**).

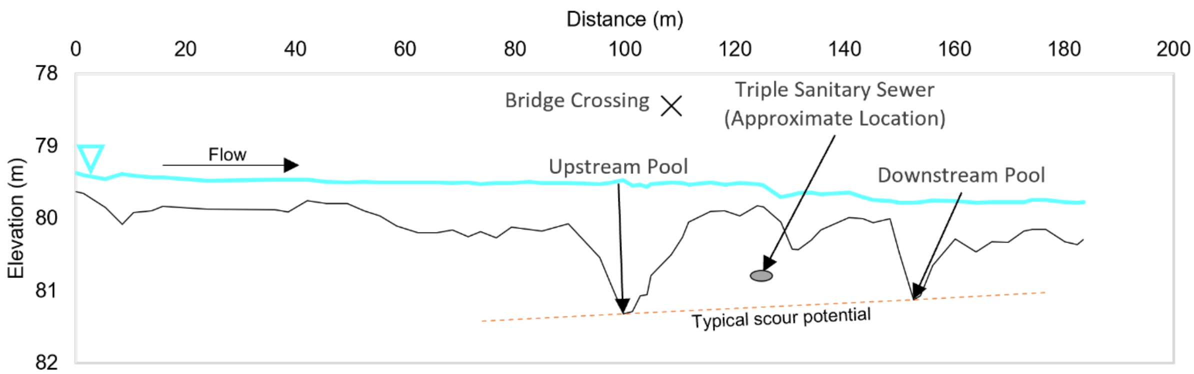

Figure 8. Longitudinal profile of bed morphology encompassing Site 4, created from local level-rod survey data referenced to 2019 LiDAR-derived elevations. Obvert of sanitary sewer is 0.9 m below the bed and 0.16 m above the grade line, tangential to upstream and downstream pools (representing typical scour potential).

Photo 8. A medial bar overtop of the sanitary sewer bifurcates flow, concentrating erosion along both banks. Downstream view.

The average bankfull width at Sites 3 and 4 is 17.9 m, the average bankfull depth is 0.7 m, and the average bankfull discharge is 23.4 m^3/s. The critical discharge to mobilize bed materials, averaged across cross-sections, is approximately 70% of the bankfull discharge (15.6 m^3/s). Coarser bed material requires a critical discharge closer to the bankfull flow condition. Comparison of the sanitary sewer as-built (1954) with the contemporary bed elevation (using LiDAR and rod-level survey data) indicates that the bed has lowered by no more than about 10 cm since 1954. Significant lateral adjustments have occurred over the same period, however, due to preferential erosion of channel banks.

4.3.2 Site 6 – Valley Wall Contact and Thomas Street Crossing

Site 6 is located along the outer bank of a meander in contact with the western valley wall of Oshawa Creek, just upstream of the Thomas Street bridge (**Figure 1**). The crest of the valley wall is approximately coincident with the edge of private property, with a dwelling and outbuildings setback approximately 10 m on adjacent tableland. Over the historical record (1927 – 2020), the radius of curvature of the impinging meander had increased, such that channel contact with the valley wall has lengthened from about 75 m to 150 m. Planimetric adjustment has slowed since 2005, although the presence of meander scrolls along the inner bank highlights migration into and along the valley wall at Site 6, since prior to the earliest available aerial photography (i.e., 1927). Continued fluvial scour and associated mass movements have the potential to impact properties along Valley Court in the long-term, without intervention.

The base of the valley wall has receded slightly through an ongoing cycle of fluvial scour, oversteepening, and repeated mass movements (**Photo 9**). The valley wall has been unable to self-stabilize due to the repeated entrainment of sloughed material that temporarily accumulates along its toe during floods. Valley wall erosion at Site 6 was noted as a “high priority” for “erosion control or bank stabilization works” in the City’s *Oshawa Creek Watershed Master Drainage* (Totten Sims Hubicki Associates, 1995) (**Figure 9**). Topographic survey of the valley wall indicated that it was already steeper than 2H:1V in 1995 (Totten Sims Hubicki Associates, 1995). LiDAR data acquired in 2019 indicates the eroded valley wall is approximately 39^{o} steep along its unvegetated, eroded face, although only 23^{o} steep along its forested upper slope (**Figure** 10). Groundwater seepage emerging part way down the erosion scar, likely perched on the contact between capping Glacial Lake Iroquois sands (high permeability) and underlying dense, sandy silt Newmarket Till (low permeability), may be contributing to instability. Private property is located within the stable slope allowance (3H:1V, as defined by MNR, 2002) plus the toe erosion allowance (6 m, based on dense till exposed along the slope toe and MNR’s (2002) Table 3) (**Figure 10**). Slope recession initiated by fluvial scour and subsequent oversteepening of the valley wall will result in headcut into the tableland, toward 204 Thomas Street, until erosion is mitigated, or a stable slope is achieved.

Channel planform adjustment upstream of Thomas Street bridge (Site 8) has started to erode the upstream extent of boulder revetment installed along the left bank to protect the bridge footing and Bike Path (**Photo 10**). Overtopping flood flows have also resulted in the outflanking and winnowing of fines underlying and behind the boulder revetment. Concentrated surface runoff along the Bike Path, from the parking lot, cascades over the boulder revetment into the creek, and acts as a secondary erosion mechanism. Average bankfull width at Site 6 and 8 is 15.9 m, average depth is 0.8 m, and average bankfull discharge is 31.7 m^3/s. The critical discharge to mobilize bed materials, averaged across cross-sections, is approximately 67.7% of the bankfull discharge (21.1 m^3/s). The energy required to mobilize sediment is concentrated along the banks and/or dispersed into the floodplain when depth is sufficient for channel water to overtop the low bank (**Photo 11**). Higher critical discharge required to move coarser bed material (D_{50}) has resulted in lateral adjustments due to preferential erosion of channel banks.

Photo 9. An actively eroding scarp, approximately 100 m long and up to 17 m high, along the western valley wall at Site 6. Downstream view.

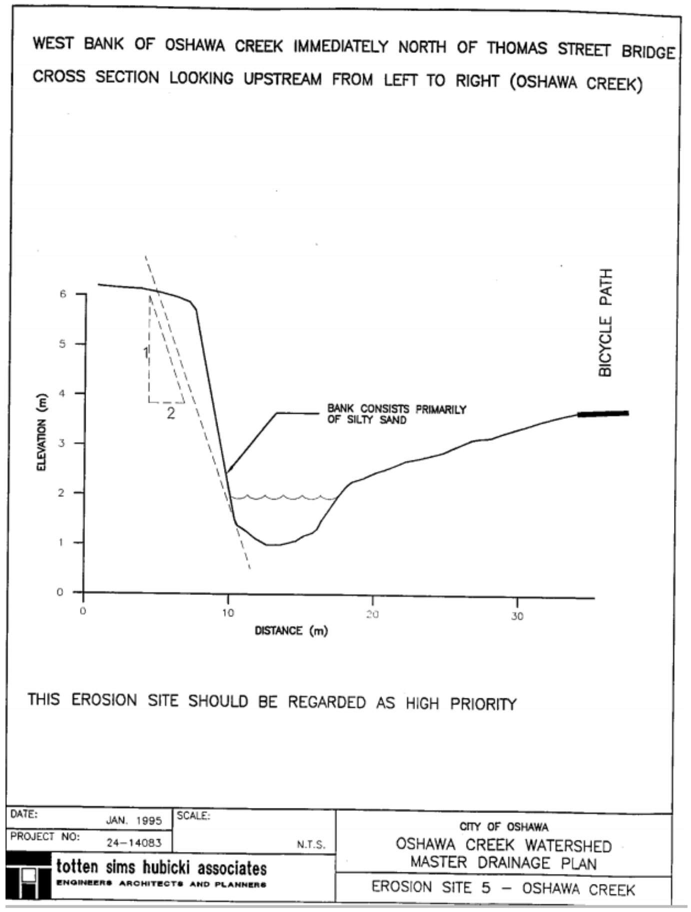

Figure 9. Upstream view of cross-section used by Totten Sims Hubicki Associates to identify the erosion hazard at Site 6 in 1995.

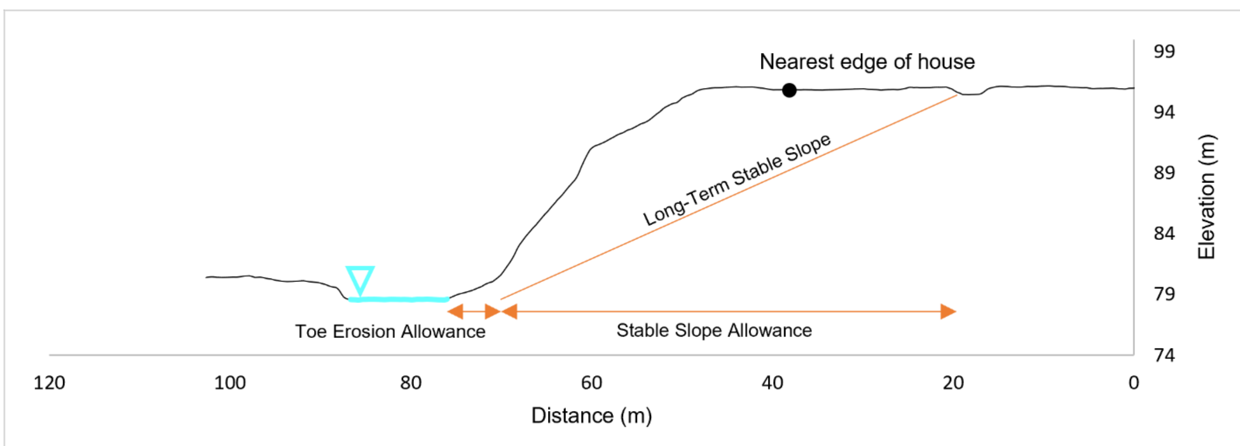

Figure 10. Downstream view of LiDAR-derived cross-section of west side of valley at Site 6, showing the toe erosion allowance (6 m) and the stable slope allowance (51 m) projected into tableland with private residences.

Photo 10. ***Riprap bank revetment at Site 8 that protects the Bike Path and left abutment of the Thomas Street bridge. Upstream view.***

Photo 11. ***Upstream view of channel approaching Site 6. A low, gentle eastern bank maintains good floodplain connectivity and helps attenuate flood energy. Upstream view.***

4.4 Implications for Watercourse Management

A synthesis of the reach- to site-scale findings from this study reveals that Oshawa Creek, between Wentworth Street and Thomas Street, is still responding geomorphologically to localized channel and floodplain modifications, and watershed urbanization. Although channel bank erosion is active and locally severe, resulting in systematic planform adjustment, relatively few elements are at immediate risk from erosion along the study corridor. The City's management of the watercourse, now and in the future, should give consideration to the distinct ways in which instability is manifested along this section of Oshawa Creek:

- **Downstream Energy Transfer** – Although there are relatively few erosion control structures along the study corridor, boulder toe protection is located in the vicinity of each bridge crossing (Wentworth Street, Bike Path, and Thomas Street). The contact of the creek with hard, smooth, erosion-resistant boundary materials (i.e., dense till) comprising high valley walls at Sites 3 and 6 transfers erosive energy downstream. This has extended bank erosion downstream toward major infrastructure. At Site 3, for example, energy transfer has exacerbated erosion immediately upstream of boulder toe protection and increased its risk of being outflanked and failing to protect the pedestrian bridge immediately downstream. Downstream energy transfer from the pinch-point between the abutments of the pedestrian bridge, which locally accelerate high flows, also appears partly responsible for paired bank erosion at Site 4. The design and construction of new erosion control structures should incorporate roughness elements to reduce the amount, and impacts, of energy transfer.
- **Lateral Adjustments** - Lateral adjustments dominate the geomorphological response of Oshawa Creek to watershed urbanization and local anthropogenic influences. Such adjustments are driven by a propensity for channel aggradation (e.g., including formation and growth of large bars) and erosion of low, erodible (alluvial) banks. Such lateral and planimetric form adjustments reflect the natural response of the watercourse to an urbanized hydrologic regime and should be allowed to continue, unimpeded, where they do not pose any risks to property or infrastructure. Mitigative efforts to reduce the risk of erosion along the base of valley walls should only be contemplated on a site-specific basis (as opposed to considering reach-scale modification) and only where risks from continued erosion are unacceptable. The City should strive to anticipate and accommodate planform adjustments when constructing new valley bottom/edge infrastructure (e.g., trails, bridges, sanitary infrastructure, etc.) to better manage long-term erosion risk. Patterns of meander migration along this study corridor are fortunately systematic and relatively predictable. Despite dynamic planform adjustment of Oshawa Creek along the study corridor, bank erosion has recruited relatively little large woody debris into the channel. Fallen trees are likely rafted downstream, relatively unimpeded, given the wide channel relatively free of obstructions, as opposed to becoming lodged against a bank and forming a debris jam. The absence of large accumulations of woody debris limits the potential for major avulsions and/or anomalous channel "blow-outs".

The City should review and consider each complaint it receives about erosion-related issues in the context of the management considerations discussed above. A generic response or action should never be taken when managing natural or urban channel systems because of how readily one alteration can lead to unexpected consequences. Consideration should be given to the reach-scale context of the contemplated change, and the potential for unfavourable site-specific impacts downstream (or upstream). Channel bed and/or bank stabilization measures should generally be as ‘soft’ as site-specific conditions and risks will allow. At least some degree of ‘bioengineering’ can usually be incorporated, such as strategic live stakes or plantings within stone, or in-stream habitat features constructed with stone. Approaches that rely entirely on log structures or live vegetation typically have shorter effective lifespans and are appropriate for protection of unused portions of private property (low risk) but are unlikely to satisfactorily mitigate risks to infrastructure (high risk).

5. Evaluation of Alternative Concepts for Erosion Mitigation at Prioritized Sites

As mentioned in Section 4.3, three sites were prioritized for follow-up assessment to support the identification and evaluation of alternative strategies for erosion mitigation. These three sites were prioritized on the basis of potentially posing risks to City property, private property, and/or infrastructure. Based on the results of the geomorphological assessment (Section 4), the ‘do nothing’ alternative assumes continued erosion with no effort to mitigate risk to infrastructure. Standardized, half-page summary characterizations of all eight inventoried sites (including the five sites that were not analyzed in detail) were prepared to provide the City with a convenient snapshot of current conditions and a reference for contemplating mitigative strategies (**Appendix B**).

Schematic illustrations of each alternative for the three prioritized sites are presented in **Appendix C**. Text overviews are provided in the following sub-sections. A basic evaluation of each alternative, based on consideration of local hydraulic implications, anticipated geomorphological adjustments (and related risks to people, property, and/or infrastructure), local aquatic and terrestrial ecology, permitting requirements[1], and approximate capital and maintenance costs, is provided in **Table 5** (Site 3), **Table 6** (Site 4), and **Table 7** (Site 6/8). The preferred alternative for each site has its score bolded in its respective table.

5.1 Sites 3 and 4

Two conceptual alternatives are evaluated, in comparison to the ‘do nothing’ alternative, to mitigate three main risks at Sites 3 and 4:

- Private property on Thomas Street (124 and 124A Thomas Street) at the crest of the eastern valley wall
- A municipal pedestrian bridge with a left (southeast) abutment vulnerable to outflanking or undermining,
- A buried sanitary sewer crossing owned by the Region (Site 4).

Conceptual design sketches are provided in **Appendix C**.

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[1] *Key environmental approvals/permits include: CLOCA permit for development, interference with wetlands and alterations to shorelines and watercourses; DFO Request for Review (RfR); and MNRF fish collection permit. Species at Risk (SAR) screening has been transferred from MNRF to Ministry of the Environment, Conservation and Parks.*

5.1.1 Site 3

5.1.1.1 Do Nothing

This alternative represents the ‘do nothing’ strategy without any intervention, whereby fluvial processes have the potential to exacerbate existing valley wall instability and increase risk to the property at 124 and 124A Thomas Street (**Table 6**). The position and general character of the valley wall has remained largely unchanged over the historical record (1927 to 2020), despite dynamic planform adjustment over the same period. Channel straightening following Wentworth Street construction has resulted in erosive energy concentrated along the toe of the valley wall at an abrupt meander bend. The toe is near-vertical, which could lead to mass movement. Downstream transfer of energy has resulted in initial outflanking of a boulder revetment that protects the abutment of a pedestrian bridge, increasing risk to public safety in addition to the bridge infrastructure itself. For the sake of the evaluation of alternatives, it is assumed that emergency works may be required to mitigate risk, with little consideration given to ecological impacts or future, evolving risks. As such, repeated emergency works and associated disturbance may be warranted over time.

5.1.1.2 Concept 1 – Slight Channel Realignment and Boulder Toe Protection

Concept 1 involves a slight realignment of Oshawa Creek to increase the radius of curvature of the meander and draw erosive energy away from the eastern valley wall. The realignment would also better align the channel with the existing pedestrian bridge. The existing bridge span would be maintained as it is appropriate; it is just misaligned with existing planform geometry. A cut-and-fill balance would be maintained through a compensatory inner-bank cut to offset the projection of a vegetated boulder revetment embedded with large wood along the outer (left) bank. The vegetated boulder revetment should rise to at least the 2-year flow level. The revetment would be keyed in slightly below the bed elevation of the existing scour pool to accommodate anticipated scour and inhibit undermining. The downstream limit of the realignment would tie in with the existing boulder toe protection to mitigate outflanking of the left bridge abutment.

5.1.1.3 Concept 2 – Vegetated Boulder Toe Protection to Mitigate Outflanking of Pedestrian Bridge

Concept 2 involves the construction of a vegetated boulder revetment along the toe of the actively eroding eastern valley wall. Embedded large wood would enhance local aquatic habitat, in addition to increasing bank roughness to help dissipate the downstream transfer of energy that has contributed the outflanking of existing boulder bank protection. Boulders would be keyed well into the bank, slightly beyond the upstream and downstream limits of scour, in order to mitigate outflanking. The top of the boulder revetment would be approximately coincident with the water surface elevation of the 2-year flow. Furthermore, a compensatory cut of the inner-bank point bar would be made to increase hydraulic cross-sectional area and distribute shear stresses more broadly across the channel.

Table 6. Erosion Mitigation Concept Evaluation – Site 3.

Objective	Criteria	Comment	Do Nothing	**Concept 1** (Slight Channel Realignment and Boulder Toe Protection)	**Concept 2** (Vegetated Boulder Toe Protection to Mitigate Outflanking of Pedestrian Bridge)	Notes
Physical and Natural Environment	Flooding	Impact on surface drainage, flooding; meet legislated criteria for flooding and water	3	3	3	Concept 1 would slightly alter planform geometry, but maintenance or increase of bankfull width would avoid any adverse impacts on flood storage/conveyance. Concept 3 would have no impact on flood levels.
	Erosion	Impacts on soils, geology, rate of erosion	1	5	5	Concepts 1 and 2 address existing erosion and will not impact erosional processes downstream.
	Terrestrial Habitat	Impact on connectivity, diversity and sustainability	3	4	4	Concepts 1 and 2 would result in localized short-term impacts to riparian vegetation. Good site access (Bike Path) and only herbaceous vegetation are at risk of disturbance from tracked equipment. Herbaceous vegetation is expected to re-establish quickly following works.
	Aquatic Habitat	Impact on connectivity, spawning and sustainability	3	4	4	In-channel works are required for Concepts 1 and 2, which would locally alter fish habitat.
Social/Cultural Environment	Aesthetic Value	Impact on existing and proposed development aesthetic value	1	5	4	Construction of vegetated boulder revetment, especially with embedded wood (Concepts 1 and 2), would improve the aesthetic of the erosion mitigation structure. Concept 1 would establish a vegetated bench, partly blocking erosion scar along the valley wall and improving aesthetic from the Bike Path.
	Benefit to Community	Access to trails, enjoyment of valley	2	3	3	Conservatively assumes construction activities for Concepts 1 and 2 would disrupt nearby park users and necessitate temporary closure of the Bike Path.
	Archaeological Features	Impacts on existing archaeological features	n/a	n/a	n/a	n/a
Environmental Approvals and Permitting	Regulatory Agency Acceptance	Satisfy CLOCA, DFO and MECP mandates	3	3	3	Do Nothing alternative can lead to agency involvement if emergency works are required. Concept 1 and 2 would require in-channel works, which would trigger a need for DFO and CLOCA review.
Financial Criteria	Capital Costs	Rough Order Magnitude (ROM) costs for implementation of the proposed concept (including engineering & environmental, mobilization & demobilization (access), earthworks, channel works)	1	3 ($518,000)	5 ($350,000)	Do Nothing would not address erosion risk and may result in costly emergency works and/or infrastructure repair. Concept 1 would require more cut/fill to accommodate slight channel alignment. Concept 2 protects the bridge and valley wall with reduced cut/fill but using a similar length of boulder revetment.
	Maintenance Costs	ROM costs to maintain the proposed structure, considering regular or periodic structural/vegetation maintenance expectations	1	5	4	Do Nothing may necessitate emergency works and/or increased maintenance frequency if not robustly designed or implemented; Concept 1 and 2 would minimize maintenance requirements. Sloughing material from the valley wall may lead to additional maintenance costs for Concept 2.
Constructability	Complexity of Treatment	Requirement for specialized services to design or install unique or proprietary specifications that must be completed by a certified contractor/consultant	4	3	3	Do Nothing alternative may require emergency works, which could be completed by non-specialists in channel works; Concepts 1 and 2 would require implementation by those experienced in natural channel works.
Risks	Potential Risks to Existing Infrastructure	Protection or potential exposure of infrastructure (fence, wall, building, etc.)	1	5	4	Both Concepts 1 and 2 alleviate long-term erosion risks for private property and the pedestrian bridge. Additionally, Concept 1 improves the approach angle of the channel toward the bridge.
	Potential Risks to Public	Impact on public safety and requirement for safety features (e.g., safety fences)	1	5	5	Concepts 1 and 2 will address erosion concerns in close proximity to the Bike Path bridge, thereby improving public safety.
	Potential Risks to Private Property	Potential for loss of private property due to bank recession	1	4	4	The property at 124 and 124A Thomas Street appears to be within the stable slope allowance (MNR, 2002), highlighting the long-term risk from continued erosion. Boulder toe protection (Concepts 1 and 2) will provide long-term toe protection and improve valley wall stability even without active slope stabilization measures.
Total Score:			**23**	**52**	**51**	
Combined Rank:			3	1	2	Concept 1 is the preferred alternative. The City should first consider a targeted geotechnical investigation to inform the urgency of erosion mitigation and the need for actual slope stabilization measures.

Note:
For each alternative concept, the criteria are evaluated such that higher scores are related to varying degrees of positive effect that an alternative, for the defined criteria, would have on the outcome. In general, the following scoring has been used: 1 = unfavourable, 2 = less favourable 3 = acceptable, 4 = more favourable and 5 = favourable, such that the sum of criteria can be scored for each alternative, with the highest score deemed to be preferred.

5.1.2 Site 4

5.1.2.1 Do Nothing

Without intervention, a 20-m long segment of sanitary sewer is a risk from continued erosion along the bed and banks of Oshawa Creek. As-built drawings indicate the sewer is not encased in concrete. Depth of cover over the sewer has decreased by only about 0.1 m since its installation in 1953, although the upper tens of centimetres of the bed are formed by a gravelly (erodible) medial bar. Headcutting of the downstream scour pool, or entrainment and migration of the capping medial bar, could expose and eventually damage the sewer. For the sake of the evaluation of alternatives, it is assumed that emergency works may be required to mitigate risk, with little consideration given to ecological impacts or future, evolving risks. As such, repeated emergency works and associated disturbance may be warranted over time.

5.1.2.2 Concept 1 – Riffle Grade Control with Armourstone Ribs

This reinforced riffle alternative is designed to inhibit bed degradation (down-cutting) over the buried sanitary sewer, which is at a heightened risk of damage without concrete encasement (**Table 7**). Armourstone ribs, flush with proposed riffle stone, would bracket the sanitary pipe for added reinforcement and bed stability. The most upstream armourstone rib would be positioned at the crest of the proposed riffle to prevent displacement of bed material and natural downstream migration of the riffle. The downstream armourstone rib would function to mitigate headcutting of the deep pool immediately downstream. A well graded gravel, cobble and boulder mixture would be applied to the bed to form a naturalized riffle and ‘hide’ armourstones. Boulder keystones would be strategically incorporated along the riffle to improve stability and provide refuge for fish. The riffle stone mixture would be extended up the bank to inhibit outflanking of the riffle and scour over a different section of sanitary sewer. Live stakes would be integrated midway up the bank to increase roughness and establish overhanging riparian cover.

5.1.2.3 Concept 2 – Riffle Grade Control Structures and Wood Debris Bank Protection

This bed stabilization alternative involves enhancing three existing morphological units (riffle-pool-riffle). The upstream riffle (Riffle 1) would be constructed over the buried sanitary sewer to maintain and/or increase the depth of cover. A second riffle would be constructed approximately 40 m downstream of Riffle 1. The second (downstream) riffle would add redundancy for bed stabilization by reducing the potential for headcutting. Riffles would consist of a well graded gravel, cobble, and boulder mixture. Boulders would be scattered across the riffles to improve stability and provide refuge for fish. Large wood would be embedded along the outer bank of the sharp meander downstream of the sewer crossing to inhibit systematic migration and outflanking of the downstream (redundancy) riffle. The wood, with sharpened ends, would be pressed into the bank using an excavator bucket to avoid unnecessary excavation. Embedded wood would project from the bank with an acute upstream angle to help draw flow away from the bank and beneficially trap additional woody debris rafted downstream.

5.1.3 Site 3/4 Coordination of Implementation

Palmer recommends the City coordinate the design and implementation of the preferred alternatives for Sites 3 and 4. Such coordination would avoid repeated disturbance to this short section of channel while also reducing costs through economies of scale and a single mobilization/demobilization of equipment.

Furthermore, protection of the downstream sewer crossing (Site 4) would wisely precede or be paired with armouring of the upstream outer bank of the meander, in case the embedment of large wood does not fully mitigate downstream energy transfer.

Table 7. Erosion Mitigation Concept Evaluation – Site 4

Objective	Criteria	Comment	(Do Nothing)	**Concept 1** (Riffle Grade Control with Armourstone Ribs)	**Concept 2** (Riffle Grade Control Structures and Wood Debris Bank Protection)	Notes
Physical and Natural Environment	Flooding	Impact on surface drainage, flooding; meet legislated criteria for flooding and water	3	3	3	In-stream works would maintain cross-sectional area and avoid raising the bed in association with installation of grade control, so there should be little to no effect on flood levels.
	Erosion	Impacts on soils, geology, rate of erosion	1	4	5	Concept 1 would inhibit bed degradation and bank erosion over the buried sanitary sewer. Concept 2 would additionally limit planform adjustment immediately downstream of the sanitary crossing.
	Terrestrial Habitat	Impact on connectivity, diversity and sustainability	3	5	4	Concept 1 would result in localized short-term impacts to riparian vegetation. Concept 2 would require additional tree removals associated with the downstream riffle and embedded wood.
	Aquatic Habitat	Impact on connectivity, spawning and sustainability	3	4	5	In-channel works are required for Concepts 1 and 2, which would result in an alteration of fish habitat. Concept 2 would introduce additional aquatic habitat.
Social/Cultural Environment	Aesthetic Value	Impact on existing and proposed development aesthetic value	3	4	5	Construction of boulder riffles, especially with embedded wood (Concept 2), would improve the aesthetic of the erosion mitigation structures.
	Benefit to Community	Access to trails, enjoyment of valley	3	3	3	Conservatively assumes construction activities for Concepts 1 and 2 would disrupt nearby park users and necessitate temporary closure of the Bike Path.
	Archaeological Features	Impacts on existing archaeological features	n/a	n/a	n/a	n/a
Environmental Approvals and Permitting	Regulatory Agency Acceptance	Satisfy CLOCA, DFO and MECP mandates	3	3	3	Do Nothing alternative can lead to agency involvement if emergency works are required. Concepts 1 and 2 would require in-channel works, which would trigger a need for DFO and CLOCA review.
Financial Criteria	Capital Costs	ROM costs for implementation of the proposed concept (including engineering & environmental, mobilization & demobilization (access), earthworks, channel works)	3	5 ($393,000)	3 ($670,000)	Do Nothing would not address erosion risk and may result in costly emergency works and/or infrastructure repair. Concept 1 would require more excavation associated with armourstone ribs installation. Concept 2 would require additional bank protection (embedded wood) and grade control.
	Maintenance Costs	ROM costs to maintain the proposed structure, considering regular or periodic structural/vegetation maintenance expectations	1	5	3	Do Nothing may necessitate emergency works and/or increased maintenance frequency if not robustly designed or implemented; Concepts 1 and 2 would minimize maintenance requirements.
Constructability	Complexity of Treatment	Requirement for specialized services to design or install unique or proprietary specifications that must be completed by a certified contractor/consultant	5	3	4	Emergency works could be completed by non-specialists in channel works; Concepts 1 and 2 would require implementation by those experienced in natural channel works. Additional excavation in association with armourstone ribs would increase complexity.
Risks	Potential Risks to Existing Infrastructure	Protection or potential exposure of infrastructure (fence, wall, building, etc.)	1	5	5	Concepts 1 and 2 address both lateral and vertical erosion risks over the sanitary sewer crossing. Both concepts offer long-term protection.
	Potential Risks to Public	Impact on public safety and requirement for safety features (e.g., safety fences)	1	3	3	Concepts 1 and 2 address erosion concerns in close proximity to the Bike Path bridge, thereby improving public safety.
	Potential Risks to Private Property	Potential for loss of private property due to bank recession	3	3	3	No private property is at risk
Total Score:			**33**	**50**	**49**	
Combined Rank:			3	1	2	Concept 1 is the preferred alternative

Note:
For each alternative concept, the criteria are evaluated such that higher scores are related to varying degrees of positive effect that an alternative, for the defined criteria, would have on the outcome. In general, the following scoring has been used: 1 = unfavourable, 2 = less favourable 3 = acceptable, 4 = more favourable and 5 = favourable, such that the sum of criteria can be scored for each alternative, with the highest score deemed to be preferred.

5.2 Site 6/8

Two conceptual alternatives are evaluated, in comparison to the 'do nothing' alternative, for both Sites 6 and 8. They aim to protect the edge-of-tableland property at 204 Thomas Street from instability driven by fluvial scour. Three properties along Valley Court (1125 to 1139) would also be protected from mitigative works. Planform adjustment and concentrated surface runoff have also begun to outflank, and winnow fine-grained sediments from, a deteriorated boulder revetment protecting the Bike Path and Thomas Street bridge (**Table 7**). Conceptual design sketches are provided in **Appendix C**.

5.2.1 Site 6/8

5.2.1.1 Do Nothing

This alternative represents the 'do nothing' strategy (**Table 8**). Without intervention, the property at 204 Thomas Street will remain at risk from a cycle of fluvial scour and mass movements along the base of the adjacent valley wall. The channel has been in contact with the valley for a period that predates the earliest available historical aerial photography (1927) and was already identified as a high-risk site by the City in 1995 (Totten Sims Hubicki Associates, 1995). The length of eroded valley wall has increased over this historical record as the meander broadens and extends its contact upstream. The expanding length of valley wall contact has the potential to impact properties along Valley Court if erosion mitigation is not implemented. For the sake of the evaluation of alternatives, it is assumed that emergency works may be required to mitigate risk, with little consideration given to ecological impacts or future, evolving risks. As such, repeated emergency works and associated disturbance may be warranted over time.

5.2.1.2 Concept 1 – Boulder-protected Slope Toe Bench and Surface Runoff Control

This conceptual alternative aims to eliminate fluvial/valley wall interaction with the construction and protection of a low floodplain bench projecting slightly into the channel from the toe of the valley wall. **Photo 12** provides an example of a similar boulder (riprap) protected slope-toe bench for illustrative purposes. Embedded large wood would be integrated into a protective revetment for additional roughness and aquatic habitat benefits. To accommodate 'fill' associated with the bench and vegetated boulder revetment, a compensatory cut of the inner bank would be required to maintain bankfull geometry and flood conveyance/storage. The top of the bench and boulder revetment would be approximately coincident with the water surface elevation of the 2-year flow. Boulders would be keyed well into the bank, slightly beyond the upstream limit of scour, in order to inhibit future outflanking. In addition,

Photo 12. Example of boulder-protected, slope-toe bench constructed along Wilket Creek, Toronto.

boulders would smoothly tie-in with existing boulder toe protection that defines the downstream limit of scour. A vegetated boulder revetment is proposed to replace an existing and deteriorated boulder revetment that extends approximately 20 m from the eastern footing of the Thomas Street bridge. Existing boulders would be reused in the new structure. Secondary erosion from concentrated surface runoff from the adjacent trailhead parking lot and paved Bike Path would be intercepted by a drainage gate that directs flow into a slope drain integrated within the proposed boulder revetment.

5.2.1.3 Concept 2 – Meander Mirroring

Concept 2 involves local realignment of the meander away from the western valley wall. Meander geometry and channel length would be maintained by mirroring the existing alignment. The existing channel would be backfilled with clean fill and compacted to prevent the reoccupation during overbank flood events. Realignment would start upstream of the valley wall contact to allow for a smooth transition into the new alignment and accommodate a straighter approach before the Thomas Street crossing. A vegetated boulder revetment with embedded large wood would be constructed along the new outer banks to help maintain the intended planform approaching the bridge. Secondary erosion from concentrated surface runoff from the adjacent trailhead parking lot and paved Bike Path would be intercepted by a drainage gate that directs flow into a slope drain integrated within the proposed boulder revetment.

Table 8. Erosion Mitigation Concept Evaluation Site 6/8

Objective	Criteria	Comment	(Do Nothing)	**Concept 1** (Boulder-protected Slope Toe Bench and Surface Runoff Control)	**Concept 2** (Channel Mirroring)	Notes
Physical and Natural Environment	Flooding	Impact on surface drainage, flooding; meet legislated criteria for flooding and water	3	3	4	In-stream works would maintain cross-sectional area, so there should be little to no effect on flood levels. Concept 2 may improve flood conveyance/storage.
	Erosion	Impacts on soils, geology, rate of erosion	1	4	5	Do Nothing would allow erosional processes to continue, increasing risk to private property and downstream infrastructure. Concepts 1 and 2 would address existing erosion and would not impact erosional processes downstream. Concept 2 would eliminate fluvial/valley wall interaction.
	Terrestrial Habitat	Impact on connectivity, diversity and sustainability	3	4	3	Concept 1 would require removal of riparian vegetation through compensatory inner-bank cut. Concept 2 would have substantial short-term impacts following the removal of mature riparian trees. Riparian vegetation, including trees, would be planted following construction to restore the area disturbed for floodplain cut. Extensive removal of existing vegetation allows for the removal of non-native species.
	Aquatic Habitat	Impact on connectivity, spawning and sustainability	3	4	5	Both concepts involve stone placement along the outer bank(s), although integrated plantings and embedded wood would help offset the armouring effects. Concept 2 offers the opportunity to increase fish habitat in the form of a new riffle and run.
Social/Cultural Environment	Aesthetic Value	Impact on existing and proposed development aesthetic value	1	4	5	Construction of a vegetated boulder revetment, especially with embedded wood (Concepts 1 and 2), would improve the aesthetic of the erosion mitigation structure.
	Benefit to Community	Access to trails, enjoyment of valley	3	2	2	Temporary closure of the trailhead parking lot and Bike Path may be required to accommodate construction activities.
	Archaeological Features	Impacts on existing archaeological features	n/a	n/a	n/a	n/a
Environmental Approvals and Permitting	Regulatory Agency Acceptance	Satisfy CLOCA, DFO and MECP mandates	3	3	3	Do Nothing alternative can lead to agency involvement if emergency works are required. Concept 1 and 2 would require in-channel works, which would trigger a need for DFO and CLOCA review.
Financial Criteria	Capital Costs	ROM costs for implementation of the proposed concept (including engineering & environmental, mobilization & demobilization (access), earthworks, channel works)	2	5 ($740,000)	3 ($1,310,000)	Do Nothing would not address erosion risk and may result in emergency works and/or additional construction costs in the long-term (e.g., infrastructure repair). Concept 1 would require continuous armoring of the long erosion scar with vegetated boulder revetment. Concept 2 would necessitate significant cut/fill to maintain existing flood conveyance/storage as well as bank protection at new channel bends.
	Maintenance Costs	ROM costs to maintain the proposed structure, considering regular or periodic structural/vegetation maintenance expectations	1	4	5	Do Nothing may necessitate emergency works and/or increased maintenance frequency if not robustly designed or implemented; Concepts 1 and 2 would minimize maintenance requirements. Sloughing material from the valley wall may lead to additional maintenance costs for Concept 1.
Constructability	Complexity of Treatment	Requirement for specialized services to design or install unique or proprietary specifications that must be completed by a certified contractor/consultant	5	3	3	Emergency works could be completed by non-specialists in channel works; Concepts 1 and 2 would require implementation by those experienced in natural channel works
Risks	Potential Risks to Existing Infrastructure	Protection or potential exposure of infrastructure (fence, wall, building, etc.)	1	4	5	Do Nothing would not alleviate erosion risks to infrastructure, unless emergency works are implemented. Concepts 1 and 2 would mitigate existing erosion risk and future impacts to infrastructure (e.g., Thomas Street bridge).
	Potential Risks to Public	Impact on public safety and requirement for safety features (e.g., safety fences)	1	5	5	Concepts 1 and 2 would address erosion concerns in close proximity to the Bike Path and private properties, thereby improving public safety.
	Potential Risks to Private Property	Potential for loss of private property due to bank recession	1	4	5	Without intervention, the private property at 204 Thomas Street appears to be at risk from a continued cycle of fluvial scour and mass movements. Properties on Valley Ct may become at risk in the future as well. Concepts 1 and 2 would provide long-term toe protection and slow or stop further recession of the erosion scar up the valley wall. Concept 2 eliminates fluvial/valley wall interaction.
Total Score:			**28**	**49**	**45**	
Combined Rank:			3	1	2	Concept 1 is the preferred alternative. It is recommended that a targeted geotechnical investigation first be completed by the City in the immediate future. Results would inform the urgency for mitigation and determine if actual slope stabilization measures are additionally required.

Note:
For each alternative concept, the criteria are evaluated such that higher scores are related to varying degrees of positive effect that an alternative, for the defined criteria, would have on the outcome. In general, the following scoring has been used: 1 = unfavourable, 2 = less favourable 3 = acceptable, 4 = more favourable and 5 = favourable, such that the sum of criteria can be scored for each alternative, with the highest score deemed to be preferred.

6. Conclusion and Recommendations

A comprehensive inventory and evaluation have been completed of erosion hazard sites along Oshawa Creek between Wentworth Street and Thomas Street, in Oshawa, based on field reconnaissance, detailed investigations at prioritized sites, and desktop analyses. The channel is responding to a history of anthropogenic disturbance, including local channel modifications (e.g., Wentworth and Thomas Street crossings), erosion mitigation (e.g., boulder revetments) and watershed urbanization. Erosion along the study corridor is most pronounced along unprotected meanders where the channel is eroding into the channel banks and/or along the valley wall. The study corridor of Oshawa Creek is situated within a broad, well-defined valley. Dynamic planform adjustment along the valley highlights a combination of natural meander migration and channel morphology that is not fully adapted to the urbanized hydrologic regime. Multiple meander bends are locally confined by valley walls and a high fill terrace. The channel is well connected to its floodplain, as evidenced by low banks and overbank deposition. Three in-channel erosion control structures (riprap bank revetments) help mitigate risk at bridge crossings along the study corridor. All erosion control structures currently mitigate risk but are vulnerable to outflanking at their upstream ends.

A total of eight erosion hazard sites were identified and characterized. Of these, three sites were prioritized for more detailed follow-up investigation and the development of conceptual strategies to mitigate erosion-related risks to City property, private property, and/or infrastructure (i.e., Sites 3, 4 and 6). Site 8 was also included as part of the detailed assessment and mitigative concepts for Site 6 due to its close proximity.

Two of the three prioritized erosion hazard sites warrant immediate attention, based on apparent risks posed to the pedestrian bridge (Site 3) and private property at 204 Thomas Street, along Valley Court (1125 to 1139) and Thomas Street bridge (Site 6/8). At Sites 3 and 6, we recommend the City complete a geotechnical investigation to more precisely establish the extent and nature of risks to private properties at the edge of adjacent tableland.

Site 3 encompasses the outer bank of a meander and a pedestrian bridge immediately downstream of a historically straightened section of channel. The concentration of erosive energy at the meander apex has formed a near-vertical toe slope along the eastern valley wall, which could lead to future instability and pose a risk to private property at the edge of adjacent tableland. Bank erosion has also begun to outflank the boulder riprap revetment that protects the left abutment of the misaligned pedestrian bridge. The City should consider replacing the existing pedestrian bridge and updating its bi-annual municipal inspection report accordingly. Bridge span and siting will be re-examined at preliminary design stage. Proactive mitigation of further erosion is recommended to avoid risk to 124 and 124A Thomas Street and pedestrian bridge. Two concepts for erosion mitigation along the outer bank of the meander were developed. Concept 1 (Slight Channel Realignment and Boulder Toe Protection) is considered the preferred alternative for long-term risk mitigation based on the additional separation between the channel and valley wall and better approach through the bridge.

At Site 6, severe erosion along the outer bank of a slowly migrating meander is responsible for decades of undercutting and mass movements along the lower half of the western valley wall. Private property (204 Thomas Street) at the edge of adjacent tableland is located within the stable slope allowance and may be at risk from continued slope recession. At Site 8, the upstream extent of boulder revetment that protects the Bike Path and left abutment of the Thomas Street bridge exhibits precursory signs of failure due to channel planform adjustment and local concentration of surface runoff from the adjacent parking lot and Bike Path. Concept 1 (Boulder-protected Slope Toe Bench and Surface Runoff Control) is the preferred option based on the reduced area of disturbance, Rough Order of Magnitude (ROM) costs and elimination of fluvial/valley wall interaction.

Site 4 is situated so close to Site 3 that we recommend coordination of preferred concepts to include protection of the sanitary sewer crossing, even if risk to the sewer may not be imminent. Coordination of the design and implementation of the preferred alternative for Site 3 would reduce costs, streamline permitting and avoid the potential for repeated disturbance by a patchwork of mitigative solutions. Site 4 includes a 50 m-long section of Oshawa Creek beneath, and immediately downstream of, the pedestrian bridge, where a sanitary sewer crosses diagonally beneath the channel. Bifurcation of flow around a large medial bar has promoted bed and bank erosion along the two, smaller channels. The buried sanitary sewer is within the envelope of scour potential between the upstream and downstream pools and is potentially at risk of exposure and damage.

Any mitigative works must respect the constraints and sensitivities of lower Oshawa Creek as a migratory corridor for spring- and fall-spawning runs of trout and Pacific Salmon. Prior permits must be received at least from CLOCA, in association with Ont. Reg. 97/04, and from MNRF, in association with fish collection as part of the dewatering process for working ‘in the dry’. Depending on the nature of proposed works, DFO should review the project (Request for Review) to determine whether a *Fisheries Act* Authorization is required. Any works must not block fish passage, as fish are usually staging early in the lower parts of the creek. The City is reminded to apply for the permits well in advance of construction, which is likely to be limited to the warm water timing window (July 1 to March 31) along this section of Oshawa Creek (P Sisson, personal communication, Sept. 28, 2020). All efforts should be made to construct during the summer growing season, when establishment of riparian vegetation is most successful and water levels tend to be low.

Based on the results of the fluvial geomorphological study described herein, Palmer recommends the City consider the following reach-wide task:

- *Basic monitoring benchmarks* – Monitoring benchmarks should be established at least at each of the inventoried erosion hazard sites involving bank recession. Such benchmarks would facilitate tracking of bank recession as part of the City’s ongoing erosion inventory program. Effective tracking of bank recession could be achieved simply through repeat measurement of the separation between the crest of the erosion scar and the benchmark. A tape measure could be extended between the crest of the erosion scar and a benchmark, such as a marked, wooden stake driven into the ground (with a position referenced to a nail in the trunk of a nearby tree, as a back-up). Monitoring should ideally be completed semi-annually (after freshet and in the fall), or at least annually (after freshet), or following any extreme (>10-year) storm events.

7. Certification

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8. References

Central Lake Ontario Conservation Authority, 2002:
Oshawa Creek Watershed Aquatic Resource Management Plan. Final July 2002.

Central Lake Ontario Conservation Authority, 2007:
Central Lake Ontario Fisheries Management Plan – Encompassing the Watersheds of Lynde Creek, Oshawa Creek, Black/Harmony/Farewell Creeks and Bowmanville/Soper Creeks. Draft July 2007.

Central Lake Ontario Conservation Authority, 2013:
Central Lake Ontario Fisheries Management Plan – Encompassing the Watersheds of Lynde Creek, Oshawa Creek, Black/Harmony/Farewell Creeks and Bowmanville/Soper Creeks.

Central Lake Ontario Conservation Authority, 2013:
Oshawa Creek Watershed Plan. FINAL – February 2013.

Central Lake Ontario Conservation Authority, 2019:
Ecological Land Classification Open Data. Web GIS Service, accessed online Oct 29, 2019: http://open-data.cloca.com/datasets/10068b7ac6c048e2b6c945a1100de57a_13?geometry=-79.755%2C43.779%2C-77.924%2C44.125

Central Lake Ontario Conservation Authority, 2020:
Oshawa Creek 2020 Watershed Update. June 16, 2020.

Chapman, L.J. & D.F. Putnam, 1984:
The Physiography of Southern Ontario, Third Edition. Ontario Geological Survey.

Church, M, 2006:
Bed Material Transport and the Morphology of Alluvial River Channels. Annual Review of Earth and Planetary Science, 34, p. 325-54.

Galli, J., 1996:
Rapid stream assessment technique (RSAT) field methods. Metropolitan Washington Council of Governments, Washington, D.C.

Gurnell, A.M., Piégay, H., Swanson, F.J., & S.V. Gregory, 2002:
Large Wood and Fluvial Processes. Freshwater Biology, 47, 601-619.

Harrelson, C.C., C.L. Rawlins, & J.P. Potyondy, 1994:
Stream Channel Reference Sites: an Illustrated Guide to Field Technique. General Technical Report RM-245. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 61 p.

McKillop, R, 2016:
Limitations and misuse of the Rapid Geomorphic Assessment for preliminary characterization of channel stability. Presentation at Natural Channel Systems conference, Niagara Falls, ON, 26-27, 2016.

Montgomery and Buffington, 1997:
Channel-reach morphology in mountain drainage basins. GSA Bulletin; 109(5) p.596-611

Ontario Geological Survey (OGS), 2006:
Bedrock Topography and Overburden Thickness Mapping, Southern Ontario, Google Earth layer, accessed online Oct 29, 2019: https://www.mndm.gov.on.ca/en/mines-and-minerals/applications/ogsearth/bedrock-topography-and-overburden-thickness

Ontario Geological Survey (OGS), 2010a:
Quaternary Geology, Ontario, Google Earth layer, accessed online Oct 29, 2019: https://www.mndm.gov.on.ca/en/mines-and-minerals/applications/ogsearth/quaternary-geology

Ontario Geological Survey (OGS), 2010b:
Surficial Geology, Southern Ontario, Google Earth layer, accessed online Oct 29, 2019: https://www.mndm.gov.on.ca/en/mines-and-minerals/applications/ogsearth/surficial-geology

Ontario Ministry of Natural Resources Water Resources Section (MNR), 2002:
Technical Guide, River & Stream Systems: Erosion Hazard Limit. 134 p.

Ontario Ministry of the Environment, 2003:
Stormwater Management Planning and Design Manual: Appendix C.3 Rapid Geomorphic Assessment. 379 p.

Palmer, 2020:
Fluvial Geomorphological Assessment of Oshawa Creek and Evaluation of Erosion mitigation Strategies at Prioritized Sites. October 7, 2020.

Parish Geomorphic, 2004:
Belt Width Delineation Procedures. Prepared for Toronto and Region Conservation Authority, September 27, 2001 (Revised January 30, 2004).

Shields, A., 1936:
Anwendung der Ähnlichkeitsmechanik und der Turbulenzforschung auf die Geschiebebewegung. Mitteilung der preussischen Versuchsanstalt fur Wasserbau und Schiffbau, 26, Berlin.

Totten Sims Hubicki Associates, 1995:
Oshawa Creek Watershed Master Drainage Plan – Erosion Site 5, Oshawa Creek. January, 1995.

Wolman, M.G., 1954:
A method of sampling coarse river-bed material. Transactions of the American Geophysical Union, 35(6), p. 951-956.

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Appendix A

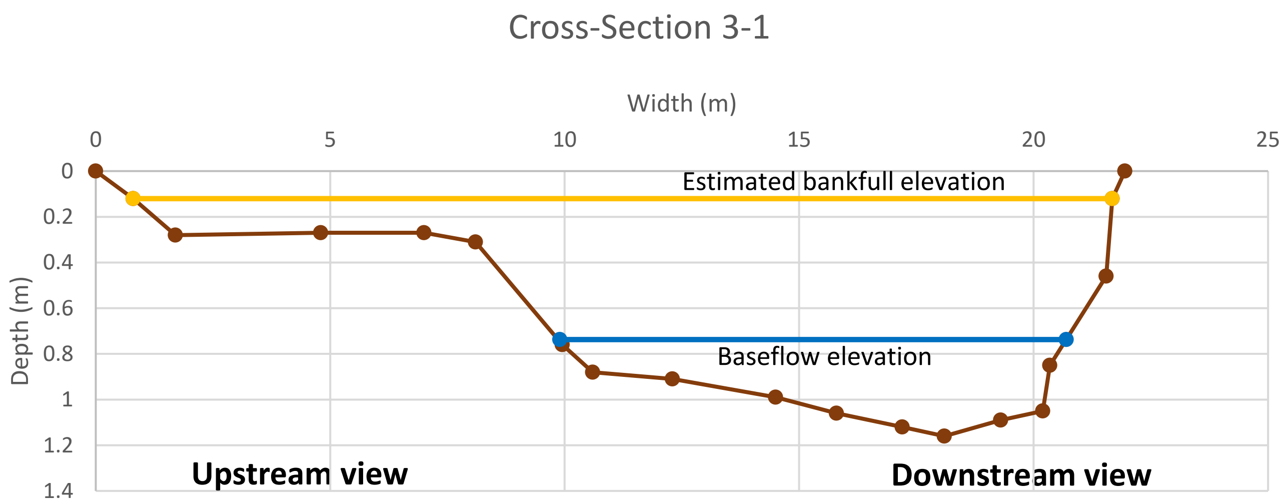
Channel Cross-Sections

Appendix A – Cross Sections

Oshawa Creek – Thomas to Wentworth

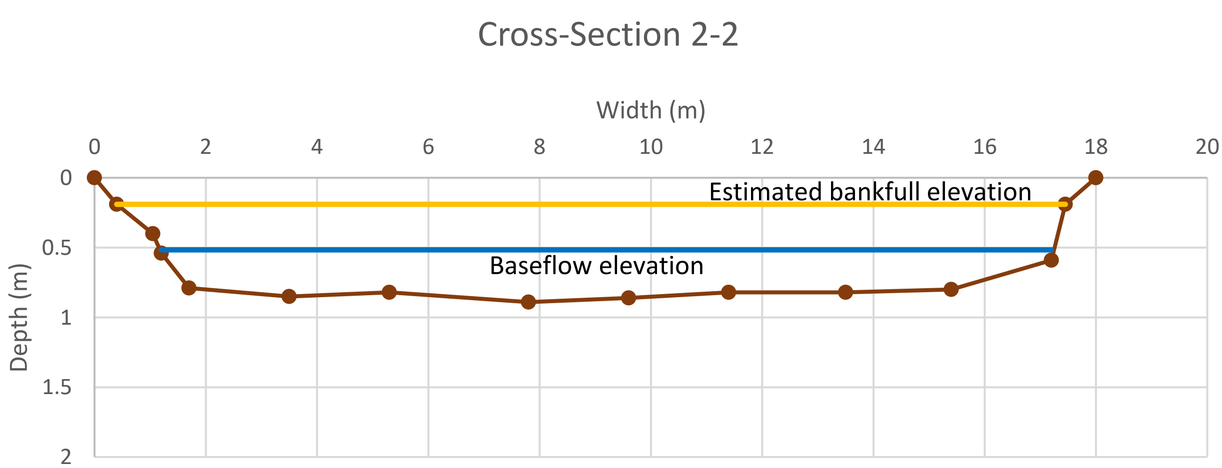
Note: Cross sections are viewed looking downstream, and are labelled from upstream to downstream.

Site 3



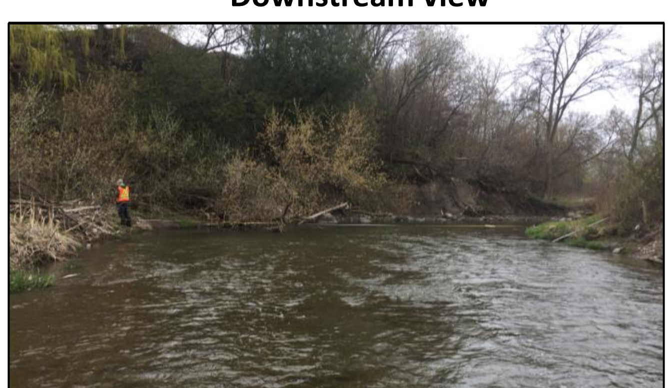
Upstream view

Downstream view

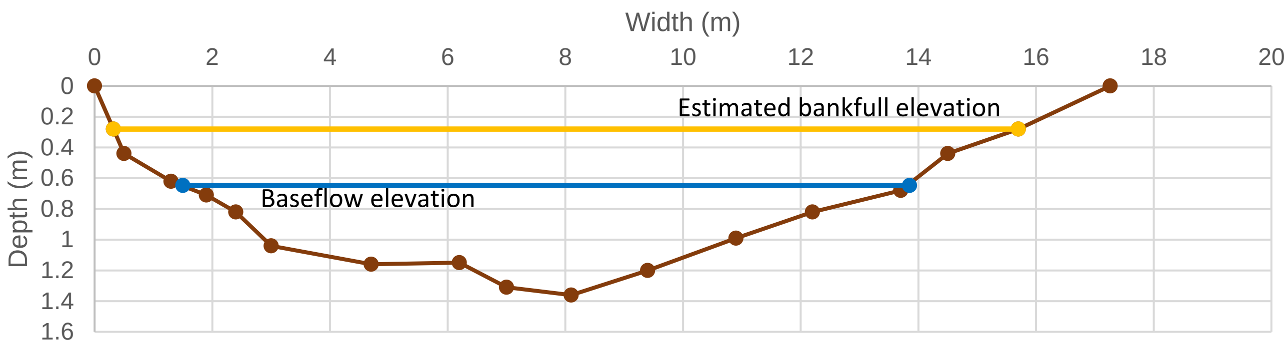


Upstream view

Downstream view



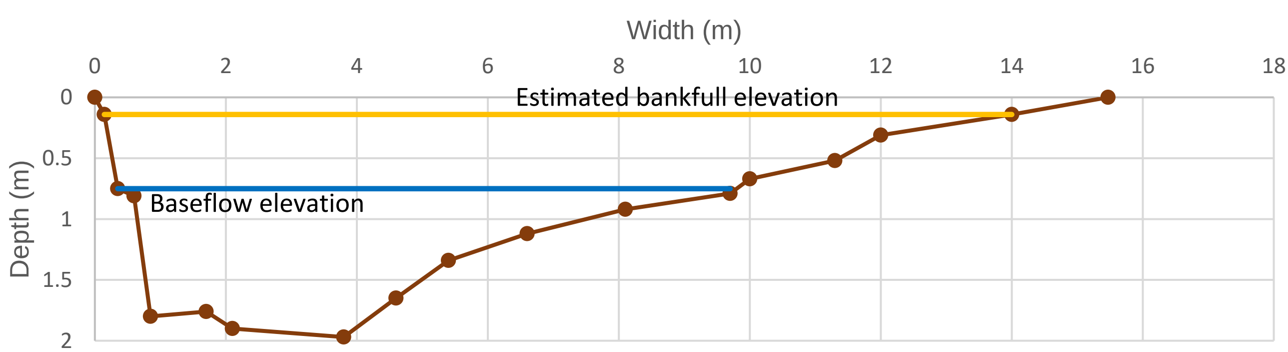
Cross-Section 3-3



Upstream view

Downstream view

Cross-Section 3-4

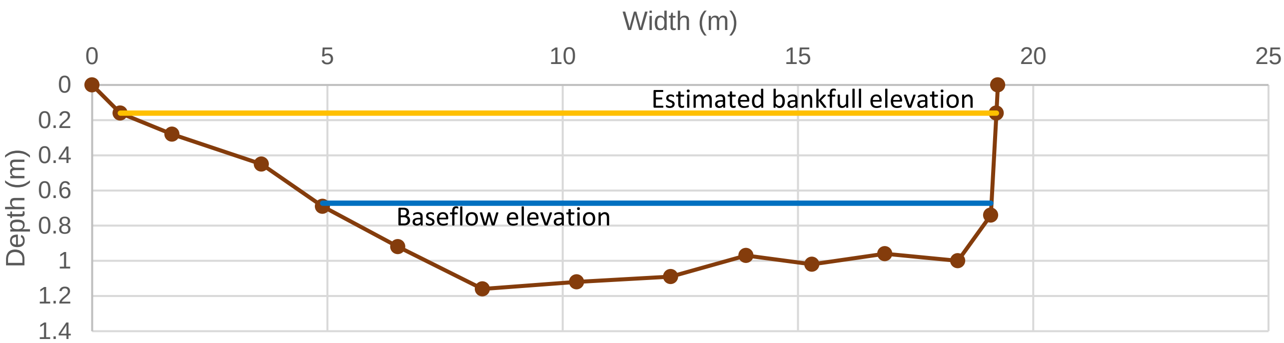


Upstream view

Downstream view

Site 4

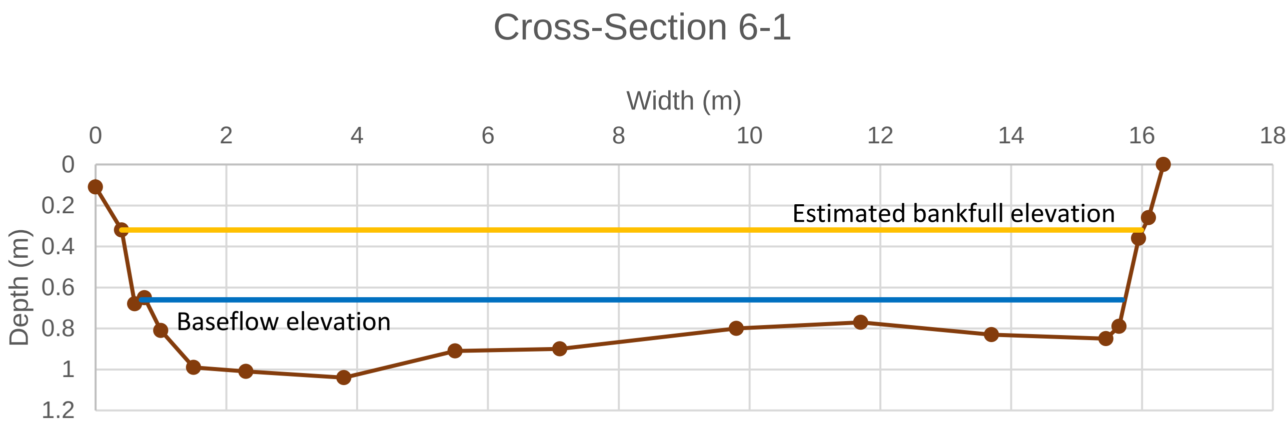
Cross-Section 4-1



Upstream view

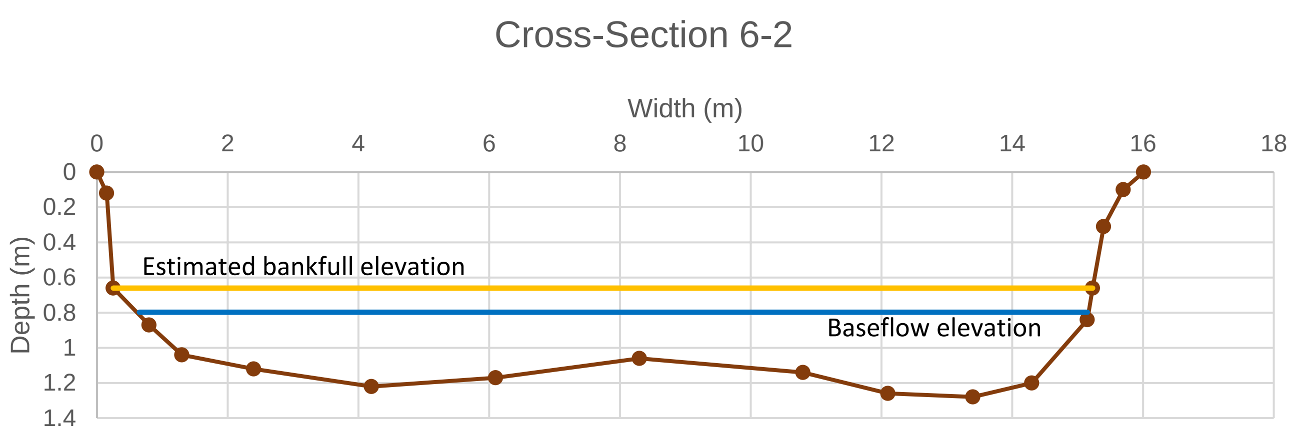
Downstream view

Site 6



Upstream view

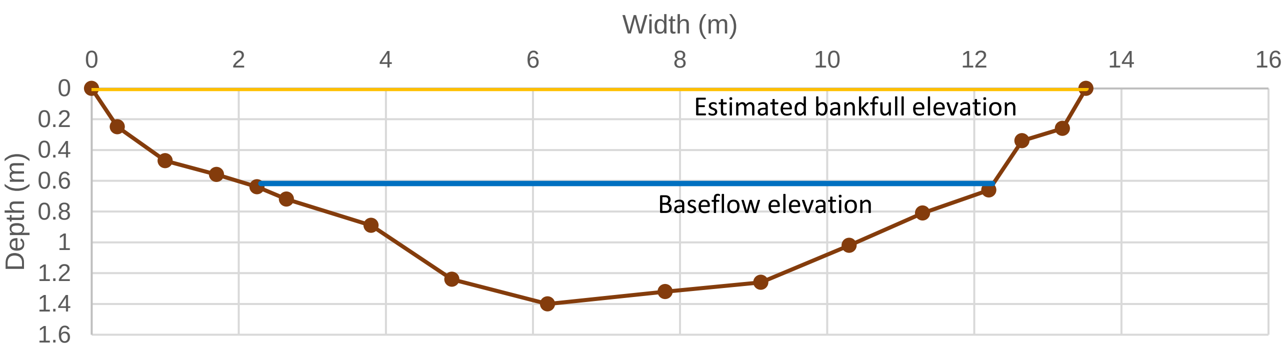
Downstream view



Upstream view

Downstream view

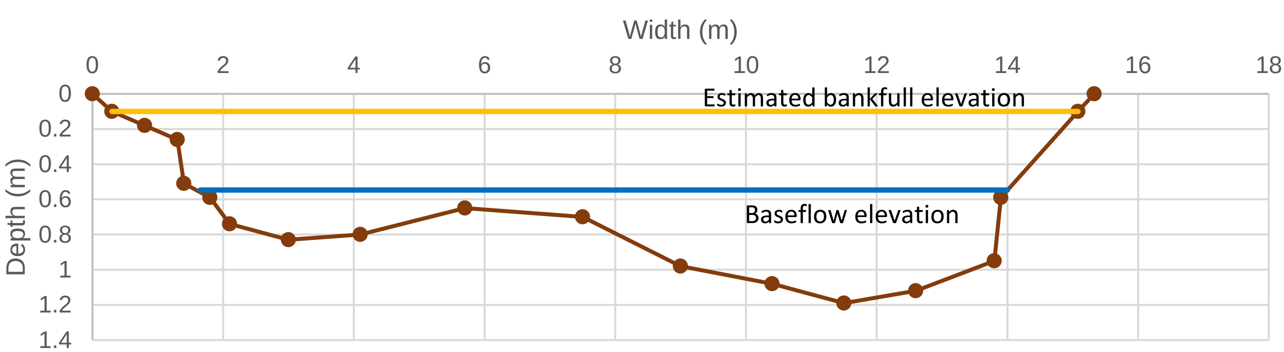
Cross-Section 6-3



Upstream view

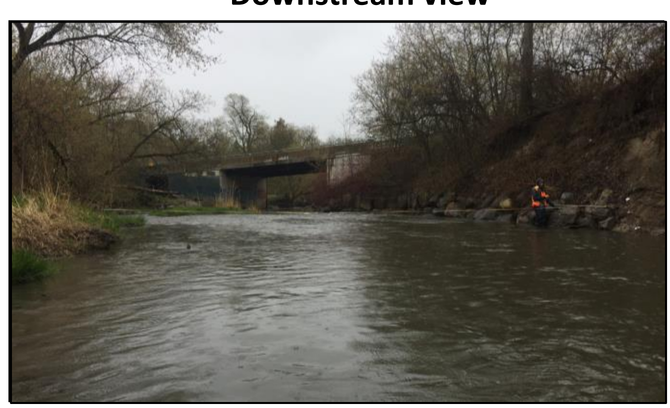
Downstream view

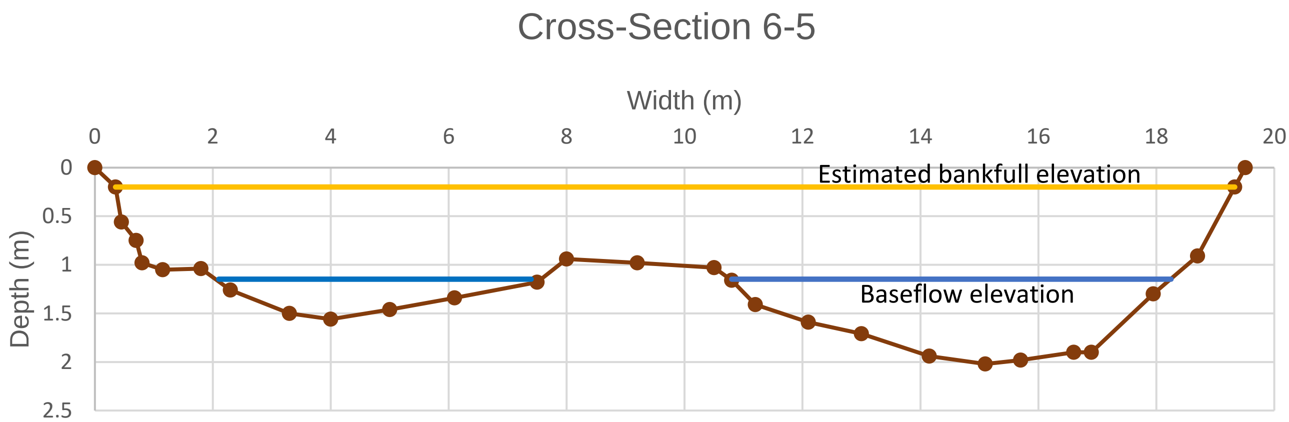
Cross-Section 6-4



Upstream view

Downstream view





Upstream view

Downstream view

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Appendix B

Standard Overviews of Erosion Hazard Sites

Description:
Erosion along right bank, beneath the elevated section of trail. Flood flows interact with the bridge abutment. Ongoing erosion could eventually cause footings of the pedestrian walkway to be undermined and outflanked. Downstream transfer of energy from smooth concrete bridge abutments may be exacerbating scour. Risk is low, so only ongoing monitoring is recommended. Flow: bottom to top.

	Feature at Risk:	Distance to Feature	Condition of Bank and/or Existing Erosion Protection:	Mechanism(s) of Failure:	Risk	Recommended Action(s):
Site 1	Elevated pedestrian walkway	0 m (contact)	Minor erosion at toe of bank	Undermining and outflanking	Low	Do nothing – continue to monitor.

Description:
Stormwater outfall located approximately 5 m from the creek has incised (down-cut) a small outflow channel into the floodplain. The outfall is not at risk from fluvial scour and is sufficiently setback from the watercourse. Grey-coloured, turbid water was discharging from the outfall during both field visits. Water quality may be a concern. Flow: top to bottom.

	Feature at Risk:	Distance to Feature	Condition of Bank and/or Existing Erosion Protection:	Mechanism(s) of Failure:	Risk	Recommended Action(s):
Site 2	Stormwater outfall	5 m	Minor erosion	Undermining	Low	Do nothing - monitor

Description:
Straightening of the previously sinuous channel has accelerated flow toward the outer bank of a meander in contact with the eastern valley wall. The upstream portion of the valley wall contact remains vegetated and exhibits no obvious signs of instability, but toe erosion along the downstream portion has forced the construction of a boulder bank revetment to protect a pedestrian bridge immediately downstream. A deep scour pool has formed along this outer bank/revetment. The bridge abutments are now at risk of being outflanked and/or undermined. Flow: top to bottom.

	Feature at Risk:	Distance to Feature	Condition of Bank and/or Existing Erosion Protection:	Mechanism(s) of Failure:	Risk	Recommended Action(s):
Site 3	Pedestrian bridge and private property on valley crest	0 m (contact)	Functional, but deteriorating	Outflanking and/or undermining	High	Design and construct protection for toe of valley wall and bridge

Description:
A sanitary sewer without concrete encasement diagonally crosses the channel at a depth of approximately 0.9 m. A prominent medial bar overtop of the sewer bifurcates flow and has promoted erosion of both banks as well as the beds of the split channels. Additionally, downstream migration of the medial bar could significantly reduce the thickness of cover over the sanitary sewer. Flow: bottom to top.

	Feature at Risk:	Distance to Feature	Condition of Bank and/or Existing Erosion Protection:	Mechanism(s) of Failure:	Risk	Recommended Action(s):
Site 4	Sanitary sewer	0.9 m (depth of cover)	Steep, eroded banks; no protection from continued bed scour	Bed scour and medial bar migration	Moderate	Protect sanitary sewer (based on assumed works to be completed at Site 3)

Description:
Erosion along the downstream portion of an outer meander bank has resulted in active down-valley migration roughly parallel to the adjacent Joseph Kolodzie Oshawa Creek Bike Path. Fill has been overlain on alluvium, which has eroded faster than the alluvial toe and created a flood bench. The flat-topped mound of fill has helped slow the rate of bank recession. Sufficient separation (10 m) exists between the eroded bank and trail to accommodate minor recession, although riparian plantings would restore some bank integrity. Flow: top to bottom.

	Feature at Risk:	Distance to Feature	Condition of Bank and/or Existing Erosion Protection:	Mechanism(s) of Failure:	Risk	Recommended Action(s):
Site 5	Joseph Kolodzie Oshawa Creek Bike Path	10 m	Eroded unprotected bank	Undermining	Low	Riparian plantings and continue to monitor

Description:
Erosion along the outer bank of a broad meander in contact with the valley wall has initiated and maintained slope instability. A point bar exhibiting a scroll pattern has developed along the inner bank, a testament to the history of lateral and down-valley migration of the meander apex. Private property is approximately coincident with the crest of the valley wall, which comprises till locally capped by glaciolacustrine sand. A dwelling and outbuilding is set 10 m back from the crest of the valley wall and is at risk if recession of the valley wall were to continue. Flow: top to bottom.

	Feature at Risk:	Distance to Feature	Condition of Bank and/or Existing Erosion Protection:	Mechanism(s) of Failure:	Risk	Recommended Action(s):
Site 6	Property at edge of adjacent tableland	10 m	Approximately 18 m high, 150 m long erosion scar along lower valley wall	Repeated fluvial scour and mass movements	High	Design and implement measures to protect valley wall from continued fluvial interaction

Description:
Boulder riprap and armourstone revetments installed along the right bank immediately upstream of the Thomas Street bridge protect the bridge footings. A medial bar locally concentrates flow along the right bank, which could eventually undermine or outflank the revetments and pose a risk to the bridge footings. Given the relative stability of the channel planform and the bank revetments in past years to decades, risk is currently considered low. Flow: right to left.

	Feature at Risk:	Distance to Feature	Condition of Bank and/or Existing Erosion Protection:	Mechanism(s) of Failure:	Risk	Recommended Action(s):
Site 7	Western bridge footing	0 m (contact)	Functional	Outflanking and/or undermining	Low	Do Nothing – continue to monitor

Description:
Boulder riprap revetments installed along the left bank immediately upstream of the Thomas Street bridge protect the bridge footings. A medial bar locally concentrates flow along the left bank, which could eventually undermine or outflank the revetment and pose a risk to the adjacent Joseph Kolodzie Oshawa Creek Bike Path and eastern bridge footing. Additionally, concentration of surface runoff from the parking lot northwest of the creek winnows fine material from behind the revetments and forms small collapse areas. Flow: top to bottom.

	Feature at Risk:	Distance to Feature	Condition of Bank and/or Existing Erosion Protection:	Mechanism(s) of Failure:	Risk	Recommended Action(s):
Site 8	Joseph Kolodzie Bike Path and bridge footing	0 m (contact)	Functional	Outflanking and/or undermining	Moderate	Design and implement measures to protect trail and bridge abutment (based on assumed works to be completed at Site 6)

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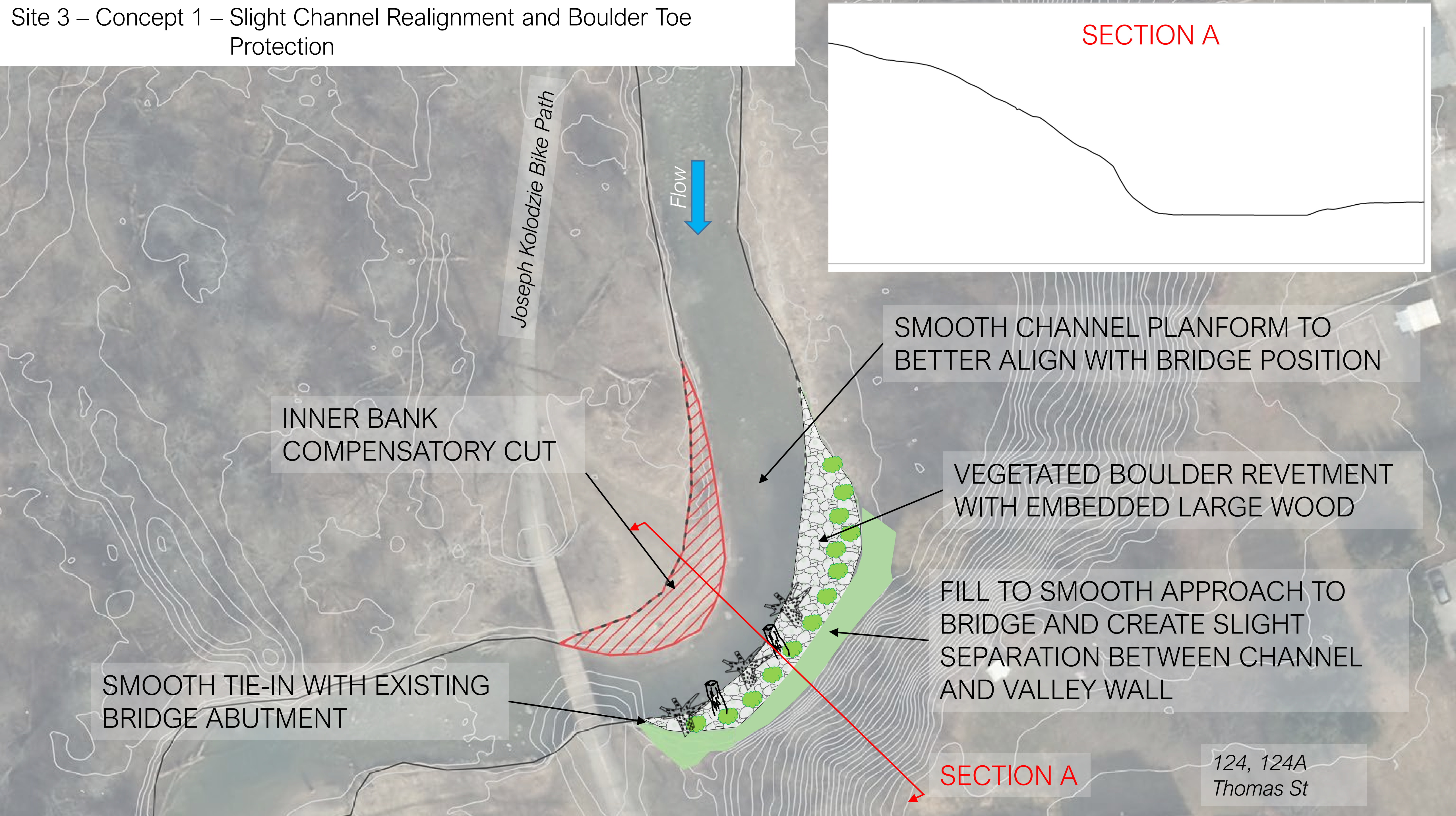
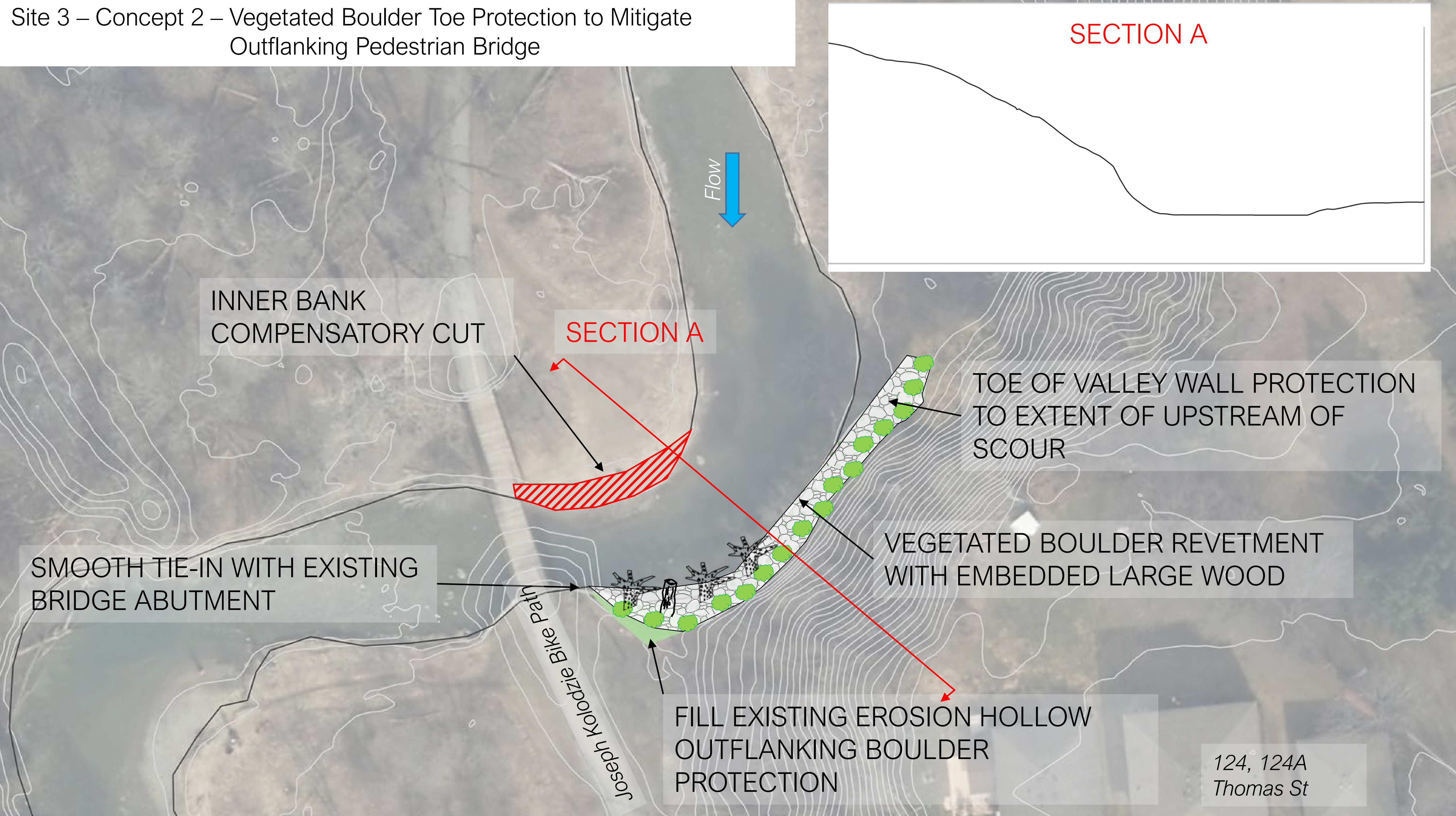
Appendix C

Erosion Mitigation Concepts for Prioritized Sites (Plan and Section)

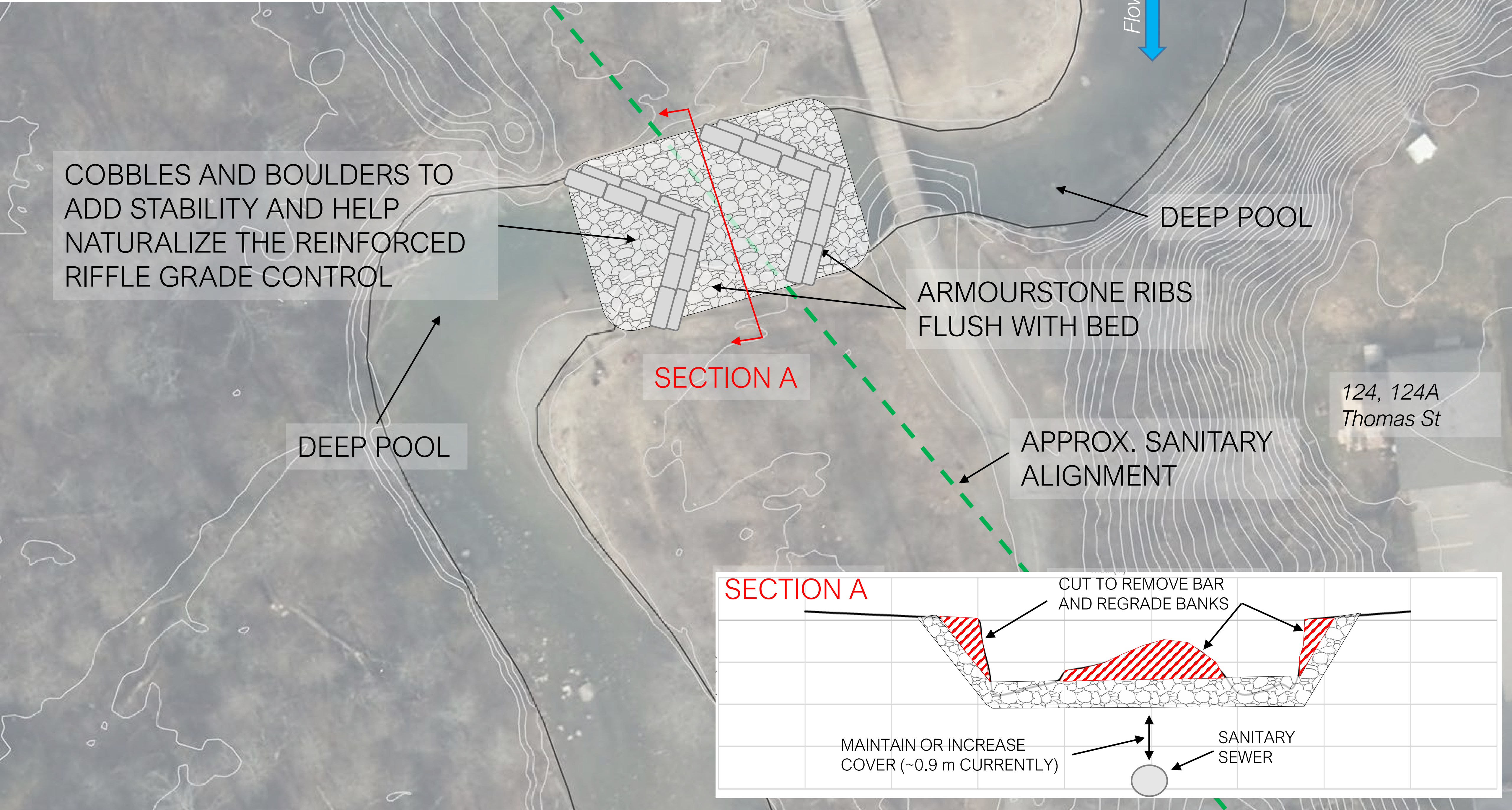
Site 3 – Concept 1 – Slight Channel Realignment and Boulder Toe Protection



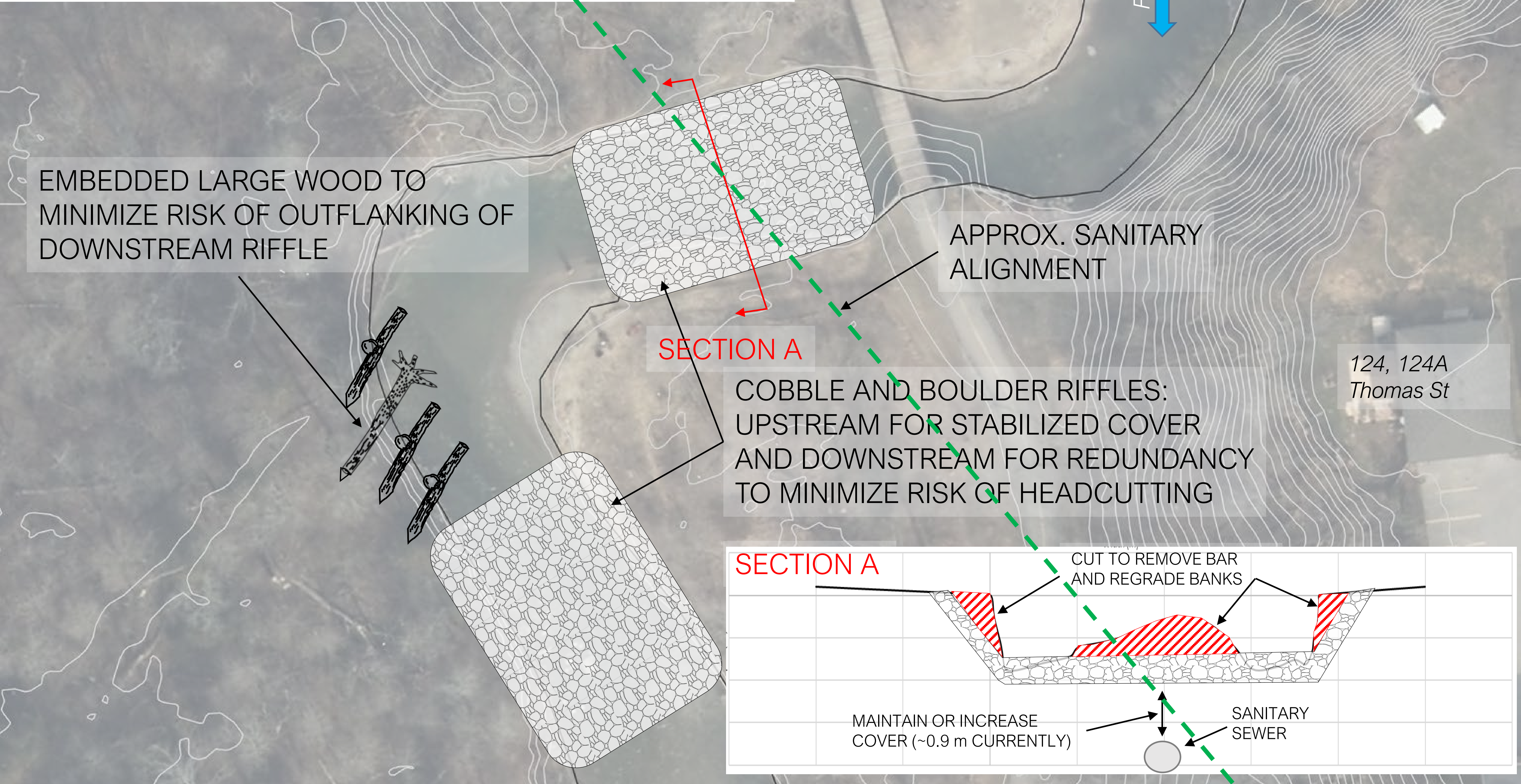
Site 3 – Concept 2 – Vegetated Boulder Toe Protection to Mitigate Outflanking Pedestrian Bridge



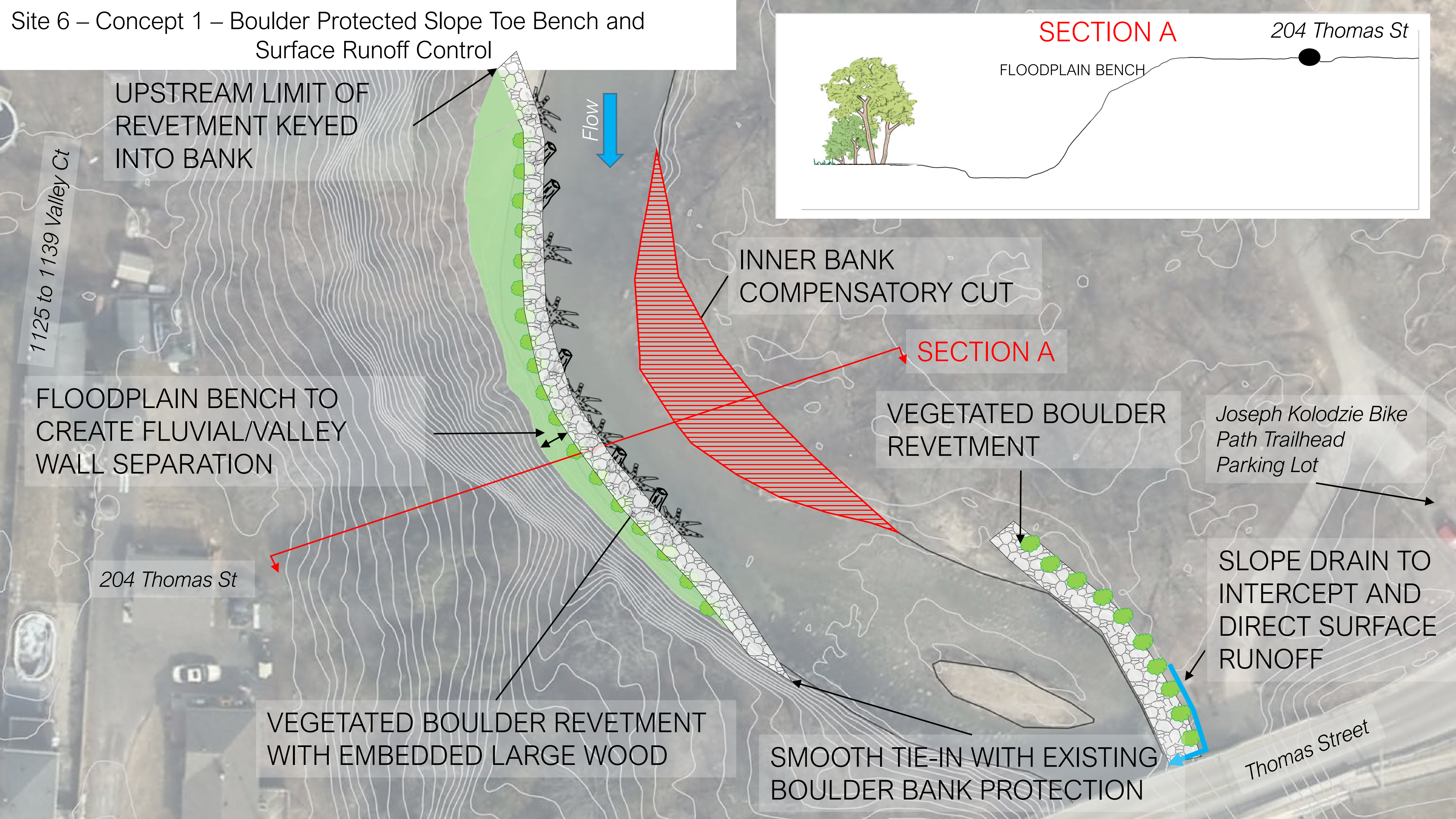
Site 4 – Concept 1 – Riffle Grade Control with Armourstone Ribs



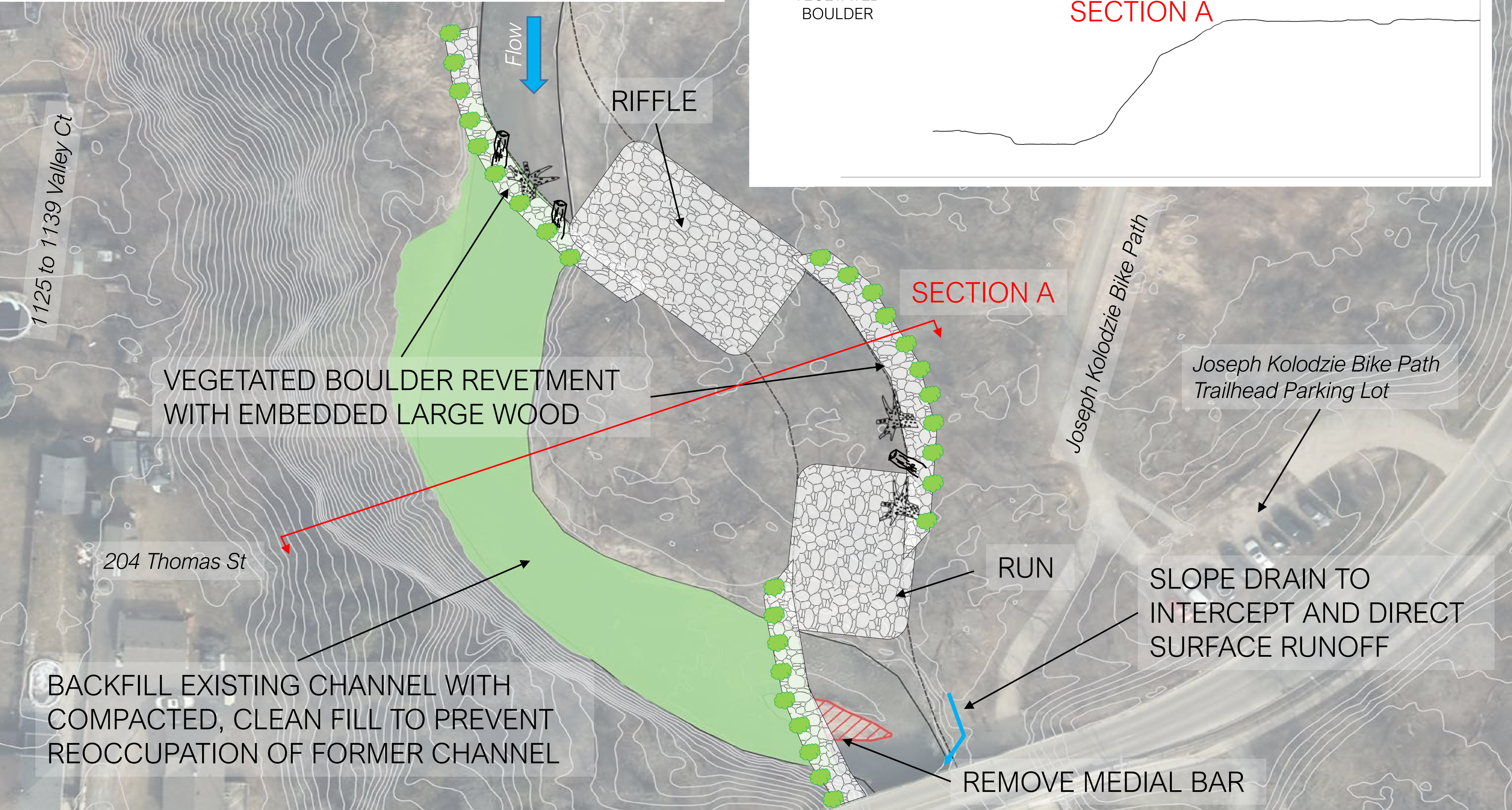
Site 4 – Concept 2 – Riffle Grade Control Structures and Wood Debris Bank Protection



Site 6 – Concept 1 – Boulder Protected Slope Toe Bench and Surface Runoff Control



Site 6 – Concept 2 – Meander Mirroring



Appendix D

Example Calculation of Critical Discharge

Example calculation of critical discharge

Below is an example of how critical discharge is calculated to determine incipient motion of a particle. We have used values based on Site 3, Cross-section 1, from the Oshawa Creek report. Please note that our results for average velocity and critical discharge may differ slightly from the values within the report, as our in-house spreadsheet allows for more refined calculation using discrete cross-sectional area panels and 1 cm flow intervals to determine critical depth.

1. What is the critical shear stress necessary to initiate motion of the median (D_{50}) grain size?

$$t_{cr} = kg(p_s - p)D_{50}$$
$$t_{cr} = (0.035)(9.81)(2650 - 1000)(0.055)$$
$$t_{cr} = 31.1\ N/m2$$

t_{cr} is the critical shear stress (N/m^2)
k is Shield's parameter (0.035 in this example)
g is the acceleration of gravity (9.81 m/s^2)
p_s is the density of sediment (~2,650 kg/m^3)
p is the density of water (~1,000 kg/m^3)
D_{50} is median grain size (m)

2. What is the actual (average) shear stress for a given flow depth (note that depth remains unknown)?

$$t_o = pgdS$$
$$t_o = (1000)(9.81)(d)(0.0044)$$
$$t_o = 43.1d$$

t_o is the average shear stress (N/m^2)
d is the flow depth (m)
S is the slope (m/m)

3. At what flow depth is the critical shear stress attained?

$$43.1d = 31.1\ N/m^2$$
$$d = 0.72\ m$$

4. What is the average velocity at this depth?

$$v = (1.49R^{\frac{2}{3}}S^{\frac{1}{2}})/n$$
$$v = (1.49(0.51)^{\frac{2}{3}}(0.0044)^{\frac{1}{2}})/n$$
$$v = 1.8\ m/s$$

v is the average velocity (m/s)
n is Manning's n (typically ~0.035 along this creek)

5. What is the (critical) discharge that corresponds to this average velocity?

$$Q = vA$$
$$Q = (1.8)(8.71)$$
$$Q = 15.7\ m^3/s$$

Q is the discharge (m^3/s)
A is the cross-sectional flow area (m^2)

Appendix E

Rapid Geomorphic Assessment and Rapid Stream Assessment Technique Results

Summary of Rapid Geomorphic Assessment (RGA) Classification

FORM / PROCESS	GEOMORPHIC INDICATOR		PRESENT? (√)		FACTOR VALUE
	Num	Description	No	Yes	
Evidence of Aggradation (AI)	1	Lobate Bar	#	#	
	2	Coarse materials in riffles embedded	#	#	
	3	Siltation in pools	#	#	
	4	Medial Bars	#	#	
	5	Accretion on point bars	#	#	
	6	Poor longitudinal sorting of bed materials	#	#	
	7	Deposition in the overbank zone	#	#	
		Sum of Indicies:	4	3	0.43
Evidence of Degradation (DI)	1	Exposed bridge footing(s)	#	#	
	2	Exposed sanitary / storm sewer / pipeline / etc.	#	#	NA
	3	Elevated storm sewer oufalls	#	#	NA
	4	Undermined gabion baskets / concrete aprons / etc.	#	#	NA
	5	Scour pools d/s of culverts / storm sewer outlets	#	#	NA
	6	Cut face on bar forms	#	#	
	7	Head cutting due to knick point migration	#	#	
	8	Terrace cut through older bar material	#	#	
	9	Suspended armour alyer visible in bank	#	#	
	10	Channel worn into undisturbed overburden / bedrock	#	#	
		Sum of Indicies:	5	1	0.17
Evidence of Widening (WI)	1	Fallen / leaning trees / fence posts / etc.	#	#	
	2	Occurrence of large organic debris	#	#	
	3	Exposed tree roots	#	#	
	4	Basal scour on inside meander bends	#	#	
	5	Basal scour on both sides of channel through riffle	#	#	
	6	Gabion baskets / concrete walls / etc. out flanked	#	#	
	7	Length of basal scour >50% through subject reach	#	#	
	8	Exposed length of previously buried pipe / cable / etc.	#	#	
	9	Fracture lines along top of bank	#	#	
	10	Exposed building foundation	#	#	NA
		Sum of Indicies:	5	4	0.44
Evidence of Planimetric Form Adjustment (PI)	1	Formation of chute(s)	#	#	NA
	2	Single thread channel to multiple channel	#	#	
	3	Evolution of pool-riffle form to low bed relief form	#	#	
	4	Cut-off channel(s)	#	#	
	5	Formation of island(s)	#	#	
	6	Thalweg alignment out of phase meander form	#	#	
	7	Bar forms poorly formed / reworked / removed	#	#	
		Sum of Indicies:	5	1	0.17

STABILITY INDEX: 0.30159

Condition: Transitional

Summary of Rapid Stream Assessment Technique (RSAT)

Project #: 1510206
Crew: KG & AS
Date: 30-Apr-21
Weather: Rain, Cold
Stream: Oshawa Creek - Bloor to Wentworth

Evaluation Category	Excellent	Good	Fair	Poor	Score
1. Channel Stability	9 - 11	6 - 8	3 - 5	0 - 2	5
2. Channel Scouring/Sediment Deposition	7 - 8	5 - 6	3 - 4	0 - 2	4
3. Physical Instream Habitat	7 - 8	5 - 6	3 - 4	0 - 2	5
4. Water Quality	7 - 8	5 - 6	3 - 4	0 - 2	2
5. Riparian Habitat Conditions	6 - 7	4 - 5	2 - 3	0 - 2	5
6. Biological Indicators	7 - 8	5 - 6	3 - 4	0 - 2	4
				Total:	25
				Verbal Ranking:	Fair

Score	Verbal Stream Quality Ranking
42 - 50	Excellent Condition
30 - 41	Good Condition
16 - 29	Fair Condition
<16	Poor Condition

Appendix F

Ontario Stream Assessment Protocol Fish Habitat Mapping

LEGEND:

TITLE:

METRE SCALE: 0 5 10 20 30 40 50	NORTH:	CLIENT: City of Oshawa
PRINT SCALE: 1:1750	PRINT SIZE: 11 x 17 "	PROJECT: Oshawa Creek - Thomas to Wentworth
DATUM: NAD 1983	PROJECTION: UTM Zone 17	
DATE: Jul 09, 2021	DRAWN: / CHECKED:	
PREPARED BY: Palmer™		FIGURE NO.: / REVISION: / PROJECT NO. 1510206

Imagery (2020) provided by the City of Oshawa

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Appendix G

Adobe Accessibility Check Report

Accessibility Report

Filename:
PECG Report - Oshawa Creek Branch 1_Oct2021.pdf

Checking Option:
Adobe PDF

Use this report to identify potential accessibility errors. Click on the link for each error to highlight the location of the error in the PDF file.

WARNING: The PDF file was not saved before running Full Check. The information contained in this report may be out-of-date. Please save the PDF file and run Full Check again.

Report Contents

Detailed Report

Page Content Errors

Page 6: Next Page

- None of the comments or other types of annotations on this page are contained in the structure tree. (How to Add Tags)

Page 7: Next Page | Prev Page

- None of the comments or other types of annotations on this page are contained in the structure tree. (How to Add Tags)

Page 23: Next Page | Prev Page

- None of the comments or other types of annotations on this page are contained in the structure tree. (How to Add Tags)

Page 83: Next Page | Prev Page

- 29 element(s) that are not contained within the structure tree. (How to Add Tags)
  1. Inaccessible page content
  2. Inaccessible link
  3. Inaccessible link
  4. Inaccessible link
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Structure Errors

- 5 Figure element(s) with no alternate text. (How to Add Alternate Text)
  1. No alternate text for Figure
  2. No alternate text for Figure
  3. No alternate text for Figure
  4. No alternate text for Figure
  5. No alternate text for Figure

Summary

The checker found problems which may prevent the document from being fully accessible.

- 5 Figure element(s) with no alternate text. (How to Add Alternate Text)
- 33 element(s) that are not contained within the structure tree. (How to Add Tags)

Hints for Repair

Adding Alternate Text

To add alternate text to an image, choose Tools > Accessibility > TouchUp Reading Order. Double click on the image. Right click and choose Edit Alternate Text from the context menu. Fill in the alternate text then click OK. To add alternate text to tags in the tags panel, select the tag, choose Options > Properties, click on the Tag tab, and fill in the alternate text field.

Adding Content to the Structure Tree

When content is not included in the Tags tree, you may wish to add it to the tree or to mark it as an artifact, since screen readers skip over artifacts.

- To mark it as an artifact, select the content in the Content panel, and then choose Options > Create Artifact.

- To add content to the tree, use the TouchUp Reading Order Tool or use the Tags Panel.
    - To use the TouchUp Reading Order Tool, choose Tools > Accessibility > TouchUp Reading Order.
    - To use the Tags Panel, select the content in the document with the Select Text tool, the TouchUp Text tool or the TouchUp Object tool. Select its parent in the Tags tree, then choose Options > Create Tag from Selection. Drag the new tag to its correct location, if necessary. For comments, links, and annotations that are not included in the structure tree, choose Options > Find. Select the type of item to search for and choose Find. Tag Element will let you add the item below the currently selected element in the Tags tree.

Disclaimer

Back to Top

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Appendix H

Summary of Responses to City of Oshawa and CLOCA Comments on the Draft Report

Comment Response Table

Date: August 27, 2021

Project #: 1510206

Project Name: Fluvial Geomorphological Assessment of Oshawa Creek and Evaluation of Erosion Mitigation Strategies at Prioritized Sites

Regarding: Responses to feedback from the City (August 17, 2021) and CLOCA (August 18, 2021)

Comment No.	City of Oshawa / CLOCA Comment	Palmer Response
Executive Summary		
1.	Executive Summary p. 3. Should 124A be also mentioned?	Yes, thank you for flagging this. It was not immediately clear to us if the property had multiple units under the same address. We have updated the report and figures to add 124A Thomas Street.
2.	Executive Summary p. 4. Should 1125-1139 be mentioned here instead?	Yes. We have updated the report and relevant figures to add 1139 Valley Ct. The report was also simplified to say “1125 to 1139 Valley Ct” rather than listing each address.
3.	Executive Summary p. 5. Is word missing (i.e. Create) in front of “upstream” word?	Actually, the sentence is not missing a word. The riffle and armourstone rib are proposed to stop the creation of a knickpoint.
Figures		
4.	Figure 1 p.14. Add abbreviation (MS) for Migration Site to be consistent with the Figure.	We have added this abbreviation to Figure 1.
5.	Figure 1 p.14. What is this for? Should it be Palmer’s logo?	The blank/blacked-out box flagged was meant to be the Palmer logo. We have re-PDF’d the figure and report to update internal links.
6.	Figure 1 p.14.	We have updated the line weight of the sanitary sewer.

	We recommend using a thicker line type for the Sanitary Sewer so it will be easy to visualize the sewer line.	
7.	Figure 2 p.17. Please show the flow direction	We have updated the figure and added the flow direction.
8.	Figure 2 p.17. What is this for? Should it be Palmer's logo?	See above.
Section 4 – Description of Channel Morphology		
9.	Section 4. p. 18. Please revise Figure 3 to show the locations and directions of all the photos.	Photos and directions have been updated in Figure 3.
10.	Section 4.1 p.18. There is no Figure 4 to be found in the report. However, it appears that the figure shown on page 16 has been referenced here. If yes, please revise the figure to add a title and figure number to it. Or, add a figure 4 in the report.	Figure 4 refers to the longitudinal profile. We have updated the figure to include the caption.
11.	Figure 3 p.19. What is this for? Should it be Palmer's logo?	See above.
12.	Figure 4 p.21. Add a title and number of this figure	Added figure caption.
13.	Section 4.1 p.28. It would be desirable to show all three existing erosion control structures on Figure 3.	Erosion control structures are included in the Figure as yellow dashed lines.
14.	Section 4.1 p.28. Do you know that these structures are structurally sound? If yes, please include the supporting information in the report.	Yes, the structures are structurally sound, despite the presence of erosion at their upstream extents. We have updated the table and paragraph.
15.	Section 4.3.1 p. 29. Should 124A be also included here?	See above.
16.	Section 4.3.1 p.30. Please note that Photos 7 to 11 are not shown on Figure 3. As such, a revision to the figure is required accordingly.	Photos and directions have been updated in Figure 3.
Section 5 – Evaluation of Conceptual Alternatives		
17.	Section 5.1 p. 38. We believe that there is no need to refer Tables 6 & 7 here as it has been referenced in the paragraph above (see Section 5.1).	Removed.

18.	Section 5.1 p. 40. Should it be Score “1” instead of “2”?	We agree and have lowered the score and updated the evaluation. The ranking was not changed.
19.	Section 5.2 p. 44. Should 1125-1139 be mentioned here instead of three properties only?	Yes. See above.
20.	Section 5.2 p. 45. Have you assess the structural integrity of the existing protection measures? If yes, please revise the text accordingly and also add the supporting information to the report from a completeness perspective.	Yes. See above.
Appendices		
21	Appendix A – Please label yellow and blue lines	Updated channel cross-sections to include estimated bankfull elevation (Yellow Line) and baseflow elevation (Blue Line).
22	Appendix C – Please add flow arrow and update property numbers	We have updated conceptual designs to include updated address and flow direction.
23	Appendix F – Please provide accessibility report for finalized version	We have completed the accessibility check and appended the report.
CLOCA Comments		
24.	The report has not been circulated to CLOCA natural heritage staff at this time. Comments on terrestrial and aquatic habitat may be provided with submission of advanced concepts and permit applications.	Noted.
25.	Site 3 is a pedestrian bridge where the concrete abutment wingwall and more recent boulder armouring continues to be outflanked by creek erosion. An option to provide a longer pedestrian bridge span may be a viable option to evaluate and could eliminate future maintenance and replacement of bank armouring.	Thank you for the comment. We agree that changes to the bridge would reduce future erosion and maintenance concerns. From our fluvial perspective the bridge *span* is appropriate, but the *siting* and *skew* are misaligned with planform geometry. Our proposed designs will realign the channel to eliminate fluvial/valley wall interaction and, in doing so, fix the bridge alignment issue by placing the left abutment at the edge of the channel rather than projecting into it. Bridge replacement is likely to occur in 8 to 9 years as recommended in the Oshawa bi-annual municipal inspection report.

26	Site 4 is a buried sanitary sewer crossing. An alternative to lower/alter the sanitary pipe should be discussed and evaluated.	The buried pipe is currently syphoned below the channel to increase its depth of cover. The existing depth of cover is sufficient over the short and medium term from our fluvial perspective as the channel has not exhibited a history of bed degradation. Lowering the pipe further would improve long-term protection for the pipe, but costs may outweigh the benefit at this time. The City of Oshawa will communicate with the Region to determine if consideration for increasing the depth of cover over the sanitary pipe (e.g. lowering) is an option worth considering.

Palmer™

Comment Response Table

Date: September 24, 2021

Project #: 1510206

Project Name: Fluvial Geomorphological Assessment of Oshawa Creek and Evaluation of Erosion Mitigation Strategies at Prioritized Sites – Second Review

Regarding: Responses to feedback from the City (Sept 24, 2021) and CLOCA (September 23, 2021)

Comment No.	City of Oshawa / CLOCA Comment	Palmer Response
Executive Summary		
1.	Executive Summary p. 3. Please update address from 210 Thomas to 204 Thomas	Address was updated accordingly
Section 4 – Description of Channel Morphology		
2.	Photo 7. P.23. Please add the photo direction.	Photo direction was added to description
Section 5 – Evaluation of Conceptual Alternatives		
3	Section 5 p. 39. Please update address from 210 Thomas to 204 Thomas	Address was updated accordingly
4	Section 5. 40. Add abbreviation to Rough Order of Magnitude	ROM added to text
Appendices		
5	Appendix C– Please revise concept numbering	Concept numbering updated for each alternative
CLOCA Comments		

6.	I am happy with the responses to CLOCA comments but ask that the responses be documented in the report. In particular, the report should note the need to keep an open mind to the potential for moving infrastructure, particularly with an aging pedestrian bridge that will need replacement within 10 years.	Noted. We will include additional text regarding replacement of the aging pedestrian bridge and append our comment response table to the report.