



Four Mile Creek

Rapid Geomorphic Assessment & Conceptual Restoration Plan

Niagara Peninsula Conservation Authority

14 December 2022

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Project name		NPCA - Four Mile Creek Geomorphic Assessment					
Document title		Four Mile Creek Rapid Geomorphic Assessment & Conceptual Restoration Plan					
Project number		12581028					
File name		NPCA Four Mile Creek Geomorphology Report					
Status Code	Revision	Author	Reviewer		Approved for issue		
			Name	Signature	Name	Signature	Date
S1	0	Abby Yates	Jeff Doucette		Jeff Doucette		9/23/22
S4	1	Abby Yates	Jeff Doucette		Jeff Doucette		12/14/22
[Status code]							

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Contents

1.	Introduction	1
1.1	Purpose of this report	1
1.2	Scope and limitations	1
2.	Background Review	3
2.1	Geology and Climate	3
2.1.1	Geology	3
2.1.2	Climate	3
3.	Geomorphic Assessment	3
3.1	Reach Delineation	3
3.2	Rapid Geomorphic Assessments	3
3.2.1	Methods	3
3.2.2	Reach Characteristics	4
3.2.3	Rapid Assessment Results	7
3.3	Detailed Geomorphic Assessment	8
3.4	Erosion Threshold Assessment	9
4.	Potential Erosion Hazards Related to Infrastructure and Opportunities for Restoration	10
4.1	Identified Potential Risks and Opportunities	10
5.	Conceptual Mitigation Recommendations	23
5.1	Treatment Options	23
5.1.1	Soft bank treatments	23
5.1.2	Hard Bank Treatments	23
6.	Recommendations	26
7.	References	28

Table index

Table 1	General Reach Characteristics	5
Table 2	Rapid Assessment Summary	7
Table 3	Summary of Detailed Geomorphic Assessment	8
Table 4	Erosion Threshold Assessment Summary	10
Table 5	Velocity and discharge based on field measurements at each cross section (USBR, 1997)	10
Table 6	Potential Hazard Risks	11
Table 7	Opportunities for Habitat Enhancement/Restoration	18
Table 8	Unit Cost Estimates	24
Table 9	Cost Estimates to Mitigate Potential Risks to Infrastructure and Property	24
Table 10	Cost Estimates for Opportunities for Habitat Restoration and Enhancement	25

Figure index

Figure 1	Study Area	2
Figure 2	Hazards to Infrastructure and Property and Opportunities for Habitat Enhancement	22

Appendices

Appendix A	Detailed Geomorphic Summary
Appendix B	Conceptual Design Details

1. Introduction

1.1 Purpose of this report

Four Mile Creek flows north from Mountain Road in Niagara Falls, Ontario, descends over the escarpment, then flows through Niagara-on-the-Lake and outlets into Lake Ontario. Several large-scale developments have taken place south of Line 9 in Niagara-on-the-Lake, contributing to an increase in impermeable surface. The increase in impermeable surfaces has resulted in increased runoff. Residents along Four Mile Creek in this area have expressed concerns to the Town of Niagara-on-the-Lake and the Niagara Peninsula Conservation Authority regarding erosion and sedimentation causing property damage.

GHD Limited (GHD) was retained by the Niagara Peninsula Conservation Authority (NPCA) for the Four Mile Creek Rapid Geomorphic Assessment and Conceptual Mitigation Plan to inform restoration measures along Four Mile Creek to address the erosion and sedimentation issues south of Line 9. The study area extends from Mountain Road downstream to Line 9 (**Figure 1**). The purpose of this report is to document existing conditions, summarize geomorphic assessments, evaluate potential erosion hazards, and provide conceptual restoration recommendations for the study area.

1.2 Scope and limitations

This report: has been prepared by GHD for Niagara Peninsula Conservation Authority and may only be used and relied on by Niagara Peninsula Conservation Authority for the purpose agreed between GHD and Niagara Peninsula Conservation Authority as set out in section 1.1 of this report.

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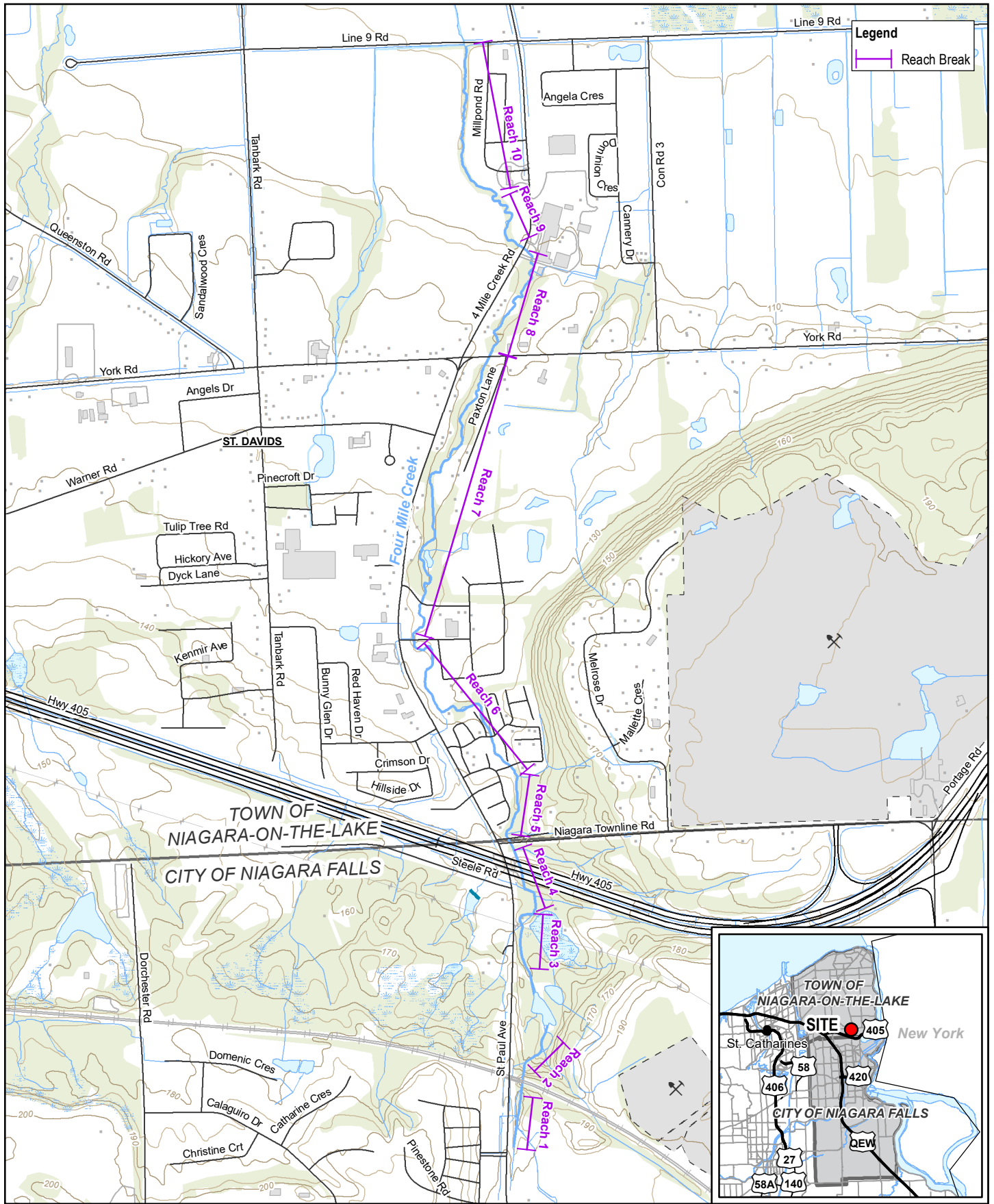
The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

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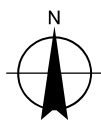
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Paper Size ANSI A
0 90 180 270 360
Metres

Map Projection: Transverse Mercator
Horizontal Datum: North American 1983
Grid: NAD 1983 UTM Zone 17N



NIAGARA PENINSULA CONSERVATION AUTHORITY
FOUR MILE CREEK
GEOMORPHIC ASSESSMENT

FOUR MILE CREEK
REACH BREAKS

Project No. 12581028
Revision No. -
Date Jul 20, 2022

FIGURE 1

2. Background Review

2.1 Geology and Climate

2.1.1 Geology

The underlying geology influences the rate of channel change (e.g., migration), sediment input (amount and type), and channel geometry. Four Mile Creek descends over the Niagara Escarpment within the study area. The local surficial geology consists of glaciolacustrine deposits. These deposits are coarse-textured, consisting of gravel and sand with minor clay and silt in the upstream portion of the study area (MNDMRF, 2022). Downstream of York Road, below the escarpment, the glaciolacustrine deposits are fine-textured, consisting of silt and clay with minor sand and gravel (MNDMRF, 2022). Bedrock geology within the study area is comprised of sandstone, shale, dolostone, and siltstone of the Lockport Formation and the Clinton and Cataract Groups (Ontario Geological Survey, 1991; MNDMRF, 2022).

2.1.2 Climate

Climate, precipitation in particular, provides the energy for the system and directly influences basin hydrology and rates of channel erosion. The precipitation averages do not vary significantly across the Niagara Falls Area and are discussed to provide some context for the typical precipitation range for these systems. Average precipitation was calculated from climate normals (1981 - 2010) for the Niagara Falls NPCSH weather station, which is approximately 5 kilometers (km) southeast of the study area. Precipitation from climate normals (1981 to 2010) recorded at the Niagara Falls NPCSH weather station (Station ID 6135657), averaged 77.58 millimeters (mm) in winter months (November to February, inclusive), and 79.1 mm in the summer months (July and August, inclusive) (Environment Canada, 2022). As with most watercourses in southern Ontario, the highest instream flows usually occur during snowmelt (i.e., freshet) and, in particular, rain on snow events. While the longest duration of high flows typically occurs during freshet, the increase over the summer months is likely a result of convective thunderstorms.

3. Geomorphic Assessment

3.1 Reach Delineation

Reaches are homogenous sections of channel with regard to form and function and can therefore be expected to behave consistently along their length to changes in hydrology and sediment inputs, as well as to other modifying factors. Reach delineation was based on changes in channel planform and active geomorphological processes, which are directly related to local surficial geology, gradient, hydrology, land use, and riparian vegetation (Montgomery et al, 1997; Richards et al, 1997).

Ten reaches were identified within the project area. The reach delineations are identified on **Figure 1**. Reach breaks were associated with road/trail crossings where the gradient, channel dimensions, and sinuosity changed.

3.2 Rapid Geomorphic Assessments

3.2.1 Methods

Existing conditions were characterized in Four Mile Creek from Mountain Road downstream to Line 9 on June 2 and 3, 2022. The total channel length was approximately 3.5 km. Two rapid assessment tools, a Rapid Geomorphic Assessment (RGA) and a Rapid Stream Assessment Technique (RSAT), were used to assess the watercourse. The

RGA documents observed indicators of channel instability (MOE, 2003) by quantifying observations using an index that identifies channel sensitivity. Sensitivity is based on evidence of aggradation, degradation, channel widening and planimetric form adjustment. The index produces values that indicate whether the channel is stable/in regime (score <0.20), stressed/transitional (score 0.21-0.40) or in adjustment (score >0.41). The possible classifications resulting from the assessment are defined as:

In regime – The watercourse form is adjusted to the flow and sediments conveyed by the system.

In transition/stress – The watercourse is showing signs of form adjustment in response to changes in the flow and/or sediment conveyed by the system.

In adjustment – The watercourse form is actively undergoing adjustment as a result of changes in the flow and/or sediment conveyed by the system.

The RSAT offers a slightly different approach by using an index to quantify overall stream health and includes the consideration of biological indicators. Observations concerning channel stability, channel scouring/sediment deposition, physical instream habitat, water quality, and riparian habitat conditions are used in an index to produce values that indicate whether the channel is in poor (<13), fair (13-24), good (25-34), or excellent (35-42) condition.

The Downs (1995) classification system was also used as an indicator of morphological adjustment. This classification scheme categorizes channels based on adjustment processes and changes in channel form. For example, streams are characterized as stable, laterally migrating, enlarging, undercutting, aggrading, or recovering. Field observations and rapid assessment results are shown in **Table 1** and **Table 2** respectively.

3.2.2 Reach Characteristics

Reaches 1 to 3 had low sinuosity and steep gradients as the watercourse descended over the escarpment. The channel through these reaches was lined with rip rap and concrete that was undermined and outflanked in several areas. At the upstream limit Reach 1 was a roadside ditch at Eagle Valley Golf Club, flowing along the east side of St Paul Avenue. The creek continued to flow along the side of the road through a forested riparian area to the CN railway crossing. Downstream of the CN railway, the concrete culvert outlet was elevated with a 5 m drop and scour pool below. Through Reach 2, flow cascaded over exposed bedrock with a transition to low-bed relief morphology before entering a pond.

From the first pond outlet, Reach 3 continued alongside St Paul Avenue at a steep gradient. The upstream portion of this reach was lined with concrete which had failed, creating a 1 m drop. The 1 m drop is located approximately mid-reach, downstream of a stormwater outlet where the creek bends away from the road. Further downstream there was a transition to low-bed morphology before the second pond outlet. Reach 4 was a poorly defined channel through a wetland area downstream of the pond outlet. The creek then flowed through a concrete culvert under Highway 405. The culvert outlet was undermined and outflanked due to the flow from an incoming drainage channel to the east. Approximately 2 m downstream of the Highway 405 culvert outlet, the creek entered another concrete culvert which passed under Townline Road.

The reaches below the escarpment had lower gradients, increased sinuosity, finer bed material, and slightly larger channel widths. Downstream of Townline Road the watercourse meandered through a valley feature along the east side of Four Mile Creek Road through Reaches 5 to 8. The watercourse was in close proximity to private properties within Reaches 5 and 6 as the creek flows through Creekside Senior Estates with minimal riparian buffer. Reaches 7 and 8 had lower gradients and generally had a wider floodplain and riparian area while the creek passes through several other residential properties. North of York Road, at the downstream limit of Reach 8, the creek crosses Four Mile Creek Road and flows along the perimeter of two new large developments to Line 9. The watercourse through Reach 9, directly downstream of the Four Mile Creek Road crossing, was recently realigned to the west with a constructed riffle-pool bed morphology. Further downstream Reach 10 was located between the new developments to the east and agricultural land to the west.

Table 1 **General Reach Characteristics**

Reach	Avg Gradient	Reach Limits	Bankfull Width (m)	Bankfull Depth (m)	Substrate		Riparian Vegetation	Notes
					Riffle	Pool		
1	6.69	Eagle Valley Golf Club to CN Rail Crossing	1.5 – 2.0	0.4 – 0.8	Sand to Gravel	Sand and concrete	Established (5-30 years) trees, shrubs, and grasses	steep gradient; low sinuosity; most of reach lined with rip rap and concrete undermined and outflanked; elevated and undermined stormwater outlet with scour pool (> 1 m depth) at left bank near downstream limit; small woody debris jams present in channel.
2	6.66	CN Rail Crossing to Pond inlet	2.0 – 2.5	0.8 – 1.0	Sand to Cobble, bedrock	Sand to bedrock	Established (5-30 years) trees and grasses	Confined valley; steep gradient; low sinuosity; >5 m drop downstream of culvert outlet under CN Rail with undermined gabion basket apron and scour pool (0.6 m); vegetated medial bar; culvert debris in channel; natural cascade over exposed bedrock; transition from cascade-pool to low bed relief morphology at downstream limit of reach.
3	3.11	Pond outlet to confluence w/ downstream pond outlet	2.5 – 3.0	0.3 – 0.8	Clay/Silt to Gravel	NA (no pools)	Established (5-30 years) trees and shrubs	Confined valley; rip rap and concrete lining channel through parts of reach; elevated stormwater outlets; fallen fence posts; no pools present; woody debris in channel; failed concrete bed (1 m drop) downstream of stormwater outlet where channel bends away from St Paul Ave; undercutting and exposed roots along outer bends; iron staining at downstream limit.

Reach	Avg Gradient	Reach Limits	Bankfull Width (m)	Bankfull Depth (m)	Substrate		Riparian Vegetation	Notes
					Riffle	Pool		
4	1.79	Confluence from Pond outlet to Townline Road	NA (poorly defined channel within wetland area)					
5	2.50	Townline Road to small tributary Confluence in Creekside Senior Estates	2.8 – 3.0	0.8 – 1.5	Sand to Cobble	Clay/Silt	Established (5-30 years) trees, shrubs, and grasses	Confined valley; moderate sinuosity, gradient, and entrenchment; erosion, leaning/fallen trees, and exposed roots along both banks; lobate and medial bar formation; private concrete slab bank protection outflanked.
6	1.68	Downstream of small tributary Confluence at Creekside Senior Estates to David Secord Drive	2.0 – 4.0	0.4 – 0.8	Sand to Cobble	Sand	Established (5-30 years) trees, shrubs, and grasses	Scour pool (0.7 m depth) downstream of culvert; lobate bar present; basal scour of outer bend, point bar formation inner bend; failing and undermined gabion basket and cribwall bank protection to both banks; undermined concrete bed towards downstream limit and large knickpoint; widened trapezoidal channel towards downstream limit
7	1.026	David Secord Drive to York Road	2.2 – 3.5	0.7 – 1.0	Sand to Cobble	Clay/Silt to Sand	Established (5-30 years) trees, shrubs, and grasses	Well vegetated banks; several fallen trees and woody debris jams; fine sediment accumulation and bar formation; undercutting and exposed roots; knickpoints; formation of chutes.
8	0.945	York Road to Four Mile Creek Road	2.2 – 2.5	0.7 – 1.0	Sand to Gravel	Clay/Silt to Sand	Grasses with few trees and shrubs	Culvert outlet at York Road elevated with downstream scour pool; riparian area predominantly mowed grass; undercutting and slumping of outer meander bends; knickpoint; concrete structures at downstream end undermined.

Reach	Avg Gradient	Reach Limits	Bankfull Width (m)	Bankfull Depth (m)	Substrate		Riparian Vegetation	Notes
					Riffle	Pool		
								outflanked, and deteriorating.
9	0.545	Four Mile Creek Road to end of realigned reach	3.5 – 4.0	0.6 – 0.8	Sand to Cobble	Clay/Silt to Gravel	Immature (< 5 years) trees	Recently restored reach; riffle-pool bed morphology; medial bar and sediment accumulation in upstream portion of reach; exposed till through pools in downstream portion of reach; high density attached algae.
10	1.190	End of realigned reach to Line 9	2.8 – 3.5	0.6 – 1.0	Sand to Cobble	Clay/Silt	Established (5-30 years) trees and shrubs	Confined valley; entrenched channel; erosion along both banks; channel bed downcut to till/clay; knickpoint; Line 9 bridge footings exposed.

3.2.3 Rapid Assessment Results

All of the assessed reaches of Four Mile Creek exhibited evidence of channel instability and adjustment. There was evidence of erosion throughout all reaches. The dominant form of adjustment within the upstream reaches was degradation, with evidence of undermined concrete, elevated stormwater outlets, scour pools, headcutting due to knickpoint migration. The dominant form of adjustment was a more aggradational form within Reaches 5 to 7. These reaches also exhibited evidence of widening which was the more dominant process in Reach 6. These reaches had lower gradients. The dominant form of adjustment in Reach 8 was degradation; however, signs of widening were also observed. Reach 9 had been recently restored and received the lowest score characterizing it as 'in regime'. Minor signs of aggradation were present in the upstream portion of the reach, while exposed till was observed through the downstream portion of the reach. Degradation was also the dominant form of adjustment within Reach 10 with evidence of widening as well.

The RSAT scores ranged from 21 to 25, generally indicating 'fair' ecological health. Physical instream habitat and channel stability was the limiting factor in the upstream reaches, while the riparian habitat condition limited the score through Reaches 5 to 10.

Table 2 *Rapid Assessment Summary*

Reach	RGA			RSAT			Down's Classification
	Score	Condition	Dominant form of Adjustment	Score	Condition	Limiting Factor	
1	0.27	In Transition/ Stress	Degradation	25	Good	Physical Instream Habitat	E – 'enlarging'
2	0.47	In Adjustment	Degradation	23	Fair	Channel Scouring	e – 'enlarging'
3	0.38	In Transition/ Stress	Degradation	21	Fair	Physical Instream Habitat	m – 'lateral migration'

Reach	RGA			RSAT			Down's Classification
	Score	Condition	Dominant form of Adjustment	Score	Condition	Limiting Factor	
4	NA (poorly defined channel in a wetland area)						
5	0.43	In Adjustment	Aggradation	21	Fair	Riparian Habitat Conditions	C – 'compound'
6	0.35	In Transition/ Stress	Widening	21	Fair	Riparian Habitat Conditions	E – 'enlarging'
7	0.43	In Adjustment	Aggradation	21	Fair	Riparian Habitat Conditions	C – 'compound'
8	0.27	In Transition/ Stress	Degradation	21	Fair	Riparian Habitat Conditions	U – 'undercutting'
9	0.19	In Regime	Aggradation	24	Fair	Riparian Habitat Conditions	N/A
10	0.35	In Transition/Stress	Degradation	22	Fair	Riparian Habitat Conditions	E – 'enlarging'

3.3 Detailed Geomorphic Assessment

A detailed geomorphic assessment was completed on July 26, 2022, in Reach 6 downstream of the second road crossing within Creekside Senior Estates to establish the natural channel properties of the watercourse. The assessment consisted of a topographic survey of the longitudinal profile and six channel cross sections; pebble counts to characterize the watercourse bed substrate; and observations of bank material, bank angle, and root density and depth. The assessments provided reference channel parameters for the drainage feature.

Bankfull discharge and velocity were calculated from these observations, and the results are summarized in **Table 3**. Bankfull discharge is the defining flow which characterizes the morphology of a fluvial channel. It is typically the maximum amount of flow the watercourse can carry without overflowing on to the floodplain. The frequency of occurrence of the bankfull flow varies from stream to stream and typically occurs from a few times each year to once every few years. Streams in Southern Ontario normally experience bankfull flow once every year or two. Bankfull discharge and velocity were determined using Manning's approach based on the channel dimensions and gradient extracted from the topographic survey. The detailed geomorphology summary for this reach is contained in **Appendix A**

Table 3 Summary of Detailed Geomorphic Assessment

Channel Parameter	
Measured	
Average bankfull width (m)	3.6
Average bankfull depth (m)	0.4
Channel bed gradient (%)	1.12
D ₅₀ (mm)	37
D ₈₄ (mm)	65

Channel Parameter	
Manning's 'n'-value	0.037
Computed	
Bankfull Discharge (m ³ /s)	1.84
Bankfull Velocity (m/s)	1.42
Tractive force at Bankfull (N/m ²)	37.8
Flow competency for D ₅₀ (m/s) *	1.0
Flow competency for D ₈₄ (m/s) *	1.3
Note:	
* Komar (1987)	

3.4 Erosion Threshold Assessment

Erosion thresholds can be used to identify potential impacts to changes in the flow regime of a watercourse. Erosion thresholds are used to define the point at which sediment entrainment occurs, but they do not necessarily define the point at which erosion occurs since entrained sediment is usually replaced by sediment transport from upstream. Flows below an erosion threshold, usually defined by a velocity or a discharge, will not typically entrain sediment. Therefore, erosion thresholds are good indicators of the amount of flow within a watercourse that will not increase erosion or cause other geomorphic changes to the watercourse.

An erosion threshold is assessed by identifying the most sensitive reaches along the network of channels that could potentially be impacted. From this reach, a target critical velocity or critical shear stress for the bed or bank materials is defined. Once the critical shear stress or velocity is known, the equivalent discharge can be determined from detailed measurements of the watercourse geometry. The most sensitive reaches within the study area were determined based on the results of the reach characteristics and rapid geomorphic assessments as well as observed erosion hazards. Reach 6 which is confined within Creekside Senior Estates was considered the most sensitive reach. Although Reach 6 did not have the highest RGA score, it was selected as the most sensitive reach due to its close proximity to private property where existing erosion concerns were observed.

A detailed erosion threshold assessment was completed for Reach 6 based on the results of the detailed geomorphic assessment. The detailed assessment provided a modified Wolman (1954) pebble count to roughly characterize the median grain size value, a longitudinal profile survey to calculate the local gradient, and cross section surveys to quantify the bankfull cross-sectional dimensions of the channel (e.g., bankfull depth and width). The median grain size over the six cross sections was found to be very coarse gravel. A threshold velocity was determined for the median grain size based on Komar (1987). Bank material consisted of sandy loam. A threshold velocity of 0.53 m/s for sandy loam was used based on Fischenich (2001). This threshold was the lower and limiting threshold. An erosion threshold discharge for the drainage feature was calculated based on flow at the threshold velocity. Results are shown in **Table 4**. Note that this threshold discharge is a theoretical threshold discharge which has not been fully confirmed through field observations. Field observations of discharge and sediment transport could be used to better refine the erosion threshold. Rough estimations of the discharge were made during the detailed geomorphic field assessment (**Table 5**). These observations were completed on July 26, 2022 between 11:30 am and 2:30 pm, when we understand that water was actively being pumped into the creek upstream as part of the irrigation system for agriculture downstream. At the time of the assessment, a maximum of 1700 gpm (0.11 m³/s) was being added to the watercourse. We understand that a maximum of 2000 gpm (0.13 m³/s) can be added to the watercourse by the pumps. The estimated discharge during the field assessment was 0.19 m³/s. This is similar to the theoretical threshold discharge. Entrainment and movement of bed and bank material was not observed at this time. This further supports the theoretical threshold discharge estimate. If the rate of pumping water into the watercourse is increased to the maximum of 2000 gpm (0.13 m³/s), then the total watercourse discharge may exceed the threshold discharge.

Table 4 Erosion Threshold Assessment Summary

Reach	Bankfull Width (m)	Bankfull Depth (m)	Slope (m/m)	D ₅₀ (mm)	Water Depth (m)	Threshold Velocity (m/s)	Theoretical Threshold Discharge (m ³ /s)
6	3.6	0.4	0.0112	37	0.195	0.68	0.211

Table 5 Velocity and discharge based on field measurements at each cross section (USBR, 1997)

Cross-Section	Area (m ²)	Field Estimated Centerline Velocity (m/s)	Calculated Average Velocity (m/s)	Calculated Average Discharge (m ³ /s)
1	0.36	0.82	0.54	0.19
2	0.31	0.93	0.62	0.19
3	0.20	0.86	0.57	0.11
4	0.37	0.90	0.60	0.22
5	0.43	0.70	0.46	0.20
6	0.29	0.93	0.62	0.23
Average	0.34	0.86	0.57	0.19

4. Potential Erosion Hazards Related to Infrastructure and Opportunities for Restoration

An assessment of potential hazards to property and infrastructure was conducted. The entire lengths of the reaches were walked (where accessible), and erosion hazards were noted during the field reconnaissance. Opportunities for aquatic habitat enhancement were also identified during the assessment.

4.1 Identified Potential Risks and Opportunities

The following sections include a map and tables documenting the potential hazards to known infrastructure and opportunities for restoration and enhancement of stream habitat identified through the field investigations. The following hazard classification was used to identify the noted potential hazards:

- Sanitary Sewer Systems (S): channel widening, migration, or channel downcutting can undermine sanitary sewer systems
- Crossings (C): channel widening, migration, or channel downcutting can undermine footings of road or rail crossings
- Existing In-channel Structures (E): various structures placed in the channel, such as gabion baskets, concrete weirs, armourstone walls, etc., may be at risk by channel widening, migration, or degradation
- Recreational Facilities/Infrastructure (R): infrastructure such as trails, etc., associated with parks and playgrounds may be at risk from channel migration, or widening
- Valley Wall Features (V): channel widening, or migration may impact valley wall features when the toe of slope is in contact with the creek
- Property (P): property adjacent to the channel may be at risk due to channel migration, or widening, leading to loss of property

Each site where hazards or issues were identified were assigned one of four risk levels, based on the following classification system. These risk levels are:

- Level 1 – highest priority – immediate restoration
- Level 2 – short-term threat – 0-5 years
- Level 3 – long-term threat – 5-10 years
- Level 4 – existing instability but no current threat – > 10 years

Monitoring was also recommended for most issues identified.

The risks to infrastructure and opportunities for restoration along Four Mile Creek south of Line 9 are presented in **Tables 6 and 7**, respectively, and are shown on **Figure 2**.

Table 6 *Potential Hazard Risks*

Reach	Site No.	Photo	Issues	Priority
U/S of Reach 1	0-1		Erosion and slumping around an open section of culvert on the east side of St Paul Avenue north of Mountain Road. Feature Type: Crossings (C)	Monitor / Level 2 priority (0 – 5 years)
1	1-1		Stormwater outlet on left bank elevated with scour pool below and erosion around headwall. Flow undermining and outflanking concrete channel lining. Feature Type: Existing In-Channel Structures (E)	Monitor/Level 2 Priority (0 – 5 years)

Reach	Site No.	Photo	Issues	Priority
1	1-2		Concrete culvert inlet at CN rail crossing slightly undermined. Feature Type: Crossings (C)	Monitor/Level 3 Priority (5 – 10 years)
2	2-1		Concrete culvert outlet downstream of CN rail elevated over 5 m, failed gabions, and scour pool. Feature Type: Crossings (C)	Monitor/Level 2 Priority (0 – 5 years)
3	3-1		Fallen fence post and debris downstream of culvert outlet under driveway/road. Feature Type: Existing In-Channel Crossings (C)	Monitor/Level 2 Priority (0 – 5 years)
3	3-2		Concrete bed lining outflanked along St Paul Avenue road embankment. Feature Type: Existing In-Channel Structures (E)	Monitor/Level 3 Priority (5 – 10 years)

Reach	Site No.	Photo	Issues	Priority
3	3-3		Failed concrete bed and 1 m drop downstream of stormwater outlet on the east side of St Paul Avenue. Concrete debris and pipes in channel downstream and significant bank erosion. Feature Type: Existing In-Channel Structures (E)	Monitor/Level 2 Priority (0 – 5 years)
4	4-1		Large drop at pond outlet. Feature Type: Existing In-Channel Structures (E)	Monitor/Level 3 Priority (5 – 10 years)
4	4-2		Culvert at base of embankment of St Paul Avenue backed up and silted in. Feature Type: Crossings (C)	Monitor/Level 2 Priority (0 – 5 years)

Reach	Site No.	Photo	Issues	Priority
4	4-3		Concrete culvert outlet below Highway 405 undermined and erosion of embankment due to flow from incoming drainage channel. Feature Type: Crossings (C)	Monitor/Level 1 Priority (Immediate restoration)
4	4-4		Undermined gabion baskets between the culvert outlet under Highway 405 and culvert inlet under Townline Road. Feature Type: Existing In-Channel Structures (E)	Monitor/Level 1 Priority (Immediate restoration)
5	5-1		Steep eroded left bank in close proximity to private property Property (P)	Monitor/Level 2 Priority (0 – 5 years)
6	6-1		Flow from culvert outlet directed towards tree on right bank. Stone bank protection on left bank falling into channel. Feature Type: Property (P); Existing In-Channel Structures (E); Crossings (C)	Monitor/Level 3 Priority (5 – 10 years)

Reach	Site No.	Photo	Issues	Priority
6	6-2		Narrow channel corridor between properties within Creekside Senior Estates. Outer bank erosion and scour pool. Feature Type: Property (P)	Monitor/Level 2 Priority (0 – 5 years)
6	6-3		Slumping, undermined gabions and erosion of private property Feature Type: Existing In-Channel Structures (E); Property (P)	Monitor/Level 1 Priority (Immediate restoration)
6	6-4		Leaning concrete retaining wall upstream of road crossing in Creekside Senior Estates Feature Type: Crossings (C); Existing In-Channel Structure (E)	Monitor/Level 3 Priority (5 – 10 years)
6	6-5		Failing concrete apron downstream of culvert outlet under road crossing in Creekside Senior Estates Feature Type: Crossings (C); Existing In-Channel Structure (E)	Monitor/Level 3 Priority (5 – 10 years)

Reach	Site No.	Photo	Issues	Priority
7	7-1		Channel widening and basal scour along left bank in close proximity to private property (shed). Feature Type: Property (P)	Monitor/Level 3 Priority (5- 10 years)
7	7-2		Knickpoint and debris accumulation upstream of culvert inlet at private driveway/road crossing. Feature Type: Crossings (C); Property (P)	Monitor/Level 2 Priority (0 – 5 years)
8	8-1		Culvert outlet at York Road crossing elevated with downstream scour pool. Feature Type: Crossings (C)	Monitor/Level 3 Priority (5- 10 years)
10	10-1		Line 9 bridge footings exposed. Feature Type: Crossings (C)	Monitor/Level 2 Priority (0 – 5 years). Depth of footings should be reviewed.

Table 7 Opportunities for Habitat Enhancement/Restoration

Reach	Site No.	Photo	Opportunities for Restoration
1	1-1R		Debris jam with culvert debris in channel. Remove debris.
2	2-1R		Debris jam with culvert debris in channel. Remove debris.
3	3-1R		Remove concrete channel lining throughout Reach 3 and replace with hydraulically sized natural bed material. This may not be practical given the steepness of this reach.
5	5-1R		Remove wooden retaining wall built into creek and establish riparian buffer between the creek and mowed lawn.

Reach	Site No.	Photo	Opportunities for Restoration
6	6-1R		Increase riparian plantings and establish a riparian buffer between the creek and mowed lawns.
6	6-2R		Remove concrete debris from channel and restore potential for fish passage.
6	6-3R		Remove concrete from bed of the channel and replace with natural substrate.

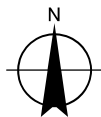
Reach	Site No.	Photo	Opportunities for Restoration
7	7-1R		Remove structure if not providing any function and restore a more natural channel with potential for fish passage.
7	7-2R		Remove concrete weir if not providing any function and restore a more natural channel with potential for fish passage.
7	7-3R		Remove failed concrete culvert and restore a more natural channel with potential for fish passage.
7	7-4R		Increase riparian plantings and establish a riparian buffer between the creek and mowed lawns.

Reach	Site No.	Photo	Opportunities for Restoration
8	8-1R		Perched culvert outlet at York Road crossing creating barrier for fish passage. Downstream channel bed elevation could be restored to provide the potential for fish passage.
8	8-2R		Increase riparian plantings and establish a riparian buffer between the creek and mowed lawns.
8	8-3R		Remove concrete weir/structures and daylight creek if not providing any function.
9	9-1R		Pools in recently realigned reach downcut to till with no instream or riparian cover. Add substrate and cover to improve fish habitat.



Paper Size ANSI A
0 90 180 270 360
Metres

Map Projection: Transverse Mercator
Horizontal Datum: North American 1983
Grid: NAD 1983 UTM Zone 17N



NIAGARA PENINSULA CONSERVATION AUTHORITY
FOUR MILE CREEK
GEOMORPHIC ASSESSMENT

**RISKS TO INFRASTRUCTURE
AND PROPERTY AND OPPORTUNITES
FOR HABITAT ENHANCEMENT**

Project No. 12581028
Revision No. -
Date Sep 22, 2022

FIGURE 2

5. Conceptual Mitigation Recommendations

5.1 Treatment Options

Each site that was identified as a potential risk to existing infrastructure or property was studied to determine the most appropriate means to mitigate the potential risk. Similarly, each area that was identified as an opportunity for habitat restoration and enhancement was examined to determine the most reasonable means of improving the degraded habitat.

Bed and/or bank treatments are recommended to mitigate the majority of the erosion hazards. Example details and photographs of the different treatments are provided in **Appendix B**.

Bed treatments consist of recreating alternating bedform morphology, through the construction of **riffle and pool sequences** or vortex rock weirs. Riffles invariably have a higher grade than the bankfull channel, and therefore are comprised of bed materials that are sufficiently large to be generally stable at higher flows. Pools are deeper sections of channel where energy is dissipated as flows exit the riffles. Water aeration occurs through the riffles and relatively quiescent flows dominate through the pools, providing refuge habitat for fish during high flow events.

Vortex rock weirs consist of a series of stones placed across the channel in an arch pattern towards the upstream side. The stones are typically keyed into the banks and embedded into the channel to ensure the materials will not be carried downstream during storm events. This type of treatment acts to slow velocities and direct flows towards the centre of the channel, thereby reducing erosive forces along the banks. This type of treatment also allows for fish passage, as the stones are spaced at intervals.

The recommended bank treatment options can be classified as relatively soft, such as live stakes, vegetated layering, etc., or relatively hard, such as vegetated rock buttresses and armourstone.

5.1.1 Soft bank treatments

Live stakes consist of dormant cuttings installed in the channel bank above the low water level in typically a mix of well compacted soil and native material. The establishment of the plantings will reduce flow velocities along the bank and limit erosion, while providing local stream shading and overhanging vegetation.

Live vegetated layering consists of dormant cuttings installed in the bank above the low water level, in lifts separated by a mix of well-compacted soil and native material. The bank treatment is blended with the existing bank to provide a smooth, natural transition. A biodegradable geotextile is placed on the bank to provide immediate stabilization. Vegetated layering used at meander bends that are particularly sharp or close to the valley wall will reduce flow velocities and limit erosion through the establishment of the plantings, as well as provide local stream shading and vegetation overhangs. Vegetated laying can also include hydraulically sized stone at the toe for higher energy environments.

5.1.2 Hard Bank Treatments

Vegetated buttresses consist of a combination of rocks and native vegetation to provide bank protection and promote flow training and deflection. As these materials can be installed at steeper slopes, this alternative has a relatively small footprint. The plantings installed between the stone lifts enhance aquatic habitat by providing shade and overhanging vegetation. While this is a relatively hard treatment, it provides long term stability.

Armourstone retaining walls are generally recommended for those sites most severely impacted by erosion where there is limited space for a sloping bank. Ideally a terraced floodplain is created to provide a larger wetted perimeter to increase flow resistance and energy dissipation, while enhancing slope stability along the valley toe and optimize hydraulic capacity. The increased stability provided by an armourstone bank treatment effectively mitigates long-term erosion hazard concerns and would offer the greatest protection to adjacent properties.

Sample details for the treatments outlined above are included in **Appendix B**.

Cost estimates were prepared for the recommended treatment at each of the sites identified as requiring protection or enhancement. The cost estimates were prepared at a rough order of magnitude level, applying average unit rates for typical restoration and protection measures. The unit pricing for the various measures proposed are summarized in **Table 8**. The estimated total cost for each project also includes additional costs related to design (including hydraulic assessment), mobilization, phasing, and erosion and sediment control. The cost estimates do not include permitting costs, construction administration, construction inspection, monitoring or tendering. Cost estimate do not include costs for Species at Risk permitting, as those requirements are not known at this time. There should be significant cost savings if issues/restoration opportunities that are close together are combined into single projects.

Table 8 Unit Cost Estimates

Treatment	Unit	Cost per Unit
Soft Bank Treatment	m	\$500
Hard Bank Treatment (higher costs used for valley wall contacts or retaining walls)	m	\$1000
Bed Treatment	m	\$1000
Bed and Bank Treatment	m	\$2500
Culvert Repair/Replacement/Removal	each	varies
Riparian Planting	m	\$200
Debris Removal	m	\$1000

The recommended treatment and associated rough order of magnitude cost estimate for each site identified as a potential risk to infrastructure is summarized in **Table 9**, and recommendations and cost estimates for the habitat restoration and enhancement sites are summarized in **Table 10**.

Table 9 Cost Estimates to Mitigate Potential Risks to Infrastructure and Property

Reach	Site No.	Level / Category	Recommended Treatment	Cost
U/S of Reach 1	0-1	3 (C)	Repair erosion around culvert in open section of channel	\$18,600
1	1-1	2 (E)	Bed and bank protection at outlet	\$48,000
1	1-2	3 (C)	Culvert footing protection at upstream end	\$31,200
2	2-1	2 (C)	Repair/replace drop structure and stabilize scour pool	\$312,000
3	3-1	2 (C)	Remove debris	\$7,200
3	3-2	3 (E)	Remove concrete and repair with bed and bank treatment	\$198,000
3	3-3	3 (E)	Remove concrete and repair with bed and bank treatment	\$138,000
4	4-1	3 (E)	Stabilize pond outlet	\$46,800
4	4-2	2 (C)	Clear out culvert	\$42,000
4	4-3	1 (C)	Repair valley wall scour to protect culvert and road	\$66,000
4	4-4	1 (E)	Protect toe of gabion baskets or replace gabion baskets	\$126,000
5	5-1	2 (P)	Bank Protection	\$258,000
6	6-1	3 (P) (E) (C)	Bank protection downstream of culvert	\$54,000
6	6-2	2 (P)	Bed and bank protection	\$75,000

Reach	Site No.	Level / Category	Recommended Treatment	Cost
6	6-3	1 (P) (E)	Remove failed gabion baskets and replace with bed and bank protection	\$75,000
6	6-4	3 (C) (E)	Replace leaning concrete wall with armourstone retaining wall	\$84,000
6	6-5	3 (C) (E)	Bed and bank treatment to protect downstream side of culvert	\$60,000
6	6-6	2 (P)	Habitat appropriate bed and bank protection	\$144,000
6	6-7	3 (P) (E)	Habitat appropriate bed and bank protection	\$90,000
6	6-8	1 (P) (E)	Replace failing wooden retaining wall with armourstone retaining wall or habitat appropriate bank treatment	\$84,000
6	6-9	3 (C)	Bank protection	\$126,000
7	7-1	3 (P)	Bank protection	\$32,400
7	7-2	2 (P) (C)	Remove debris and repair bed and bank	\$42,000
8	8-1	3 (C)	Bed and bank protection downstream of York Road culvert	\$90,000
10	10-1	2 (C)	Bed protection for bridge footings	\$90,000

Table 10 Cost Estimates for Opportunities for Habitat Restoration and Enhancement

Reach	Site No.	Recommended Treatment	Cost
1	1-1R	Debris removal	\$16,100
2	2-1R	Debris removal	\$16,100
3	3-1R	Remove concrete and repair with bed and bank treatment	\$630,000
5	5-1R	Remove wooden retaining wall and establish a natural bank	\$77,000
6	6-1R	Riparian plantings on both banks through manicured lawn areas	\$126,000
6	6-2R	Remove concrete and repair with bed and bank treatment	\$84,000
6	6-3R	Remove concrete and replace with more natural bed material	\$91,000
7	7-1R	Remove structure and restore stream bed and bank with habitat appropriate treatment	\$140,000
7	7-2R	Remove structure and restore stream bed and bank with habitat appropriate treatment	\$154,000
7	7-3R	Remove structure and restore stream bed and bank with habitat appropriate treatment	\$154,000
7	7-4R	Riparian plantings on both banks through manicured lawn areas	\$38,500
8	8-1R	Bed and bank restoration to eliminate perched culvert	\$90,000
8	8-2R	Riparian plantings on both banks through manicured lawn areas	\$126,000
8	8-3R	Remove weir/structure and daylight creek; install habitat appropriate bed and bank treatment	\$192,500
9	9-1R	Add substrate to downstream portion of realigned reach	\$119,000

6. Recommendations

The following observations, recommendations and conclusions are provided. Note that various landowners are impacted by potential hazards identified, including private landowners, businesses, Niagara Region, the Town of Niagara-on-the-Lake, City of Niagara Falls, and CN Rail.

Potential Hazard Mitigation

Potential hazards to infrastructure/private property were identified. Recommendations were provided to protect infrastructure/private property with habitat appropriate bank or bed and bank treatments. Rough order of magnitude cost estimates were determined for each issue identified. An estimated priority level was also provided for each issue.

Restoration

Geomorphic restoration opportunities were identified within the creek. These opportunities aim to improve the geomorphic form and function of the watercourse. Geomorphic recommendations also typically benefit aquatic and terrestrial habitat as well as water quality.

Watershed priorities and objectives should be considered to determine which restoration opportunities should be applied. An aquatic habitat assessment for Four Mile Creek is recommended to determine the benefit that improving fish passage within the study area would provide, given the high costs of eliminating fish barriers.

We recommend that the most cost-effective opportunity for restoration is establishment of riparian buffer zones in areas with manicure lawns. This would provide geomorphic, habitat and water quality improvements for low costs compared to other opportunities.

Hydrology and Hydraulics

A theoretical erosion threshold was determined for a sensitive reach within the study area. The erosion threshold should be used in developing stormwater management plans for future developments in the catchment by applying an erosion exceedance analysis.

The rate of pumping for the irrigation inputs should be kept below the erosion threshold discharge to prevent exacerbation of erosion. However, it should be noted that the irrigation input raises the baseflow, increasing the sensitivity of the system to minor increases in flow due to rainfall events. We recommend that an erosion exceedance analysis be conducted to provide guidance to the rate of irrigation input pumping.

We recommend a hydraulic assessment to determine flooding issues and causes of flooding issues to better focus restoration efforts.

Please contact the undersigned if you have any questions on this report.

All of Which is Respectfully Submitted,
GHD



Jeff Doucette, Ph.D., P.Geo. (Limited)
Fluvial Geomorphologist

Abby Yates, B.Sc.
Stream Restoration Scientist

7. References

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Appendices

Appendix A

Detailed Geomorphic Summary



Fluvial Geomorphology Summary

Reach 6, Four Mile Creek

Location:	Creekside Senior Estates, Niagara	Date:	July 26, 2022
Length Surveyed:	137 m	Number of Cross Sections:	6

GENERAL SITE CHARACTERISTICS

Drainage Area:		Riparian Vegetation:	
Geology/Soils:		Dominant Vegetation Type:	Trees, Shrubs, and Grasses
Surrounding Land Use:	Residential	Extent of Riparian Buffer Zone:	Fragmentary
Channel Disturbances:	N/A	Width of Riparian Buffer Zone:	1-5 Channel Widths
Aquatic Vegetation:		Age Class of Riparian Vegetation:	Established (5-30 years)
Dominant Vegetation Type:	Rooted Emergent/Submergent	Extent of Encroachment into Channel:	Minimal
Portion of Reach with Vegetation:	10-20%	Large Woody Debris:	Low Density Present in Channel and Cutbank

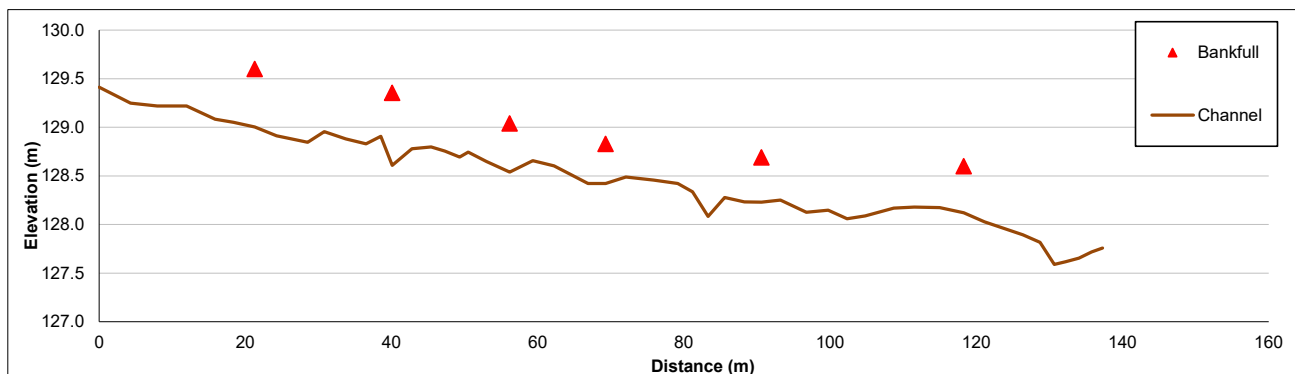
HYDROLOGY

Measured Discharge:	Not measured m ³ /s	Calculated Bankfull Discharge:	1.84 m ³ /s
Modeled 2-year Discharge:	Not calculated m ³ /s	Calculated Bankfull Velocity:	1.42 m/s
Modeled 2-year Velocity:	Not calculated m/s		

PLANFORM CHARACTERISTICS

<i>Profile</i>		<i>Meander Geometry</i>	
Bankfull Gradient:	1.07 %	Sinuosity:	1.49
Channel Bed Gradient:	1.12 %	Belt Width:	Not measured m
		Radius of Curvature:	Not measured m
		Amplitude:	Not measured m
		Wavelength:	Not measured m

Longitudinal Profile



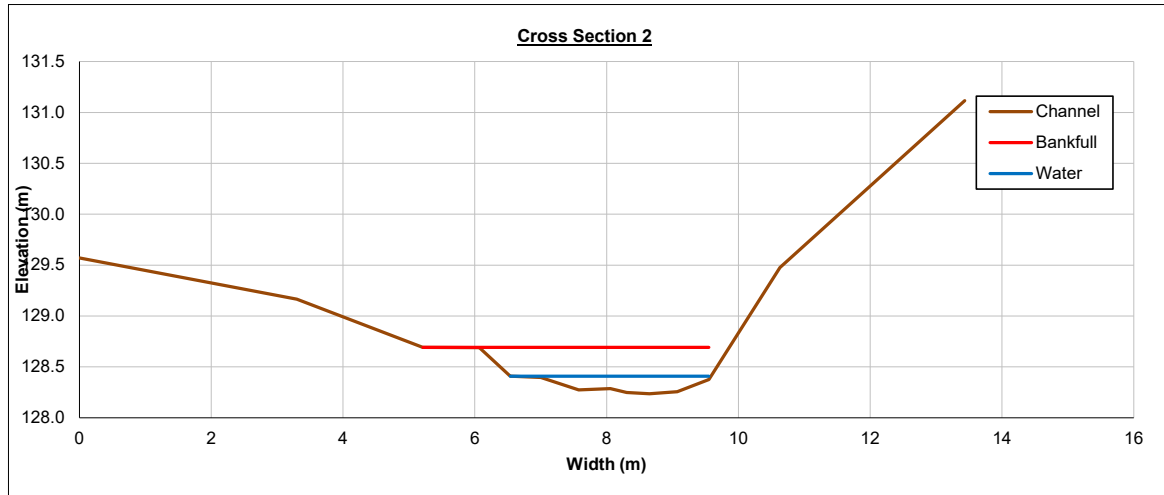
BANK CHARACTERISTICS

	<i>Minimum</i>	<i>Maximum</i>	<i>Average</i>		<i>Minimum</i>	<i>Maximum</i>	<i>Average</i>
Bank Height (m):	0.3	1.7	0.7				
Bank Angle (degrees):	35.0	90.0	70.0	Torvane Value (kg/cm ²):	Not Measured		
Root Depth (m):	0.1	0.6	0.2	Penetrometer Value (kg/cm ²):	Not Measured		
Root Density (%):	10.0	80.0	40.8	Bank Material (range):	Clay to Sand		
Undercut Banks (%):		20.0					
Depth of Undercut (m):	0.0	0.0	0.0				

CROSS-SECTIONAL CHARACTERISTICS

	Minimum	Maximum	Average
Bankfull Width (m):	2.1	5.6	3.6
Average Bankfull Depth (m):	0.2	0.4	0.4
Bankfull Width/Depth:	6.1	15.0	10.5
Wetted Width (m):	1.8	4.2	2.5
Average Water Depth (m):	0.0	0.2	0.1
Wetted Width/Depth:	9.1	89.5	33.9
Max. Wetted Depth (m):	0.08	0.36	0.21
Manning's n:	0.037		

Representative Cross-Section (#2)



SUBSTRATE CHARACTERISTICS

Particle size

D ₁₀	16 mm
D ₅₀	37 mm
D ₉₀	80 mm

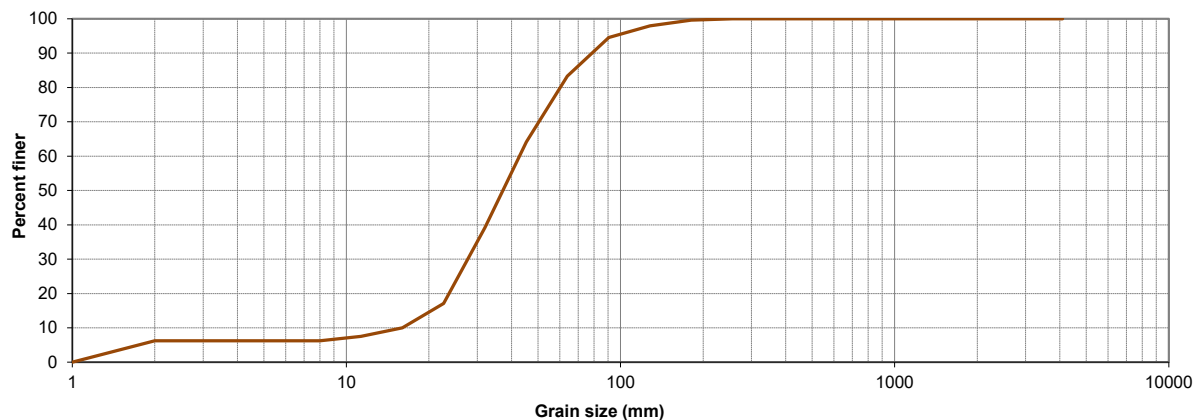
Subpavement:

Particle shape:	
Embeddedness (%):	
Particle range (riffle):	
Particle Range (pool):	

Till

Sub-Rounded
10 - 40%
Sand to Cobble
Sand to Gravel

Cumulative Particle Size Distribution



CHANNEL THRESHOLDS

Flow Competency:		Tractive Force at Bankfull:	37.8 N/m ²
for D ₅₀ :	1.0 m/s	Tractive Force at 2-year flow:	Not calculated N/m ²
for D ₈₄ :	1.3 m/s	Critical Shear Stress:	27.0 N/m ²
Unit Stream Power at Bankfull:	53.49 W/m ²		

GENERAL FIELD OBSERVATIONS

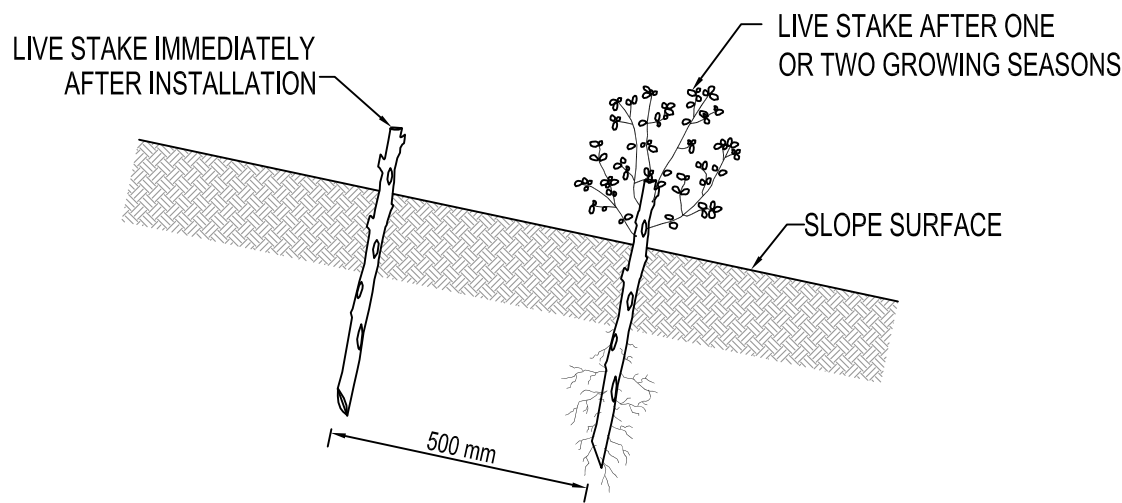
Well-defined, partially confined watercourse with narrow riparian zone. Narrow, meandering channel through Creekside Senior Estates. Predominantly riffle and run bed morphology. Steep banks comprised of sand with some silt/clay. Bed material consists of sand, gravel, and cobble. Bank protection measures such as retaining walls and rip rap lining the toe of slope. Signs of erosion on exposed banks.



Downstream view of cross section # 2

Appendix B

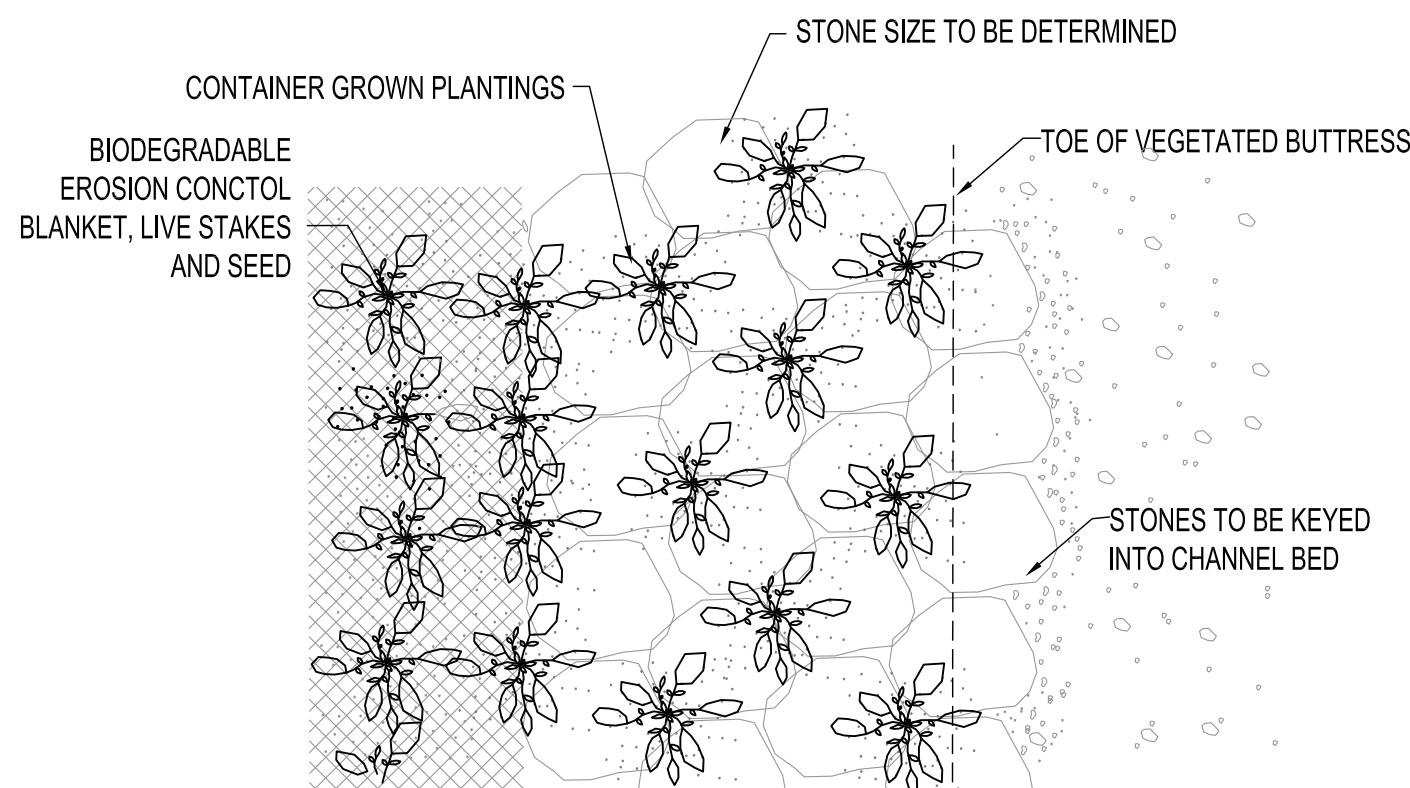
Conceptual Design Details



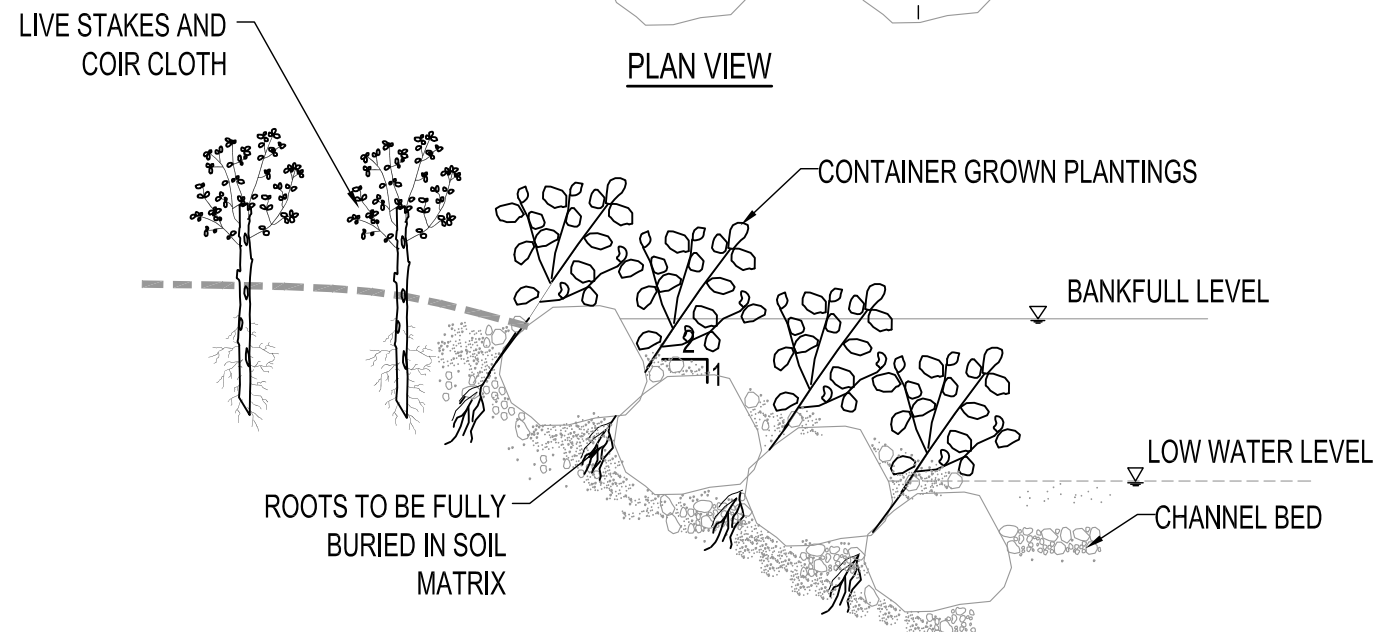
NOTES

- LIVE STAKES MUST BE CUT FROM DORMANT MATERIALS.
- LIVE STAKES SHALL BE PLANTED THE SAME DAY AS HARVESTED, OR STORED FOR A PERIOD NO LONGER THAN TWO (2) DAYS.
- THE CONTRACTOR SHALL PROTECT PLANT MATERIALS FROM DRYING AND OVERHEATING AT THE TIME OF HARVEST, DURING TRANSPORT AND DURING THE CONSTRUCTION PROCESS.
- LIVE STAKES TO BE 2.4 cm DIAMETER AND CUT TO A LENGTH OF 1.0-1.5 m
- MAKE AN ANGLE CUT AT THE BASAL END, OR BOTTOM OF THE STAKE.
- TRIM ALL SIDE BRANCHES, TAKING CARE NOT TO DAMAGE THE BARK.
- DO NOT PLANT UPSIDE DOWN.
- LIVE STAKES SHOULD BE INSTALLED USING A DEADBLOW HAMMER (LARGE RUBBER Mallet WITH THE HEAD FILLED WITH LEAD PELLETS).
- 80 PERCENT OF STAKE TO BE BELOW SURFACE.
- GENTLY TAMP THE LIVE STAKE INTO THE GROUND AT RIGHT ANGLES TO THE SLOPE.
- IF THE SOIL IS COMPACT A PILOT HOLE MADE WITH A STEEL BAR SHOULD BE USED.
- IF USING A PILOT HOLE REPACK SOIL AROUND THE STAKE.
- DENSITY OF LIVE STAKES TO BE 4 PER SQUARE METRE.

LIVE STAKE DETAIL



PLAN VIEW



CROSS-SECTION

SPECIES AND QUANTITIES

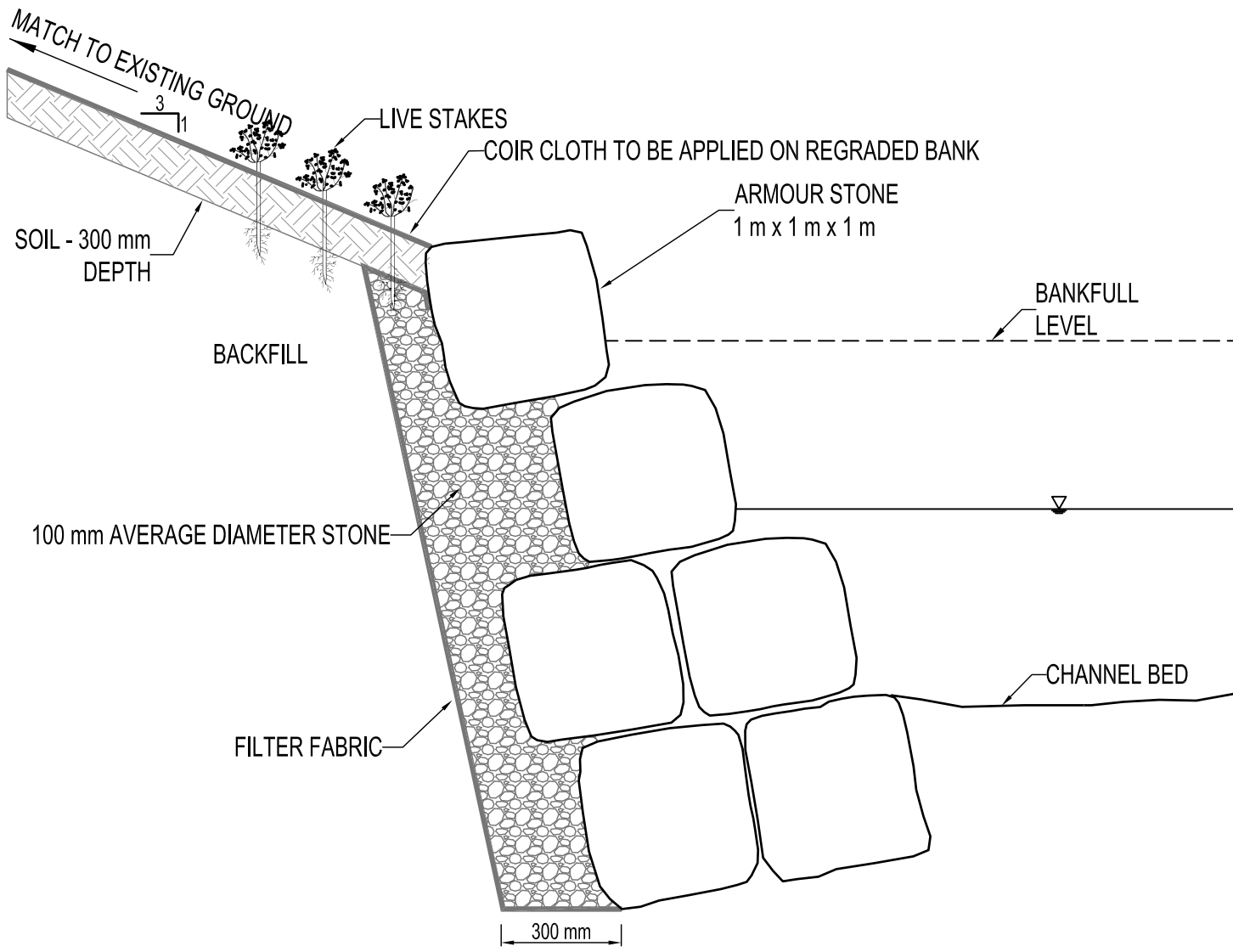
BOTANICAL NAME	COMMON NAME	QUANTITY
Salix discolor	PUSSY WILLOW	XX
Salix exigua	SANDBAR WILLOW	XX
Cornus stolonifera	RED OSIER DOGWOOD	XX

NOTES

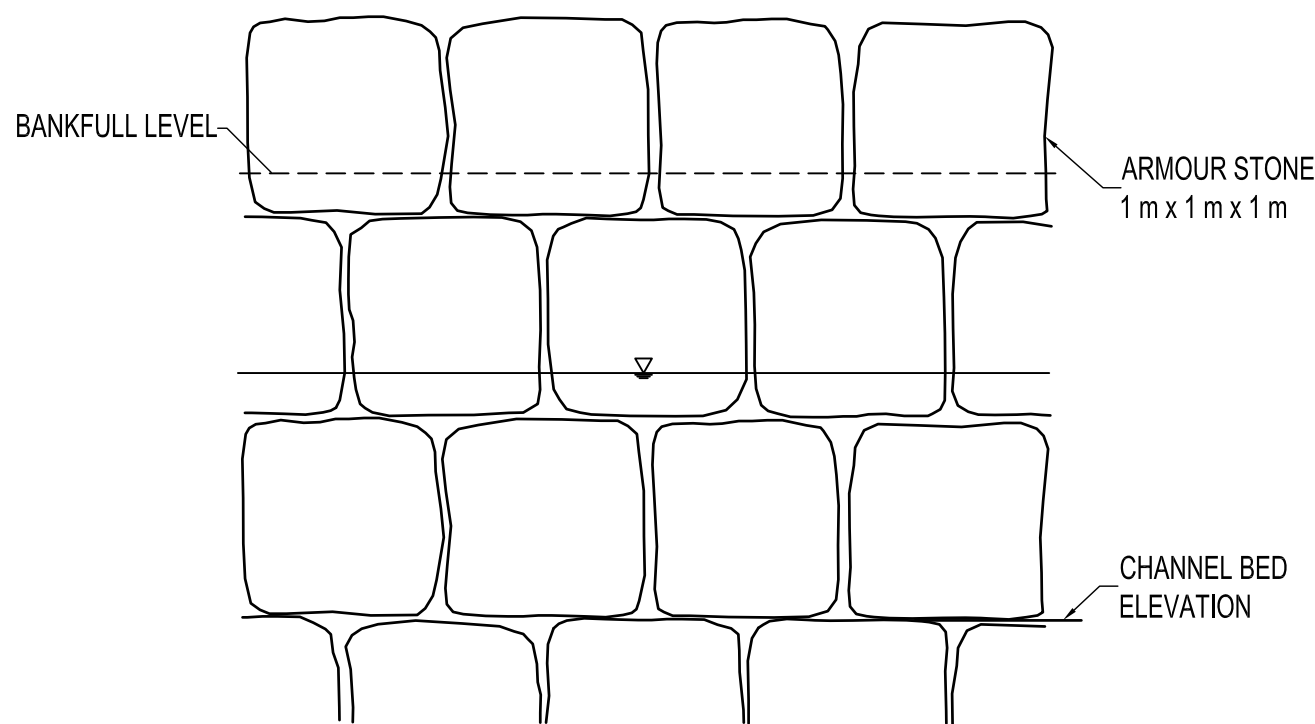
- VEGETATED BUTTRESS TO BE INSTALLED IN LIFTS.
- NUMBER OF LIFTS DEPENDENT ON BANK HEIGHT, SLOPE AND STONE SIZE.
- STONE TO BE KEYED INTO CHANNEL BED.
- PLANTS TO BE INSTALLED ONE METRE APART HORIZONTALLY IN EACH LAYER. SPECIES ARRANGEMENT TO BE RANDOM. PLANT PLACEMENT SHALL BE STAGGERED SUCH THAT THEY ARE NOT VERTICALLY ALIGNED AND ARE PLANTED 'ON CENTRE'.
- CONTAINER GROWN PLANTINGS TO BE USED IN NON DORMANT SEASON

VEGETATED ROCK BUTTRESS

N.T.S.



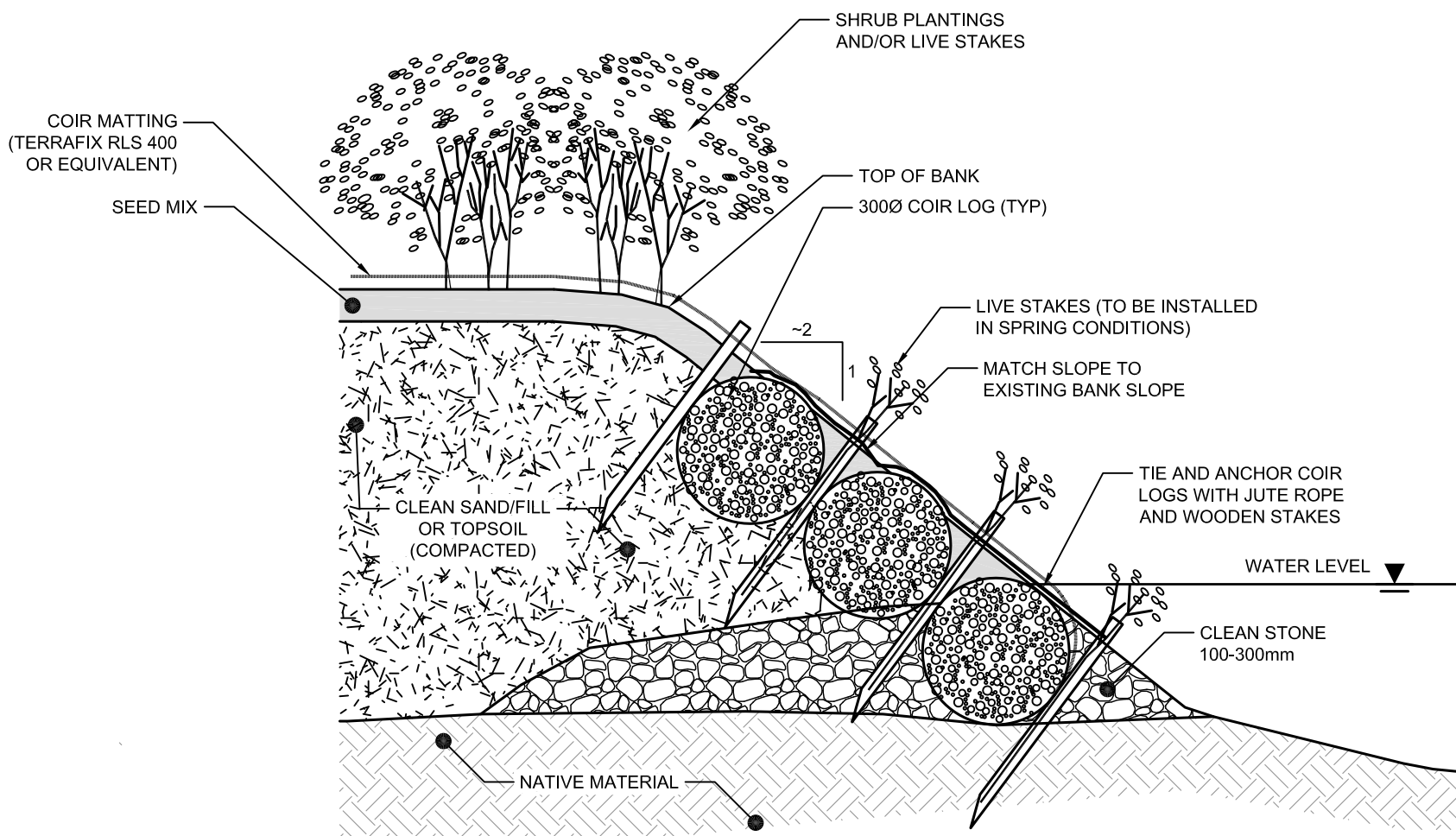
CROSS-SECTION



FRONT VIEW

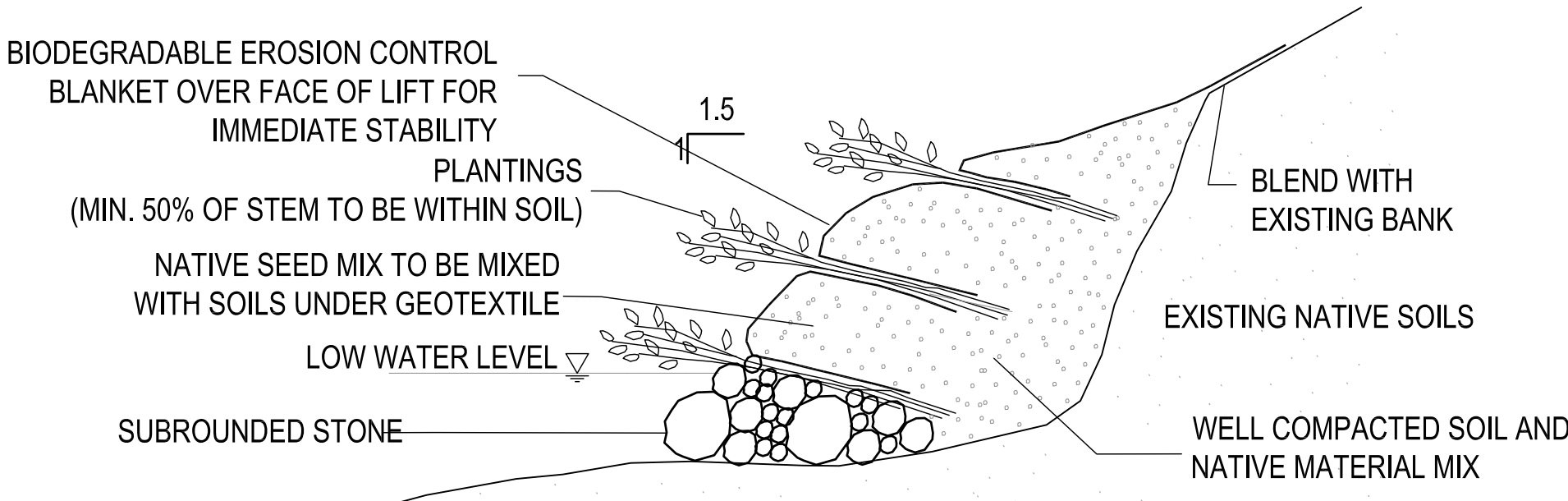
ARMOUR STONE RETAINING WALL

N.T.S.



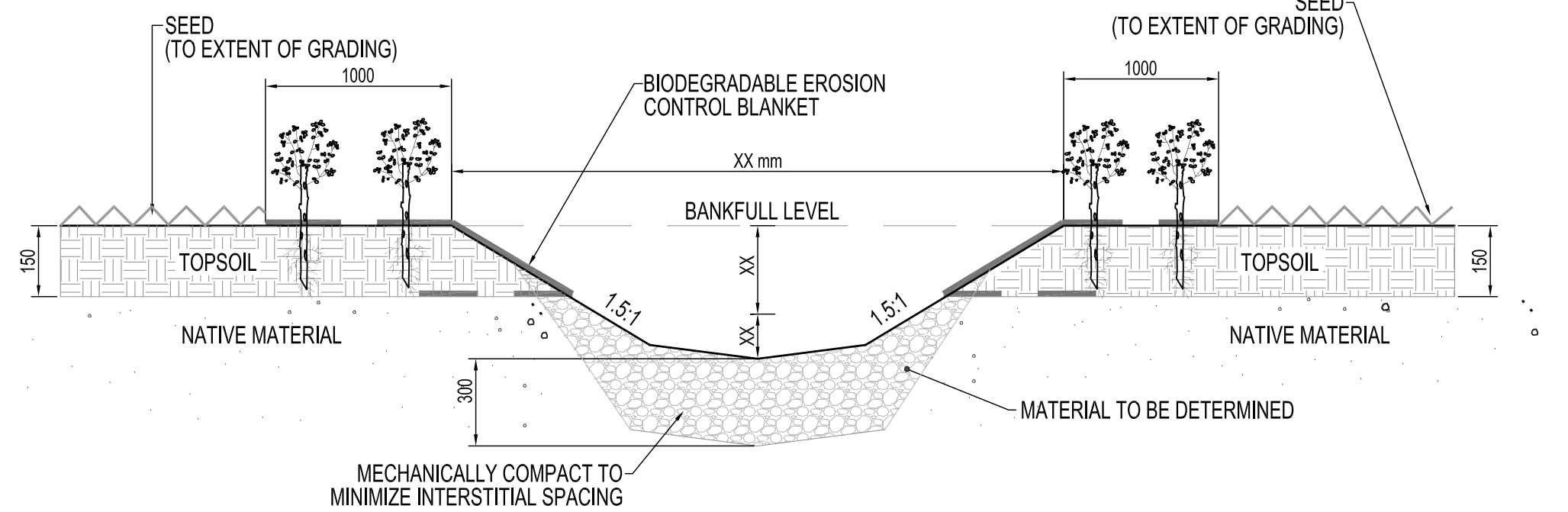
COIR LOG BANK TREATMENT

N.T.S.



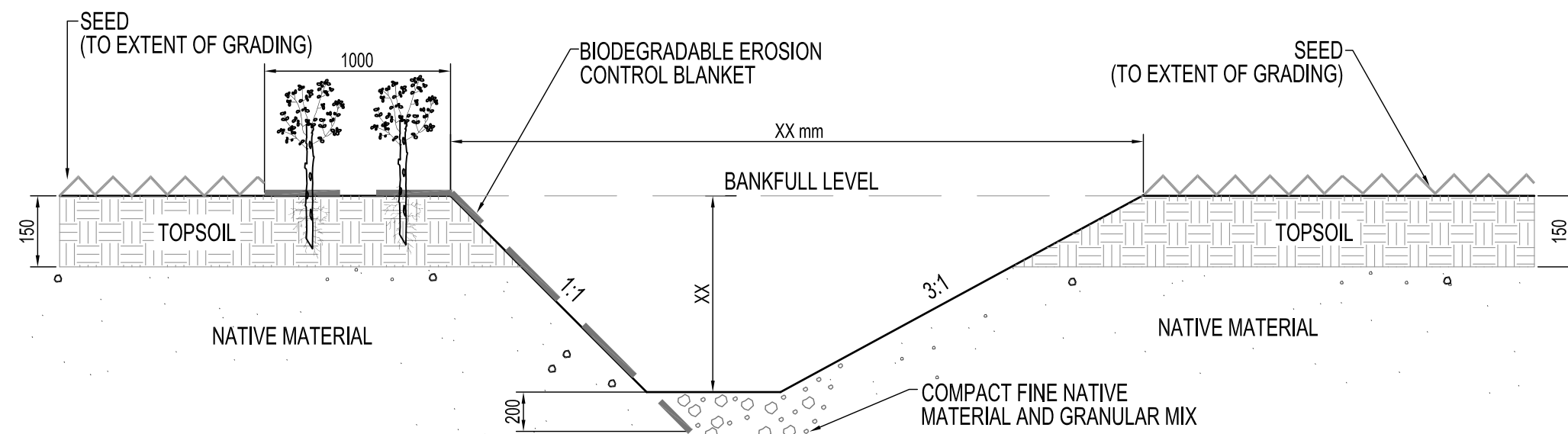
VEGETATED LAYERING WITH STONE TOE

N.T.S.



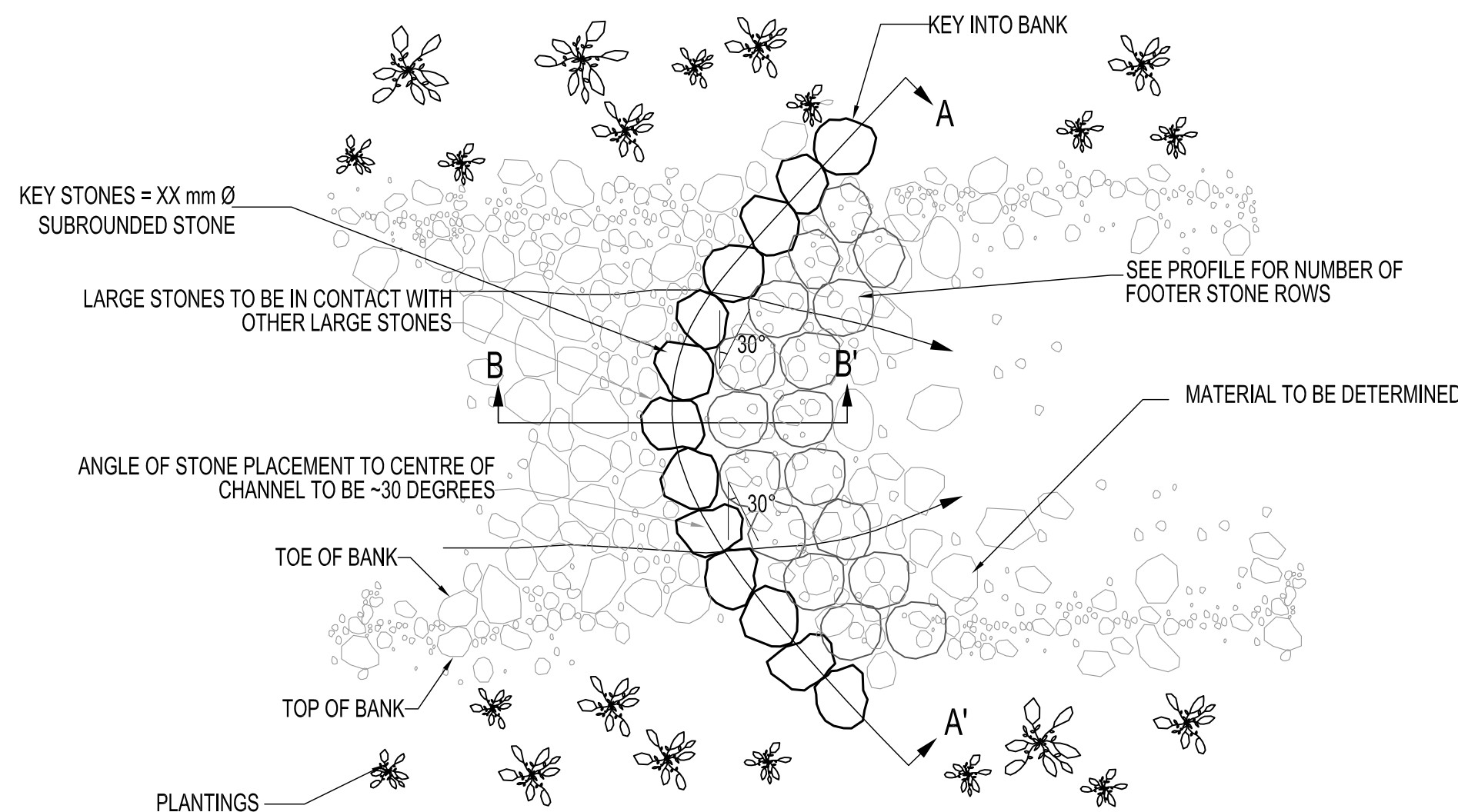
TYPICAL RIFFLE CROSS SECTION

N.T.S.

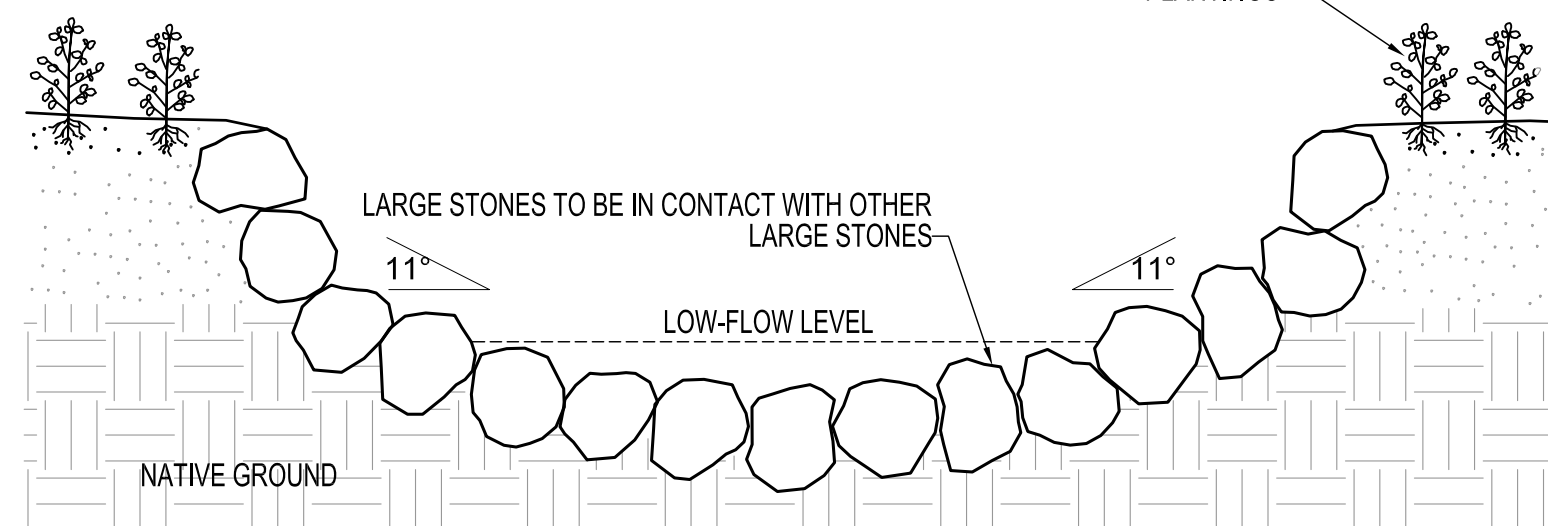


TYPICAL POOL CROSS SECTION

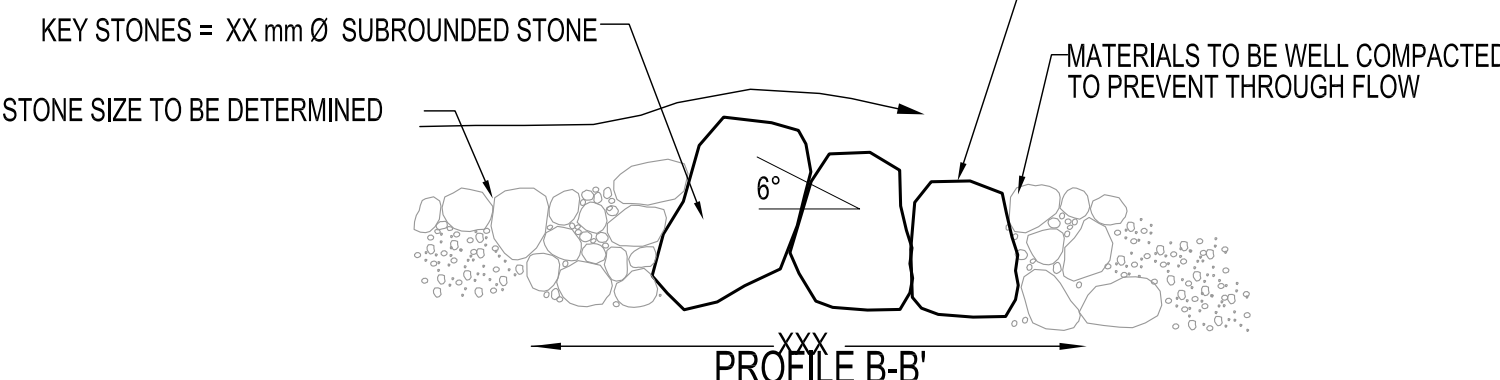
N.T.S.



PLAN VIEW



CROSS-SECTION A-A'



PROFILE B-B'

N.T.S.

ROCK VORTEX WEIR

DRAFT FOR DISCUSSION

KEY MAP

No.	Revision	Drawn	Job Manager	Project Director	Date
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Drawing Revisions

Note: * Indicates signatures on original issue of drawing or last revision of drawing

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Client **NIAGARA PENINSULA**
Project **CONSERVATION AUTHORITY**
FOUR MILE CREEK
GEOMORPHOLOGY ASSESSMENT

Title RESTORATION DETAILS

Scale	AS NOTED	DO NOT SCALE
Drawn	J.C.	
Designer	X.X.	
Drafting Check	X.X.	
Design Check	X.X.	
Approved (Project Director)	XXXXXXXXXX	
Date	XXXXXXXXXX	

This Drawing must not be used for Construction unless signed as Approved

Drawing No. Original Size

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