Appendix C:
Fluvial Geomorphological Assessment and Design Alternative Review

water's edge
ENVIRONMENTAL SOLUTIONS TEAM LTD.

City of Barrie

Whiskey Creek at Minet's Point

Fluvial Geomorphological Assessment and Design Alternative Review

December 11, 2020

TABLE OF CONTENTS

December 11, 2020
WE 20027

Mr. Daniel Twigger, B.Sc. Eng., P.Eng.
Senior Engineer
Tatham Engineering Ltd.
115 Sandford Fleming Dr.
Suite 200
Collingwood, Ontario
L9Y 5A6

Dear Mr. Twigger:

RE: Whiskey Creek - Minet's Point, Barrie, Ontario
Fluvial Geomorphological, Erosion, and Design Alternatives Assessment

1.0 INTRODUCTION

1.1 Background

Water's Edge was authorized by Tatham Engineering and the City of Barrie to conduct fluvial geomorphological investigations as part of the Whiskey Creek Class EA design phase. The Study Area and Whiskey Creek are located in Minet's Point Park in the City of Barrie. The Park is located on Lake Simcoe north of Lakeshore Ave. Repeated flooding and erosion concerns caused by Whiskey Creek through the Study Area have required the City of Barrie to investigate mitigation options for the site.

1.2 Study Scope and Purpose

The scoped purpose of the study is to complete an assessment on the fluvial geomorphological characteristics of Whiskey Creek through the Study Area. This will include general Study Area conditions, channel characterization, rapid assessments, and bankfull discharge. Additionally, an erosion threshold analysis will also be conducted to determine the potential for erosion through the site. A meander beltwidth assessment will also be completed to determine the ideal corridor width of Whiskey Creek. Lastly, Water's Edge will provide input and review any design alternatives produced by the Study Team.

Water's Edge was part of the previous phase of the EA that assessed the stream reaches throughout the City of Barrie.

We have completed our assessment of Whiskey Creek through the Study Area as per the approved methods. Data sources for the analysis include:

- City of Barrie – Drainage Master Plan (Water's Edge 2018)
- 1954, 1989, 2002, 2008, 2012, 2016, and 2019 Aerial Photos (Simcoe County),
- Physiography of Southern Ontario by Chapman & Putnam (digital data from Ministry of Northern Development and Mines (MNDM)),
- HEC-RAS Models for all watercourses obtained from Tatham,
- Ontario Flow Assessment Tools III (OFAT III) (from MNRF) and,
- Site Inspections by Water's Edge staff.

Site inspections and a geomorphic survey was completed by Water's Edge staff in September 2020. The initial site inspection was undertaken after review of the mapping and available literature was completed in order to confirm site and general system characteristics. Historical air photos were obtained from the County of Simcoe and Tatham. **Map 1** shows the site location.

1.3 Barrie Drainage Master Plan Background Review

The City of Barrie, along with Tatham Engineering and Water's Edge, completed the Drainage Master Plan (DMP) in 2018. The DMP was developed in order to address solutions with drainage deficiencies throughout the City. As part of that study all the creeks in Barrie were assessed from a fluvial geomorphological perspective. Specific areas of erosion were identified, and the erosion thresholds of specific reaches were assessed.

Whiskey Creek, and specifically the Study Reach for this assessment, was included in the 2018 DMP. The fluvial assessment portion of the DMP classified Whiskey Creek within the Minet's Point Study Area as Whiskey Creek Reach 10 (WH-10). Much of the information within the DMP is relevant to the analysis in this report.

2.0 EXISTING CONDITIONS

2.1 Geology and Physiography

Reviewing the site area's surficial materials is important to evaluate active channel processes and to understand the contributing sediment and substrate of the site. Stream channel form and sediment supply are controlled by the region's physiography and underlying surficial geology. **Figure 2.1** shows the local surficial geology of the study area.

The study area is located within the Simcoe Lowlands physiographic region and within a sand plains physiographic landform. The surficial geology of the area is a coarse textured, glaciolacustrine deposit. This is generally composed of gravel with sands which were deposited through glaciolacustrine processes. This gravel and sand are clearly present throughout the Study Reaches.

2.2 General Site Conditions

The following data was acquired using the Ontario Flow Assessment Tool III (OFAT III). The landcover percentages are based on the subwatershed upstream of the study area. Whiskey Creek is a 3rd order stream that has a total drainage area of roughly 638km^2 in size. The stream originates to the west of the site and has approximately 8 kms of length in the main channel before the Study Site. The general slope of Whiskey Creek above the Study Area is 1.0%. The major land cover/use for the Whiskey Creek subwatershed is urbanized at 76%, while forested areas and rural/agricultural make up 17% and 7.5%, respectively (OFAT III).

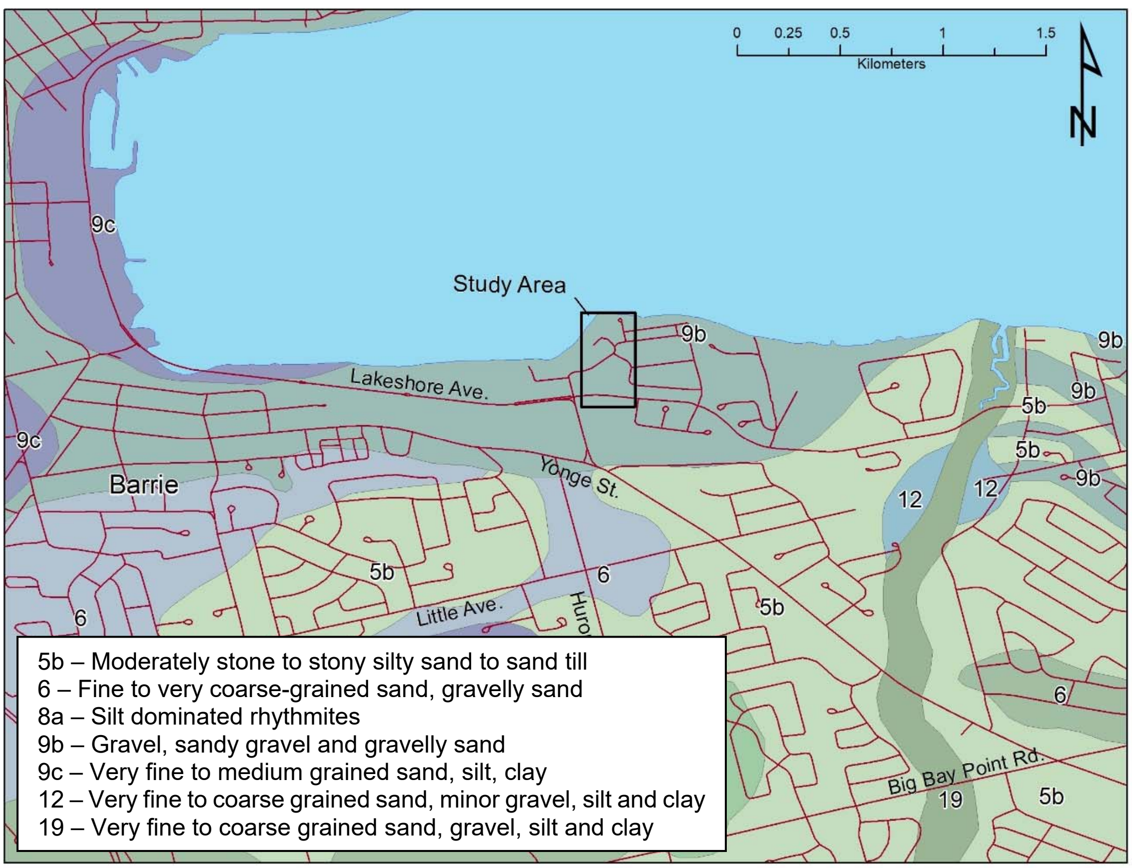


Figure 2.1: Surficial Geology (Ontario Geological Survey)

2.3 Fluvial Geomorphological Assessment

2.3.1 Reach Delineation

Channel morphology and substrate characteristics can change along a watercourse. Hence, it becomes important to account for these changes by delineating lengths of a watercourse that exhibit similar planform, sediment substrate, land use, local geology, valley confinement, hydrology and slope. In the Barrie Drainage Master Plan, the Study Area for this report was labelled as Whiskey Creek Reach 10 (WH10). This reach name will still be used for this reach of Whiskey Creek however a further breakdown of the reach will also be used to describe the creek. Reach Wh-10a is from Hurst Drive to The Boulevard. Reach Wh-10b is from The Boulevard to Brennan Ave. Reach Wh-10c is from Brennan Ave to the lake. Reach lengths for Wh-10a, b, and c are 215m, 50m, and 145m, respectively, for a total length of 410m. There are fluvial geomorphic differences from reach to reach, including slope, sinuosity, substrate, and also riparian vegetation.

2.3.2 Channel Characterization

The site visit was conducted on September 3, 2020 with a follow up visit on September 11 and multiple cross sections and a channel profile were surveyed. Each reach had a minimum of 2 cross sections surveyed to characterize the fluvial geomorphic conditions. The data collected is used to determine typical bankfull characteristics and to analyze and describe the existing conditions of the river. The characteristics of Whiskey Creek through Minet's Point Park are described below and shown in **Table 1.1**.

Reach Wh-10a

Reach Wh-10a is the longest of the sub-reaches through Reach 10. The creek meanders through a valley which it is confined in. The creek makes contact with the valley walls on a few occasions through this reach. The majority of the reach is well vegetated with mature trees and shrubs. The banks of the creek are typically steep, shaped by the scouring of the banks. Most large meanders typically have a large point bar which has been formed with sand deposition. There are many occurrences of fallen or leaning trees through the reach, and along with the significant amount of basal scour, indicates that the creek is migrating laterally.

A profile and 3 cross sections were surveyed through this reach. The average bankfull width was 5.33m. The average depth across the river at bankfull was 0.43m, while the average maximum depth through the riffles is 0.62m. The average bankfull area of the river was 2.25m^2 and the wetted perimeter was 5.78m. The bankfull slope along the Study Reach was calculated to be 0.012m/m.

The substrate found within the river is sourced from the glacial deposits of the area. These are typically made up of gravel and sand which are present in the creek. Riffles were dominated by gravels typically ranging in size from 10mm to 100mm while sands filled the interstitial voids. Clay and silt were found in slow moving sections of the river such as in pools or on the inside bend of the meanders. Sands were present in the overbank areas suggesting overtopping of the bank has resulted in deposition of finer materials.

Reach Wh-10b

Reach Wh-10b is the shortest of the sub-reaches. It runs along White Oaks Rd. between Brennan Ave. and The Boulevard. The sub reach has a very narrow riparian width with the road to the left and mowed private lawn to the right. The lack of riparian vegetation in areas has led to little root stabilization of the banks, and therefore increased erosion.

The average bankfull width was 4.24m. The average depth across the river at bankfull was 0.55m, while the average maximum depth through the riffles is 0.69m. The average bankfull area of the river was 2.63m^2 and the wetted perimeter was 5.30m. The bankfull slope along the Study Reach was calculated to be 0.013m/m.

The substrate through the reach were typically gravels and sands. The D_{50} particles size in the reach was 15.4mm, which is a small gravel. Some rip rap was located at the outlet of the upstream road crossing. This rip rap has remained close to where it was originally placed.

Reach Wh-10c
This sub-reach is the last reach and is the outlet of Whiskey Creek into Kempenfelt Bay. The majority of this reach was backwatered by the lake level at the time of the survey. Only a short section downstream of White Oaks Rd. culvert was not backwatered. The backwatering of this reach plays an important role in the fluvial geomorphic characteristics of the creek. The majority of the reach was well vegetated with mature trees and shrubs, except for on the right bank near the mouth of the creek.

Three cross sections were surveyed through this sub-reach and the average bankfull width was 5.99m. The average depth across the river at bankfull was 0.61m, while the average maximum depth through the riffles is 0.76m. The average bankfull area of the river was 3.62m^2 and the wetted perimeter was 6.54m. The bankfull slope along the Study Reach was calculated to be 0.008m/m.

Much of the reach substrates were covered over with a layer of sand, which is attributed to the backwatering of the reach. Underlying this deposition was a harder sub pavement with larger gravels and some cobbles. The D_{50} particles size within the reach was 9.67mm.

Table 2.1: Whiskey Creek Geomorphic Parameters.

Parameter	WH-10a	WH-10b	WH-10c
Bankfull Width (m)	5.99	4.24	5.33
Bankfull Mean Depth (m)	0.61	0.55	0.43
Bankfull Max Depth (m)	0.76	0.69	0.62
Bankfull Area (m^2)	3.62	2.63	2.25
Wetted Perimeter (m)	6.54	5.30	5.78
Hydraulic Radius (m)	0.55	0.49	0.40
Width-Depth Ratio	10.03	8.65	12.83
Entrenchment Ratio	1.72	1.74	2.19
Bankfull Slope (m/m)	0.012	0.013	0.008
Substrate D_{50} (mm)	28.4	15.7	9.67

2.3.3 Rapid Assessments of Channel Conditions

In addition to classification of a stream system, various techniques for geomorphic assessments are used to better understand general stream conditions (stability, habitat, erosion/degradation, riparian, etc.). In our assessment of Whiskey Creek, we used Rapid Geomorphic Assessment and Rapid Stream Assessment Technique.

Rapid Geomorphic Assessment (RGA)
River stability was assessed using a Rapid Geomorphic Assessment (MOE, 2003). The RGA assessment focuses entirely on the geomorphic component of a river system. The RGA method consists of four factors that summarize various components of channel adjustment, specifically: aggradation, degradation, channel widening and plan form adjustment. Each factor is assessed separately, and the total score indicates the overall stability of the system. This methodology has been applied to numerous streams and rivers and the following table details the ranking criteria (see **Table 2.2**).

Table 2.3 presents the results of the RGA assessments. Generally, the lower the score the more stable the channel is. With these criteria each of the sub-reaches were assessed to have a scores between 0.21 and 0.40 which ranks them as 'Transitional/Stressed'. Generally, each reach showed similar indices throughout. Two processes were particularly evident from the assessments form which are aggradation and widening. Indices present in the creek for aggradation were siltation in pools, accretion on point bars, and deposition in the overbank zone. Indices for widening were fallen/leaning trees, large organic debris, exposed tree roots, and basal scour throughout the creek. The other two categories of degradation and planimetric form adjustment had minimal indices present.

Table 2.2: Interpretation of RGA Score

Stability Index (SI) Value	Classification	Interpretation
SI ≤ 0.20	In Regime	The channel morphology is within a range of variance for rivers of similar hydrographic characteristics and evidence of instability is isolated or associated with normal river meander processes.
0.21 ≤ SI ≤0.40	Transitional/Stressed	Channel morphology is within a range of variance for rivers of similar hydrographic characteristics, but the evidence of instability is frequent.
SI ≥ 0.40	In Adjustment	Channel morphology is not within the range of variance and evidence of instability is widespread.

Table 2.3: RGA Scores and Ranking

Reach	Score	Verbal Ranking
WH-10a	0.36	Transitional/Stressed
WH-10b	0.27	Transitional/Stressed
WH-10c	0.35	Transitional/Stressed

Rapid Stream Assessment Technique (RSAT)

Rapid Stream Assessment Technique was developed by John Galli and other staff of the Metropolitan Washington (DC) Council of Governments (Galli et al, 1996). The RSAT systematically focuses on conditions reflecting aquatic-system response to watershed urbanization. It groups responses into six categories, presumed to adequately evaluate the conditions of the river system at the time of measurement on a reach-by-reach basis. The six categories are:

1. Channel stability,
2. Channel scouring and sediment deposition,
3. Physical in-stream habitat,
4. Water quality,
5. Riparian habitat conditions, and
6. Biological conditions.

Stream channel stability and cross-sectional characterization is a critical component of RSAT. The entire channel was inspected for signs of instability (such as bank sloughing, recently exposed non-woody tree roots, general absence of vegetation within bottom third of the bank, recent tree falls, etc.) and channel degradation or downcutting (such as high banks in small headwater streams and erosion around man-made structures). Observations were noted and cross-section measurements were made.

A rapid assessment of soil conditions along the riverbanks is also conducted to determine soil texture and potential erodibility of the watercourse bank. Qualitative water quality measurements were also made (temperature, turbidity, colour and odour) along with an indication of substrate fouling (i.e., the unwanted accumulation of sediment).

RSAT also typically involves a quantitative sampling and evaluation of benthic organisms. As no benthic sampling was undertaken, the score was based on site conditions and general observations of water quality.

Each category was assigned a value which was then summed to provide an overall score and ranking. **Table 2.4** details the range of scores and rankings with a higher score suggesting a healthier system.

Within these broad categories, we evaluated the sub-reaches and determined the RSAT scores which are outlined in **Table 2.5**. Reach Wh-10a received the highest score which was 35. The verbal ranking for this reach is 'Good'. This reach had higher average scores in all categories but particularly the Riparian Conditions section was significantly better due to the width of the riparian and the amount of canopy shading. Reach Wh-10b and Wh-10c had similar scores and they received poor scores in Channel Stability as well as Riparian Conditions. The width of the riparian buffer and the general lack of mature tree roots is the reason for the low scores.

Table 2.4: Interpretation of RSAT Score

RSAT Score	Ranking
41-50	Excellent
31-40	Good
21-30	Fair
11-20	Poor
0-10	Degraded

Table 2.5: RSAT Scores and Ranking

Sub-Reach	Score	Verbal Ranking
WH-10a	35	Good
WH-10b	27	Fair
WH-10c	28	Fair

2.4 Bankfull Discharge

Based on the surveyed cross sections, we have estimated bankfull flows for the existing channel through each sub-reach. Bankfull is based on channel indicators noted during site inspections. The bankfull flows can then be determined using the parameters collected. After existing bankfull flows are calculated they can be used as a guideline for determining proposed channel sizing as well as calculating the erosion threshold. In this case the bankfull flows should be the guiding principle when designing the new channel because of the disturbed nature of the site. It is however useful to compare with any available hydrology data.

The existing average channel dimensions can be seen in **Table 2.1**. **Table 2.1** includes the key components used in the analysis, including bankfull width, depth, slope, and stone sizing. With these parameters, a bankfull discharge of 7.52m^3/s, 4.54m^3/s, and 4.02m^3/s, were calculated using an assumed 'n' of 0.032 for Reaches Wh-10a, Wh-10b, and Wh-10c (see **Table 2.7** for details).

Table 2.7: Estimated Existing Bankfull Hydraulics

Hydraulic Parameter	Wh-10a	Wh-10b	Wh-10c
Relative Roughness (m/m)	7.9	13.6	7.4
Shear Velocity (m/s)	0.24	0.23	0.21
Velocity based on (ff/RR) (m/s)	**2.06**	**2.02**	**1.43**
Velocity based on assumed 'n' (0.32) (m/s)	2.18	2.05	1.44
Velocity based on Limerinos 'n' (m/s)	2.49	2.79	1.70
Bkf Discharge (ff/RR) (m/s)	**7.52**	**4.72**	**3.28**
Bkf Discharge assumed 'n' (0.32) (m/s)	7.995	4.78	3.30
Bkf Discharge Limerinos 'n' (m/s)	9.09	6.50	3.90

2.5 Flow Regression Analysis

An important concept in fluvial geomorphology is that of channel forming discharges or dominant discharges, also commonly referred to as bankfull flows. Dunne and Leopold (1978) define bankfull discharge as "*…the discharge at which channel maintenance is the most effective, that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meander, and generally doing work results in the average morphologic characteristics of channels.*" The bankfull discharges typically have an average recurrence interval of 1.5 years to 2 years. Although in some urban settings, the recurrence can be more frequent.

When re-naturalizing a channel, natural channel design concepts include the creation of a bankfull flow channel to accommodate the dominant discharge.

Hydrology data obtained from Tatham Engineering, and agreed upon by the LSRCA, is used to compare to the bankfull channel discharge. The hydrology data provided includes typical return periods of 100, (50), 25, 10, 5, and 2-year flows, however as mentioned above, the bankfull flow is often associated with the 1.5-year return period. Therefore, the provided return periods were regressed to determine the 1.5-year return period.

The results of the discharge analysis show a good correlation between the hydrology based and bankfull channel based calculations. The bankfull discharge of Wh-10b is the closest to the 1.5-yr return period discharge. The 1.5-yr flow has an average capacity from all three reaches of 4.69m^3/s, while the average existing conditions bankfull flow from the three reaches was similar at 5.17m^3/s. **Table 2.8** outlines the results of the regression analysis and **Figure 2.2** shows the regression analysis.

Table 2.8: Bankfull Discharge Analysis Results

SUB-REACH	Discharge based on friction factor/Relative Roughness (m^3/s)	1:1.5-yr Regression Analysis (m^3/s) (Tatham)
WH-10a	7.52	4.68
WH-10b	4.72	4.69
WH-10c	3.28	4.71

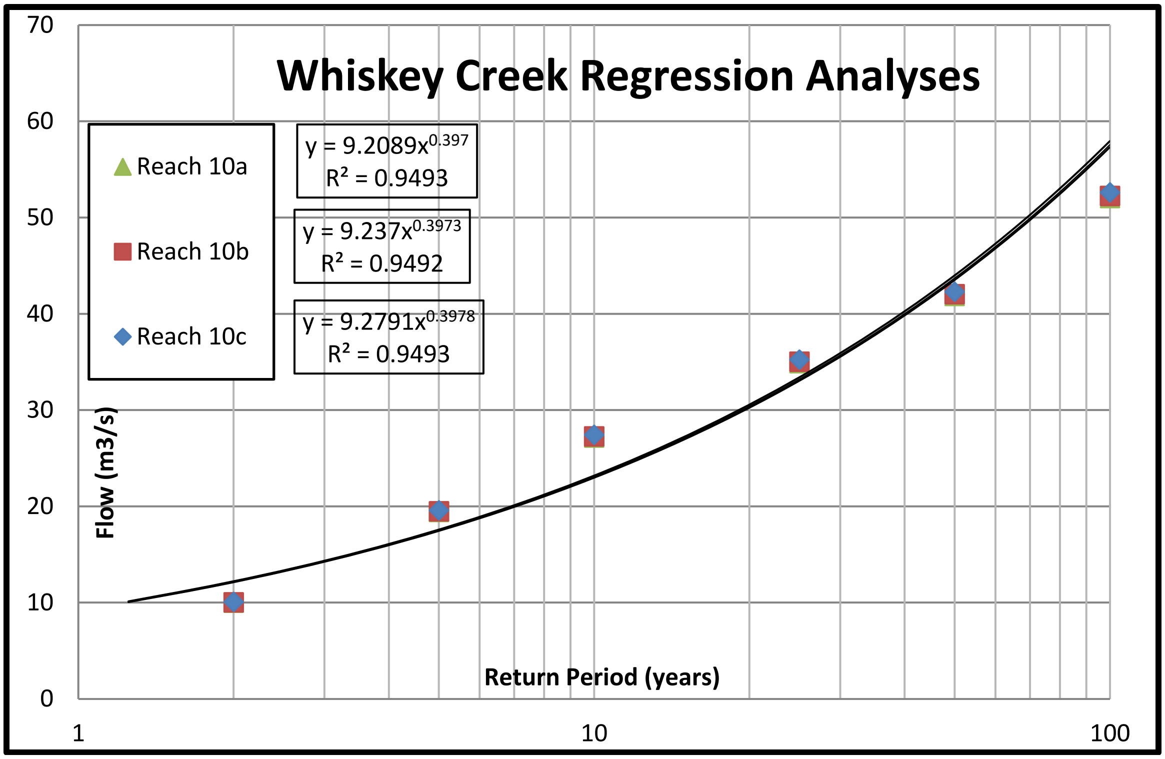


Figure 2.2: Return Period Flows Regression Analyses (data from Tatham)

3.0 EROSION THRESHOLD ASSESSMENT

3.1 Erosion Threshold Analysis

Urbanization has led to a reduction in infiltration and an increase in surficial runoff, which in turn has led to the increase in volume and rate of discharge in the receiving watercourses. This increased volume and rate of discharge not only results in increased downstream flood risk but also in increased erosion of the watercourse. As part of stormwater management, the current practice requires the establishment of erosion controls. Erosion threshold analyses support and direct various control methods for land development by the establishment of erosion control criteria to mitigate increased runoff that may adversely affect stream channel form and process.

3.2 Methodology

An erosion threshold flow represents the flow above which the channel substrate is expected to be entrained and transported. To determine this threshold flow, a critical discharge at which a channel particle of a representative size (typically D_{50} or D_{84}) is expected to undergo incipient motion, is calculated. Specifically, the critical discharge indicates the point at which sustained flows will tend to entrain and transport sediment. The critical discharge was calculated for each of the cross sections surveyed in the sub-reaches.

A geomorphic survey of the entire Whiskey Creek Reach 10 was undertaken using a combination of GPS and Total Station. For the purpose of an erosion threshold assessment, bankfull cross-sections were surveyed at a few locations, particularly riffles, where it can be expected that channel velocities and shear stresses on the bed are greatest through these sections therefore providing the most representative values. The longitudinal profile was also surveyed to determine the channel slope. Pebble-counts and sieve analyses were completed to characterize the bed materials and create a distribution to determine the D_{50} and D_{84} particle sizes. This information is listed in **Table 2.1.**

The detailed field data (cross-section, slope, and particle distribution) is used to estimate the bankfull discharge, shear stress, and critical discharge values. Typically, to determine the critical shear stress for particle entrainment, the methods presented by Komar (1987) and Fischenich (2001) are used. These methods adapt and update the work of Shields (1936). The Komar method is most appropriate to gravel sized material, while Fischenich also incorporates finer material (sands). Based on the critical shear stress determined by each method, a critical depth is back calculated. Flows are modeled at a 1 cm depth increments through each cross-section until the critical depth to mobilize the representative particle size (D_{50} or D_{84}) is achieved. The critical discharge at this depth is then calculated based the Limerinos approach for determining channel roughness. This critical discharge can then be applied as an erosion threshold target when controlling stormwater discharges input to the watercourse.

3.3 Erosion Threshold Considerations

Specific cross-section locations were surveyed within the site that potentially receives stormwater discharge. Critical threshold parameters were computed for those cross sections where bankfull indicators were considered to be reliable. Generally, naturally formed riffles for cross-sectional surveys were used as these provide locations where flows are concentrated, and their composition is indicative of the type of material that becomes mobilized under frequent flow conditions below and up to the bankfull discharge. **Figure 3.1** shows the locations selected for the cross sections. The erosion threshold of each of the cross sections surveyed in the sub-reaches were assessed.

Using the data collected during the field investigations and desktop analysis, bankfull characteristics for cross-sections were summarized. The bankfull slope, bed materials, and channel classification are also summarized. Related hydraulic parameters were determined, including stream power, unit stream power, and bed shear stress. These parameters were established at each cross-section. Of these, the critical cross sections were chosen based on the most conservative critical flow value. The results of these cross sections are summarized in **Table 3.1.**

3.4 Discussion of Erosion Threshold Results

The critical discharge values generally vary depending on the slope, roughness, and grain size of the individual cross sections. Influencing factors such as prevailing flows, land use, geology, human intervention, and in-channel structures will cause variation along the channel and need careful consideration when observing natural thresholds of erosion.

The results show that generally as substrate sizes increase, the critical flow also increases. For example, Cross Section 1 in Wh-10c has a D_{50} of 1.48mm and had a very low critical flow of 0.01m3/s, while Cross Section 7 in Wh-10a had a D_{50} of 44.19mm and a much higher critical flow of 1.75m3/s (using Fischenich method). Given that the various methods applied at the same cross section yield similar results, it is appropriate to average the results of the Shields methods of the most sensitive cross section to obtain a critical flow. This approach in determining the critical flow is fairly conservative. The results of the average critical discharge are shown in **Table 3.1.** This table also shows the ratio of bankfull flow to threshold flow (Qb_{bkf}/Q_{thr}), and the ratio of mean boundary shear stress to the average critical shear stress (average of the various Shields methods' results).

Examining these values indicates that the mean boundary shear stresses are significantly higher than the critical shear stresses. Also, the bankfull flow is much larger than the threshold flow. The correlation of these two results indicates that the Whiskey Creek is sensitive to increases in discharge as well as changes in sediment quantities.

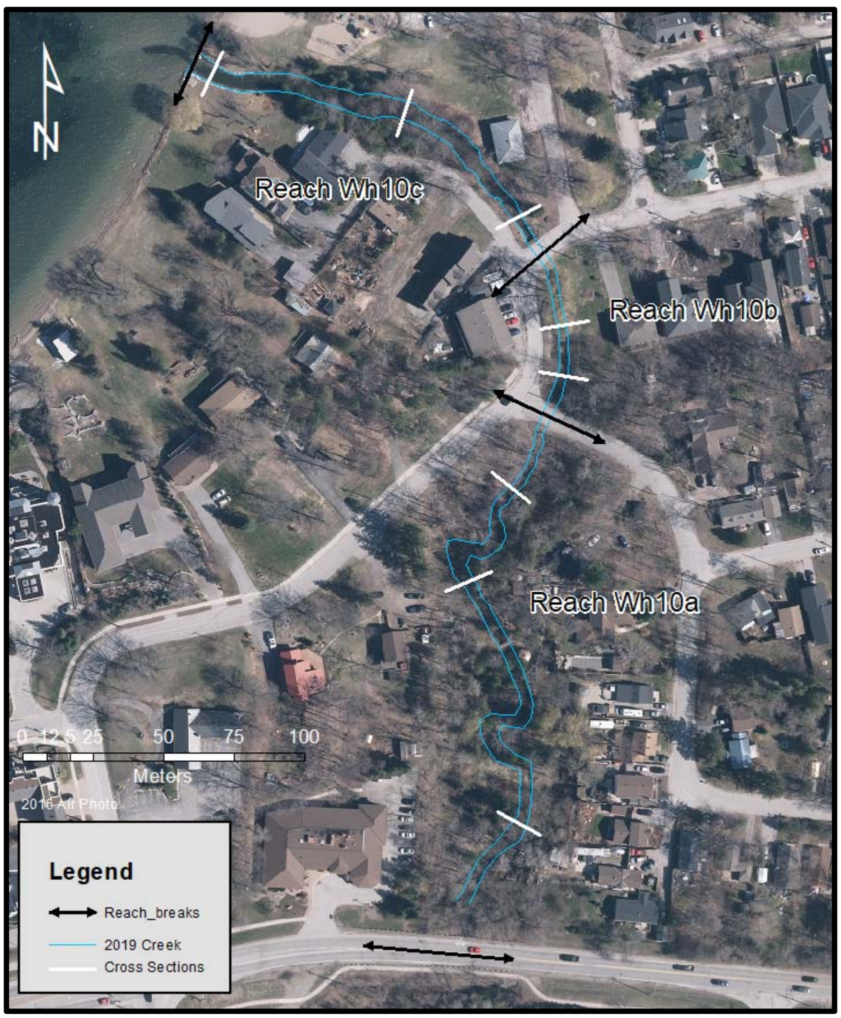


Figure 3.1: Cross Section Locations and Reaches

Table 3.1: Hydraulics & Erosion Threshold Parameters of Critical Sections – Whiskey Creek

	Reach	Wh-10c	Wh-10c	Wh-10b	Wh-10b	Wh-10a	Wh-10a	Wh-10a
	Cross Section	XS1	XS2	XS3	XS4	XS5	XS6	XS7
Geomorphic Parameters	Bankfull Width (m)	6.82	3.84	4.32	4.16	5.57	6.32	6.09
	Bankfull Mean Depth (m)	0.39	0.47	0.50	0.45	0.69	0.54	0.59
	Bankfull Max Depth (m)	0.60	0.63	0.72	0.51	0.84	0.67	0.77
	Bankfull Slope (m/m)	0.008	0.008	0.013	0.013	0.012	0.012	0.012
	Channel Substrate D_{50} (mm)	1.48	17.88	8.17	23.27	16.88	24.16	44.19
	Channel Substrate D_{84} (mm)	1.83	98.85	21.78	42.56	37.20	49.82	105.71
Hydraulic Parameters	Relative Roughness (m/m)	129.6	21.1	49.7	15.9	14.9	9.3	4.7
	Shear Velocity (m/s)	0.17	0.17	0.23	0.22	0.26	0.23	0.24
	Velocity based on FF/RR (m/s)	2.45	1.78	2.83	2.09	2.41	1.93	1.60
	Bankfull Q (m3/s)	6.52	3.21	6.11	3.92	9.28	6.60	5.74
	Froude #	1.25	0.83	1.28	1.00	0.93	0.84	0.66
	Stream Power (W/m)	511.6	251.8	779.2	499.4	1092.5	777.0	675.5
	Unit Stream Power (W/m2)	75.0	65.6	180.4	120.0	196.1	122.9	110.9
	Bed Shear τ_o (N/m2)	27.5	29.6	51.8	47.2	65.1	54.3	58.2
Komar Method	CRITICAL τ_{cr} (N/m2)	1.97	13.02	5.95	16.95	12.30	17.60	32.19
	RATIO τ_o/τ_{cr}	13.97	2.28	8.70	2.78	5.29	3.09	1.81
	Critical Hydraulic Radius (m)	0.03	0.17	0.05	0.13	0.10	0.15	0.27
	Critical Flow (m3/s)	0.01	0.27	0.03	0.44	0.32	0.57	1.34
Shields – Modified Method (Julien)	CRITICAL τ_{cr} (N/m2)	1.70	13.60	5.82	17.70	12.84	18.38	35.76
	RATIO τ_o/τ_{cr}	16.11	2.18	8.90	2.67	5.07	2.95	1.63
	Critical Hydraulic Radius (m)	0.02	0.17	0.05	0.14	0.11	0.16	0.30
	Critical Flow (m3/s)	0.01	0.30	0.03	0.48	0.34	0.62	1.73
Fischenich Method	CRITICAL τ_{cr} (N/m2)	1.70	13.57	5.76	17.66	12.81	18.33	36.01
	RATIO τ_o/τ_{cr}	16.13	2.18	8.98	2.67	5.08	2.96	1.62
	Critical Hydraulic Radius (m)	0.02	0.17	0.05	0.14	0.11	0.16	0.31
	Critical Flow (m3/s)	0.01	0.30	0.03	0.48	0.34	0.62	1.75
	Average Critical Flow (m3/s)	0.01	0.29	0.03	0.47	0.33	0.60	1.61

3.5 Proposed Channel Conditions

As part of the Class EA process the Study Team has prepared alternatives to address the flooding issues. In order to compare the existing and proposed alternative conditions, an ideal bankfull channel as well as riffle stone sizing is required. The channel and stone sizing are not meant to be used in a final design but to provide an estimate that can be used in future planning. Once the channel is sized to the bankfull conditions and a substrate stone size is calculated, the proposed channel can be compared to the existing conditions erosion threshold cross sections. This is to establish the advantages of an appropriately sized channel compared to a channel that is severely impacted.

3.5.1 Channel Sizing

The channel is sized such that it can pass the 1.5-yr flow determined by the hydrology and calculated bankfull discharges. The 1.5-yr flow as noted in **Table 2.8** has an average capacity from all three reaches of 4.69m^3/s, while the average existing conditions bankfull flow from the three reaches was similar at 5.17m^3/s. Using a Mannings 'n' channel flow formula with a target flow of 4.69m^3/s, a bankfull width and depth can be determined. The resultant bankfull width is 6.0m and mean bankfull depth is 0.40m. These parameters provide a flow of 4.74 m^3/s which is close to the target flow rate. A summary of the riffle hydraulics is shown in **Table 3.2**.

Table 3.2: Proposed Riffle Hydraulic Conditions

Parameter	Proposed Riffle
Bankfull Width (m)	6.00
Bankfull Depth (m)	0.40
Channel Area (m^2)	2.08
Slope (m/m)	0.02
Roughness ('n')	0.032
Velocity (m/s)	2.28
Bankfull Discharge (m^3/s)	4.74

3.5.2 Riffle Stone Sizing

This section addresses the design steps taken to calculate the stone sizes of the riffle stones required for the channel designs. Typically, when sizing substrate for natural channels the size of the stone is based on the calculations of average bed shear stress balanced with an understanding of the existing substrate in the channel. The Whiskey Creek Study Reaches have a gravel substrate, as noted in the fluvial assessment. A larger stone size than the existing D_{50} of the channel will mean that the stone will only move during large storm events. The riffle riverstone is sized to ensure that the bed does not remain armoured through large flood events, such as the Hazel stormflow, but does during channel-forming discharge events to ensure that the bed is protected from persistent erosion (e.g. plucking, weathering and scour). Riffle riverstone sizes were calculated for the proposed bankfull capacity.

Therefore, the stones will be sized such that their stability is not affected by the average bed shear stress τ_b. The formula for τ_b is given by: $\tau_b = \gamma D S$. In this analysis, we have assumed that D = Depth.

A critical shear stress τ_{cr} is first computed for the site. This parameter is a function of particle size as shown in the formula below (Komar, 1987): $\tau_{cr} = 0.045 g (\rho_s - \rho_w) D_{50}$

The stones are then sized such that the ratio τ_{cr} / τ_b is generally less than 1, where greater than 1 means the particle is mobile. For the purpose of developing conservative estimates, a Factor of

Safety may be included in the calculation of the average bed shear, however this is not necessary at this stage of planning. Using the equations presented, a few iterations were performed to obtain the minimum standard size for which the critical ratio is less than or near 1.

The proposed bankfull dimensions discussed previously were used to determine the stone sizing, as was the proposed riffle slope. A range of discrete particle sizes were examined using the modified Shields equation for entrainment thresholds of sediment motion (Julien, 1955). The range of sediments used in the individual analysis varied but generally ranged from 50 to 250 mm. A safety factor of 1.0 was used in the calculations. The resultant bed load entrainment threshold is shown in **Table 3.3** along with the calculations.

Table 3.3: Sediment Entrainment Threshold Parameters

Parameter	Riffle Substrate
Max Bkf Depth [m]	0.45
Riffle Slope	2.00%
Safety Factor	1.00
t_o [N/m^2]	88
t_{cr} [N/m^2]	131
t_o/t_{cr}	0.67
D_{50} [mm]	150

3.5.3 Proposed Cross Section to Existing Cross Section Erosion Threshold Comparison

Using the calculated channel size dimensions based on the hydrology, the proposed cross section was analyzed using the same methodology described in **Section 3.1**. The resultant average critical flow from the three formulae is 28.86m3/s. This flow is slightly higher than the 10-yr flow provided from the hydrologic modelling. This suggests that the channel size and stone size are adequate to sustain greater than the bankfull flow but not so armoured that it will remain in place above the 10-yr flow.

In comparison to the minimum and maximum erosion thresholds calculated from the existing cross sections in all of Reach Wh-10, the proposed cross section far exceeds these. The minimum and maximum thresholds were 0.01m3/s and 1.61m3/s, respectively while the proposed cross section was 28.86m3/s. This is largely to do with the increase in stone size for the proposed cross section. **Table 3.4** provides the results of the analysis on the proposed cross section as well as the comparison to the minimum and maximum critical thresholds from the existing conditions.

Table 3.4: Hydraulics & Erosion Threshold Parameters Comparison of Existing and Proposed

	Reach	**Wh-10**	**Wh-10**	**Wh-10**
	Cross Section	Proposed	Ex. Min.	Ex. Max.
Geomorphic Parameters	Bankfull Width (m)	6.0	6.82	6.09
	Bankfull Mean Depth (m)	0.32	0.39	0.59
	Bankfull Max Depth (m)	0.40	0.60	0.77
	Bankfull Slope (m/m)	0.015	0.008	0.012
	Channel Substrate D_{50} (mm)	150	1.48	44.19
	Channel Substrate D_{84} (mm)	300	1.83	105.71
Hydraulic Parameters	Relative Roughness (m/m)	1.90	129.6	4.7
	Shear Velocity (m/s)	0.21	0.17	0.24
	Velocity based on FF/RR (m/s)	0.92	2.45	1.60
	Bankfull Q (m3/s)	1.76	6.52	5.74
	Froude #	0.52	1.25	0.66
	Stream Power (W/m)	259.0	511.6	675.5
	Unit Stream Power (W/m2)	43.2	75.0	110.9
	Bed Shear τ_o (N/m2)	42.5	27.5	58.2
Komar Method	CRITICAL τ_{cr} (N/m2)	109.26	1.97	32.19
	RATIO τ_o/τ_{cr}	0.39	13.97	1.81
	Critical Hydraulic Radius (m)	0.74	0.03	0.27
	Critical Flow (m3/s)	25.46	0.01	1.34
Shields – Modified Method (Julien)	CRITICAL τ_{cr} (N/m2)	131.11	1.70	35.76
	RATIO τ_o/τ_{cr}	0.32	16.11	1.63
	Critical Hydraulic Radius (m)	0.89	0.02	0.30
	Critical Flow (m3/s)	30.56	0.01	1.73
Fischenich Method	CRITICAL τ_{cr} (N/m2)	131.17	1.70	36.01
	RATIO τ_o/τ_{cr}	0.32	16.13	1.62
	Critical Hydraulic Radius (m)	0.89	0.02	0.31
	Critical Flow (m3/s)	30.57	0.01	1.75
	Average Critical Flow (m3/s)	28.86	0.01	1.61

4.0 MEANDER BELTWIDTH ASSESSMENT

4.1 Background and Methodology

A meander beltwidth assessment is required as part of the Class EA process. For this study, the meander beltwidth will be useful for informing any future design decisions in regard to potential channel realignments. The LSRCA's Watershed Development Guidelines state that the meander belt allowance 'is defined as 20 times the bankfull channel width of the reach and centred on the meander belt axis, or as defined by a study completed by a qualified geomorphologist' (LSRCA, 2020). As per the LSRCA guideline a more detailed study is based on the MNRF's guideline, Understanding Natural Hazards from 2001. The MNRF's guideline discusses a similar beltwidth determination procedure which is calculated as 20 times the bankfull channel. It also discusses erosion hazard limits that can be used in conjunction to determine an appropriate corridor. Using the 20 times the bankfull width methodology, the final beltwidth of the Whiskey Creek channel would be approximately 120m. A 120m beltwidth would not be a feasible option when determining options for the channel moving forward, therefore an alternative method is required.

Conducting a typical meander beltwidth analysis on the lower portion of Whiskey Creek through Minet's Point is not useful because the channel is currently constrained, with very little sinuosity. This is particularly true for Reaches Wh-10b and Wh-10c where residential development has forced the channel to remain in the same meander axis for the past 30 or more years. However, Reach Wh-10a is different due to the valley and available floodplain area where the channel is able to meander through. Channel migration has regularly occurred through this section as can be seen in the historical channel comparison on **Map 2**. Reach Wh-10a can be used as a surrogate meander beltwidth for the lower portions near Minet's Point.

In order to identify an ideal meander beltwidth for Reach Wh-10b and Wh-10c of Whiskey Creek the meander beltwidth of Reach Wh-10a will be used. Air photos will be analyzed to delineate the historical alignment of the channel through the reach and if possible, erosion rates will also be collected using the air photos. Once the overall beltwidth of the reach is determined this can be used as the surrogate beltwidth for future planning and channel designs as an ideal, or best case scenario goal.

4.2 Air Photo Analysis

Air photos from 1954, 1989, 2002, 2008, 2012, 2016, and 2019 were used to determine the meander beltwidth of all the reaches. The air photos were analyzed for changes in the river's planform using GIS mapping. The photos are used to trace the bankfull limits of the channel which the meander axis and beltwidths are based on. The 1954 air photo is typically not useful for delineating small creeks and fine details due to the very low quality, which also proved true for this Study Reach. The 1989 air photo also proved to be inadequate to delineate the stream channel. The remaining years provided clear enough resolution to delineate the approximate bankfull channel although some of the upper reaches were difficult due to heavy canopy coverage. It is noted that heavy canopy coverage is present through all the air photos that were reviewed. Typically, the channel alignments can be used to complete a 100-year erosion analysis, however in this case there are no reliable locations to complete such an analysis.

4.3 Beltwidth Delineation

The standard practice in determining meander beltwidths is based on the TRCA's manual entitled 'Beltwidth Delineation Procedures'. This procedure is generally applicable for this situation as well. Using the Beltwidth Delineation Procedures manual, the Study Reach air photos were reviewed to determine the final meander beltwidth through Reach Wh-10a.

Typically, one of the first steps in determining the meander beltwidth of a channel is to determine whether the channel is confined or unconfined. In this case Reach Wh-10a is considered confined with large valley walls on both sides. There are a couple noted valley wall contacts in the reach where the channel has eroded into steep sections of the valley. However, the majority of the reach is setback from the valley walls and generally meanders freely through the floodplain. The confinement of the valley is not necessarily applicable in this situation because we are attempting to use the beltwidth of Wh10a as a surrogate for Wh-10b and Wh-10c where there is no confinement of the channel.

Next, the meander axis needs to be determined for the channel. The meander axis is the general valley direction or trend of a stream's planform. Once the river has a line drawn as its meander axis (seen in **Map 2**), parallel lines are drawn on either side of the primary meander axis at the outermost edge of the meanders. These parallel lines follow the meander axis of the respective reach and make up the preliminary beltwidth of the reach.

In order to account for future changes in the stream corridor erosion rates are typically applied to meander beltwidths in the form of a 100-year rate offset. These are added on top of the preliminary beltwidth (maximum historical beltwidth). No erosion rates were able to be measured from the historical air photos due to the heavy canopy coverage. In place of a 100-year erosion rate offset, a 10% offset will be applied to the beltwidth.

4.3 Final Meander Beltwidth

Based on the calculated preliminary meander beltwidths using aerial photographs, we have determined the final meander beltwidths for Reach Wh-10a of Whiskey Creek. The determination for the final beltwidth is simply the beltwidth plus the 10% erosion rate. **Map 2** shows the meander axis and final beltwidth for the Reach Wh-10a.

The average beltwidth for Reach Wh10a was calculated to be 20.0 metres, where the narrowest beltwidth was 12.9m and the widest 26.3m. The 20m beltwidth is a more practical option than that generated by the LSRCA procedure, particularly for the lower section which is in the middle of a residential neighbourhood.

This final beltwidth is provided as an ideal meander width for Whiskey Creek near the WH-10 reaches. The beltwidth does not take into account the real-world constraints that are imposed upon the creek such as roads, houses, and other infrastructure which may severely impact the final width of the Whiskey Creek meander belt. It is understood that given these constraints it may not be possible to achieve the ideal beltwidth, however every effort should be made to construct the widest possible meander beltwidth where feasible.

5.0 DESIGN ALTERNATIVES DISCUSSION

5.1 Natural Channel Design Alternatives

The study team has prepared alternatives to address the flooding concerns through the Study Area. These alternatives all include plans options that would affect the planform of Whiskey Creek, aside for the first alternative. We will discuss the alternatives from a fluvial geomorphological perspective which will include, meander beltwidths, erosion concerns, culvert sizes, channel constraints, and channel naturalization.

As noted, each of the alternatives except for the first one, which is a passive 'do nothing' alternative, include a watercourse improvement component. Any watercourse improvement will include the regrading of the existing banks for flood conveyance and the design of a bankfull channel. The alternatives can be judged against each other based on these criteria in future planning iterations. Each ranking criteria category is discussed in detail below.

Properly-Sized, Stable Stream

This category scores the alternatives based on the quality of the bankfull channel and a proper riffle-pool sequence. The combination of the bank grading and an appropriately sized bankfull channel will aid the stream during flood events to be able to access the floodplain and also reduce shear stresses through the corridor. Currently the existing channel is only able to access the floodplain in large events, while smaller events are confined to the channel. This creates greater shear stresses on the bed and bank which causes further bank erosion. A regraded stream corridor is a positive step to reducing flooding concerns not only in the short term but also in the long term as the channel is less likely to down cut if the flood flows have the ability to rise above the bankfull channel. If not properly designed, downcutting due to a channel that has not been properly connected to its floodplain will cause the flooding issues to reappear in future. An alternative is scored well for having an improved bankfull channel and an ideal riffle-pool sequence. An alternative is scored poorly for a bankfull channel that does have properly formed banks and a riffle-pool sequence that has significantly more of one feature than the other.

Meander Beltwidth

This category scores the alternatives based on the width of the regraded floodplain. The meander beltwidth analysis determined that a 20 metre beltwidth is appropriate for these reaches of Whiskey Creek and is therefore the preferred width. However, a higher scoring is possible for alternatives that have proposed beltwidths that may be wider than the calculated beltwidth. This is because in a completely natural setting the creek would have full access to meander with no constraints to hinder its planform migration. A narrow meander beltwidth is scored poorly.

Culvert Size

This category scores the alternatives based on the size of the culverts that are proposed. Small culverts are generally not able to include appropriate depths of substrate, meandering channels, or bankfull benches. Geomorphic processes, including sediment transport, are scientifically impacted by improperly sized culverts. It is recommended that at a minimum, a culvert should be three times the bankfull width to allow for a meandering channel that does not interact with the outside walls of the culvert. A wider culvert gives the ability to construct a proper bankfull channel through a culvert so that during low flow conditions the depth of water does not impede fish passage. However, similarly to the meander beltwidth of the creek, it is not always possible to achieve the recommended culvert width due to site constraints. If site constraints dictate the culvert size cannot be the recommended width, then a culvert can be sized by the appropriate hydraulic capacity. However, all culverts must be embedded or open footed and able to maintain a low flow channel through them.

Culvert Removal

This category scores alternatives based on if a culvert has been proposed for removal through the Study Reach. Two culverts are currently in use at The Boulevard and Brennan Ave. and there are proposed alternatives that include the removal of one or both of these culverts. Daylighting the channel has a number of benefits when compared to a culvert. The continuation of the full bankfull channel is preferred to the transitioning to a smaller low flow channel through a culvert. The channel banks are also able to include vegetation such as grasses and shrubs which improve the bank strength thereby reducing erosion. Culverts can also increase flow velocities which can increase the risk of erosion downstream of the culvert. Additionally, an improperly designed/constructed culvert or a culvert that has been impacted by erosion can become perched above the downstream channel which increases scour and limits fish passage. The removal of culverts eliminates any risk of these potential impacts from occurring and is therefore an advantage to a design alternative.

Erosion Risk
This category scores alternatives based the overall potential for erosion. An alternative should be scored poorly if typical bank conditions are exposed soils, inadequate substrate size and type, lack of harder bank stabilization materials at key locations, and the sediment transport ability. Sediment transport is a key component to a 'healthy' stream, or a stream that is in equilibrium. When a stream is only flushing sediments out of the system and not replacing them from upstream the channel will begin to move out of equilibrium, increasing the likelihood of erosion and bank failure. An alternative is scored well in this category for appropriate bank stabilization techniques, continuous sediment transport ability, and where key infrastructure and high-risk erosion locations are properly protected.

Riparian Conditions
This category scores the alternatives based on the conditions of the riparian zone. The riparian zone is the buffer along a stream corridor. The riparian area is ideally well vegetated and wide enough to support a variety of vegetation, from large trees, shrubs, and grasses. These varying types of vegetation provide differing degrees of root density throughout the banks which aids in the reduction of erosion. An alternative is scored high or low based on the width of the riparian area.

These criteria are developed based on the specific alternatives presented by the Study Team. Every alternative assessment has unique challenges and goals and would therefore be critique differently. These criteria are also developed from a uniquely fluvial geomorphological perspective, where simply the form and function of a stable natural channel are analyzed. Additional criteria such as flooding and natural environmental aspects related to the proposed alternatives are closely aligned with many of the criteria outlined above, however they are covered by other portions of the study.

6.0 RECOMMENDATIONS

6.1 Techniques to Minimize Erosion Impacts from Flooding

Future channel design plans should include options to limit potential bank erosion. This can include natural channel design options such as vegetated riverstone, brush mattressing, and shrub plantings. These natural techniques provide erosion protection through rooting stabilization of the banks and reduce velocities on soils. Vegetated riverstone also has the added protection of the stone during the interim when the shrubs have not yet established in the bank. After one or two seasons the roots will spread through the rock and lock them in place.

Harder options to protect specific infrastructure such as culverts, roads, buildings, or linear infrastructure are also recommended. Appropriately sized stone placed in riffles up to the bankfull elevation are recommended to stabilize the channel. A larger sized stone can be used in the bed of the riffle while a smaller gravel can be spread over top. This is to fill in the interstitial voids of the larger rock as well as provide substrate that is similar to the existing gravel substrate in the creek. Boulder cross vanes can be used to control steep gradients, protect tight bends, or to backwater a specific portion of channel such as through a culvert. Armourstone retaining walls can also be used in locations that are too narrow to accommodate with bank grading. Armourstone is a preferred method for the situations because of their stability and longevity. Gabion baskets are not recommended for any bank stabilization projects in or near watercourses, due to their high rate of failure.

It is recommended that if culverts are to be used that they be sized to comfortably include the bankfull channel. This also includes the potential for meandering in the culvert. At a minimum, a culvert should be three times the bankfull width to allow for a meandering channel that does not interact with the outside walls of the culvert. A low flow channel should be designed through the culvert that seamlessly transitions from the upstream channel to the downstream channel. The same stone sized that is used for the riffles should be used in the culverts. This is important to ensure that a box culvert bottom (if necessary) is not exposed to open flow. Open bottom arch or box culverts are preferred to closed box culverts, as recommended by the LSRCA.

6.2 Construction Impacts and Post-Construction Monitoring

Direct impacts of construction on a natural channel are difficult to quantify due to the many moving parts. Potential impacts include short term sedimentation caused by disruption of channel during construction, disruption due to temporary crossings, and erosion due to removal of bank and floodplain vegetation. Increased sedimentation from these impacts can create additional scour in downstream reaches but would more severely impact aquatic species living in the stream.

Consideration also needs to be given to the state of the existing channel and how it is currently functioning and comparing that to proposed channel conditions. The existing creek does not have an adequate floodplain which ideally reduces shear stresses on the banks and bed of the channel. This concentration of flows creates excessive erosion in various locations, while a regraded stream corridor would decrease this potential for erosion. Excessive erosion also leads to unwanted deposition of sediments into the downstream channel and ultimately Kempenfelt Bay, which to an extent can be mitigated by stabilizing the creek banks.

Post-construction monitoring should be conducted on realigned sections of Whiskey Creek. Annual site investigations should be conducted for years 1, 2, 3, 5, and 10 following completion of channel works.

The following are recommended to be included in the post-construction monitoring program:

- Established cross section surveys

- Long profile survey
- Erosion pin measurements
- Pebble counts
- Photographic inventory
- Evidence of fish habitat and fish passage
- Riparian vegetation

Cross sectional and longitudinal surveys are recommended to precisely analyze any changes in the constructed channel over time. Permanent monitoring cross sections should be established following construction and resurveyed in subsequent monitoring periods. Monitoring should also include erosion pin installation at multiple locations along the stream corridor. This will ensure that the bank stabilization techniques implemented during construction were completed satisfactorily and also confirm the long-term stability of the banks. Substrate monitoring in the form of pebble counts at established cross section locations is also recommended. Pebble counts will monitor the changes of the substrate in select riffles and pools through the Study Area. This will ensure that the riffle stone placed during construction is stable immediately following construction and also monitor the long-term sedimentation or erosion trends. A photographic inventory is also recommended to visually document any changes or trends that occur post-construction. Photos should be taken at established locations for each monitoring period. Lastly, a visual inspection for evidence of fish habitat, fish passage and the riparian vegetation should be completed and compared to previous inspections.

7.0 APPENDICES

Appendix A: Maps 1-2
Appendix B: Photographs
Appendix C: Surveyed Cross Sections

Respectfully submitted,

Ed Gazendam, Ph.D., P.Eng.,
President, Sr. Geomorphologist
Water's Edge Environmental Solutions Team Ltd.

Nik Gazendam, C.Tech. CAN-CISEC
River Restoration Technician

References

Chapman, L. J. and D. F. Putnam. 1984. The Physiography of Southern Ontario, Third Edition. Ontario Geological Survey, Special Volume 2, Ontario Ministry of Natural Resources, Toronto.

Galli, J. 1996, *Rapid Stream Assessment Technique (RSAT) field methods*. 36 pp. Metropolitan Washington Council of Governments, Department of Environmental Programs, Washington, DC.

LSRCA, 2020. Development, Interference with Wetlands and Alteration to Shorelines and Watercourses Regulation.

Ministry of Natural Resources Ontario. 2002. Technical Guide River & Stream Systems: Erosion Hazard Limits.

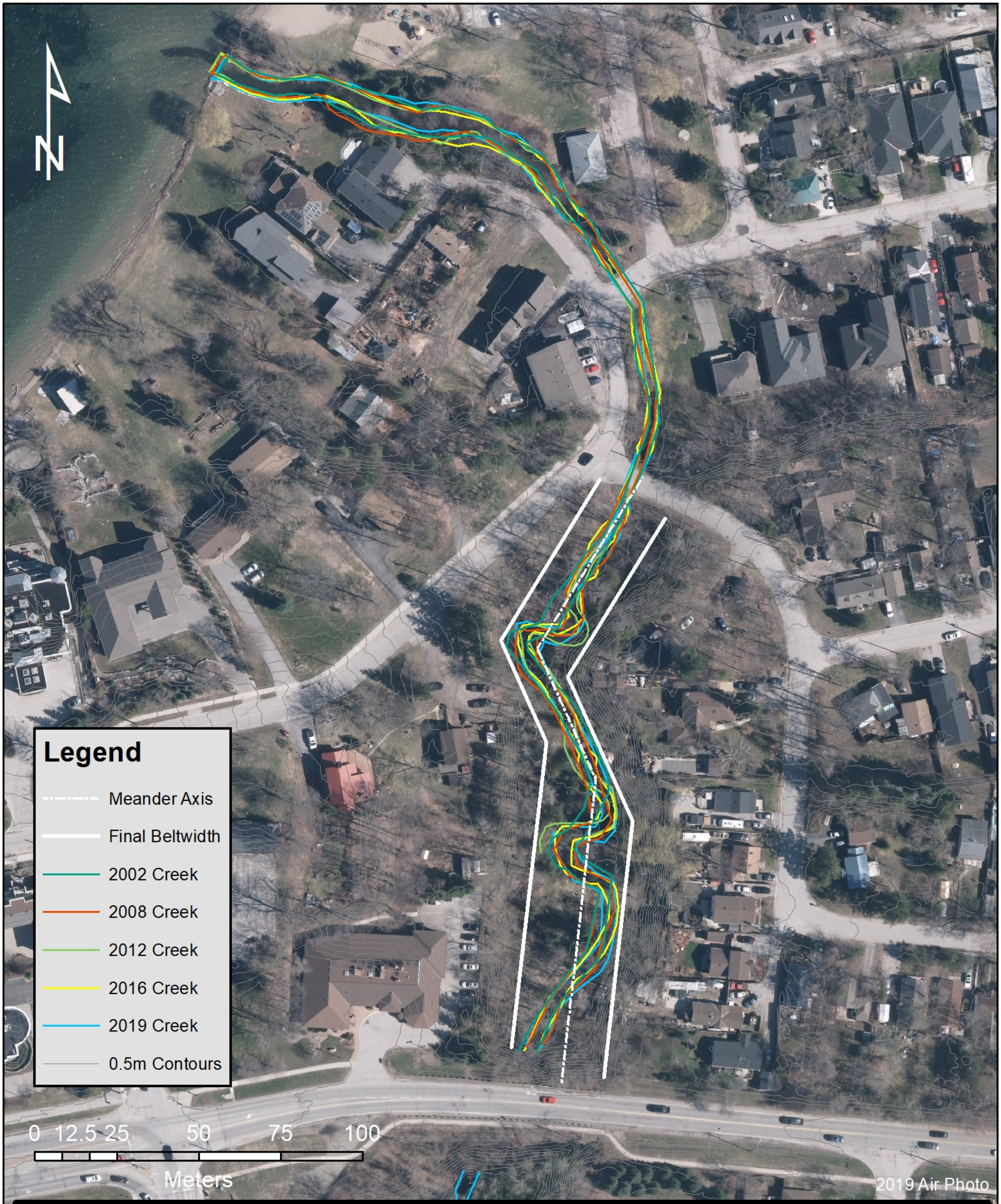
Nottawasaga Valley Conservation Authority. 2009. Planning and Regulation Guidelines.

Toronto and Region Conservation Authority. 2004b. TRCA Belt Width Delineation Procedures. Prepared by Parish Geomorphic Ltd., Sept 27, 2001 (rev'd Jan 30, 2004).

APPENDIX A:

Maps 1-2

water's edge ENVIRONMENTAL SOLUTIONS TEAM LTD.	Minet's Point Barrie, ON	Map No.: 1	Date: Oct. 9, 2020
	Whiskey Creek Study Area map with DEM	Checked By: EG	Drawn By: NG



water's edge ENVIRONMENTAL SOLUTIONS TEAM LTD.	Minet's Point Barrie, ON	Map No.: 2	Date: Oct. 9, 2020
	Whiskey Creek Final Beltwidth of Reach Wh10a	Checked By: EG	Drawn By: NG

APPENDIX B:

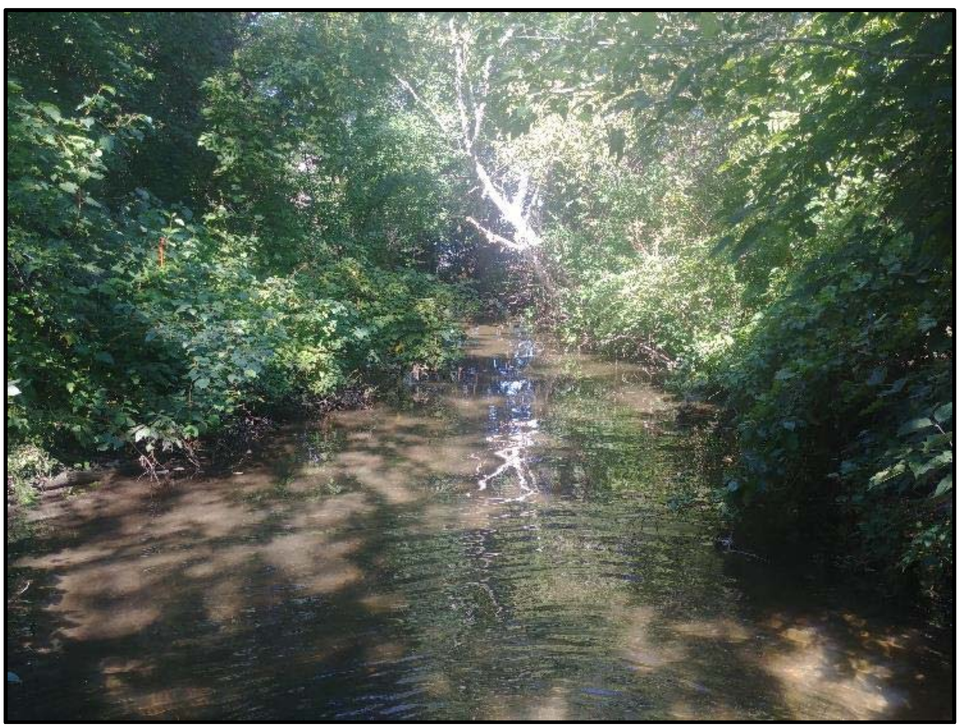
Site Photos

REACH WH10c

FROM: Right Bank
LOOKING: Downstream at Kempenfelt Bay
COMMENT: Armourstone lined channel at the mouth

FROM: Right Bank
LOOKING: Upstream
COMMENT: Armourstone lined channel at the mouth

FROM: Right bank
LOOKING: Downstream
COMMENT: Erosion issues causing fence and tree to fall into creek



FROM: Centre of creek
LOOKING: Upstream
COMMENT: Typical creek conditions, sandy bottom due to backwater

FROM: Centre of creek
LOOKING: Upstream
COMMENT: Deposition on right bank

FROM: Centre of creek
LOOKING: Upstream at box culvert for Brennan Ave.
COMMENT: Gabion leaning, rip rap protecting creek bed

FROM: Centre of creek
LOOKING: Upstream at box culvert for Brennan Ave.
COMMENT: Gabion visible on right side

FROM: Centre of creek
LOOKING: Upstream through box culvert
COMMENT: No distinct low flow channel

REACH WH10b

FROM: Centre of creek
LOOKING: Downstream towards box culvert at Brennan Ave.
COMMENT: Gabion basket lined channel

FROM: Centre of creek
LOOKING: Upstream
COMMENT: Deposition in pools, undercut banks

FROM: Centre of channel
LOOKING: At left bank, towards White Oaks Rd
COMMENT: Bank erosion, woody debris common, road in close proximity

FROM: Centre of channel
LOOKING: At right bank, towards private property
COMMENT: Heavy bank erosion

FROM: Centre of creek
LOOKING: Upstream towards culverts at The Blvd
COMMENT: Gravel substrate becoming more typical, undercut banks

FROM: Centre of creek
LOOKING: Upstream towards culvert at The Blvd
COMMENT: Rip rap present at downstream end of culvert

REACH WH10a

FROM: Centre of creek
LOOKING: Downstream at culvert for The Blvd
COMMENT: Erosion around culvert, rip rap has been placed and partially failed

FROM: Centre of creek
LOOKING: Upstream
COMMENT: Undercut banks common, gravel substrate typical

FROM: Centre of creek
LOOKING: Upstream at left bank
COMMENT: Undercut banks, sand deposition on the overbank

FROM: Centre of creek
LOOKING: Upstream at left bank
COMMENT: Undercut banks

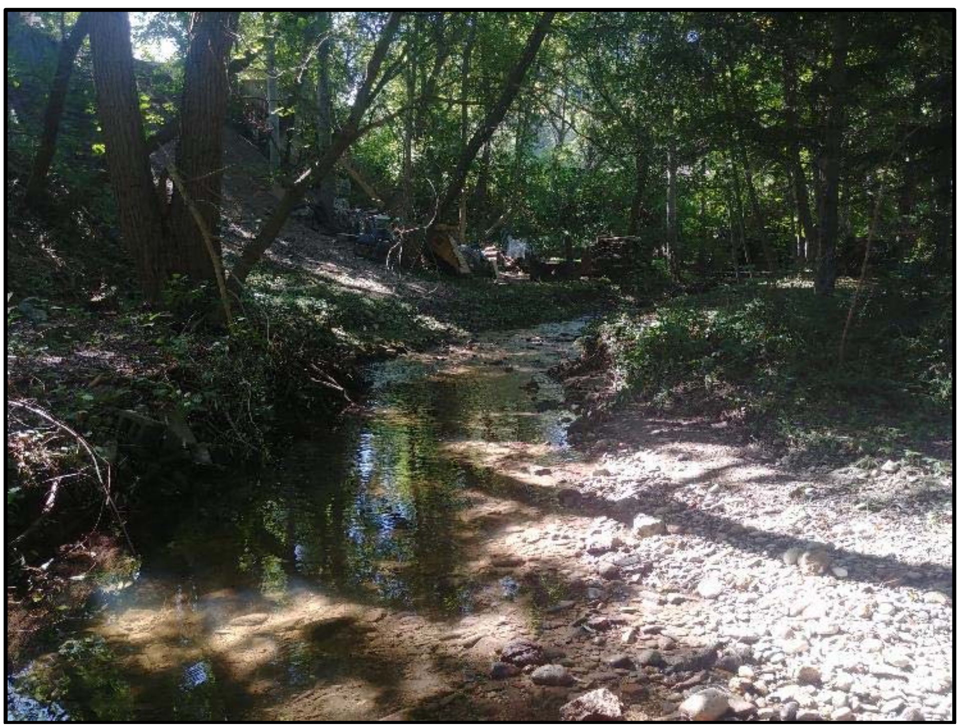
FROM: Centre of creek
LOOKING: Upstream
COMMENT: Deposition on point bar, valley wall contact, leaning trees

FROM: Centre of creek
LOOKING: Upstream
COMMENT: Eroding banks, leaning trees, gravel substrate

FROM: Centre of creek
LOOKING: Upstream
COMMENT: Undercut banks, small creek crossing

FROM: Centre of creek
LOOKING: Upstream
COMMENT: Undercut banks at outside meander bend

FROM: Centre of creek
LOOKING: Upstream
COMMENT: Significant deposit of rip rap, and large gravels from upstream plunge pool



FROM: Centre of creek
LOOKING: Upstream towards Hurst Dr culvert
COMMENT: Heavy erosion on both banks, debris and personal items on floodplain

FROM: Centre of creek
LOOKING: Upstream towards Hurst Dr culvert
COMMENT: Heavy erosion on both banks

FROM: Centre of creek
LOOKING: Upstream towards Hurst Dr culvert
COMMENT: Culverts are perched, deep scour pool at outlets

APPENDIX C:

Surveyed Cross Sections

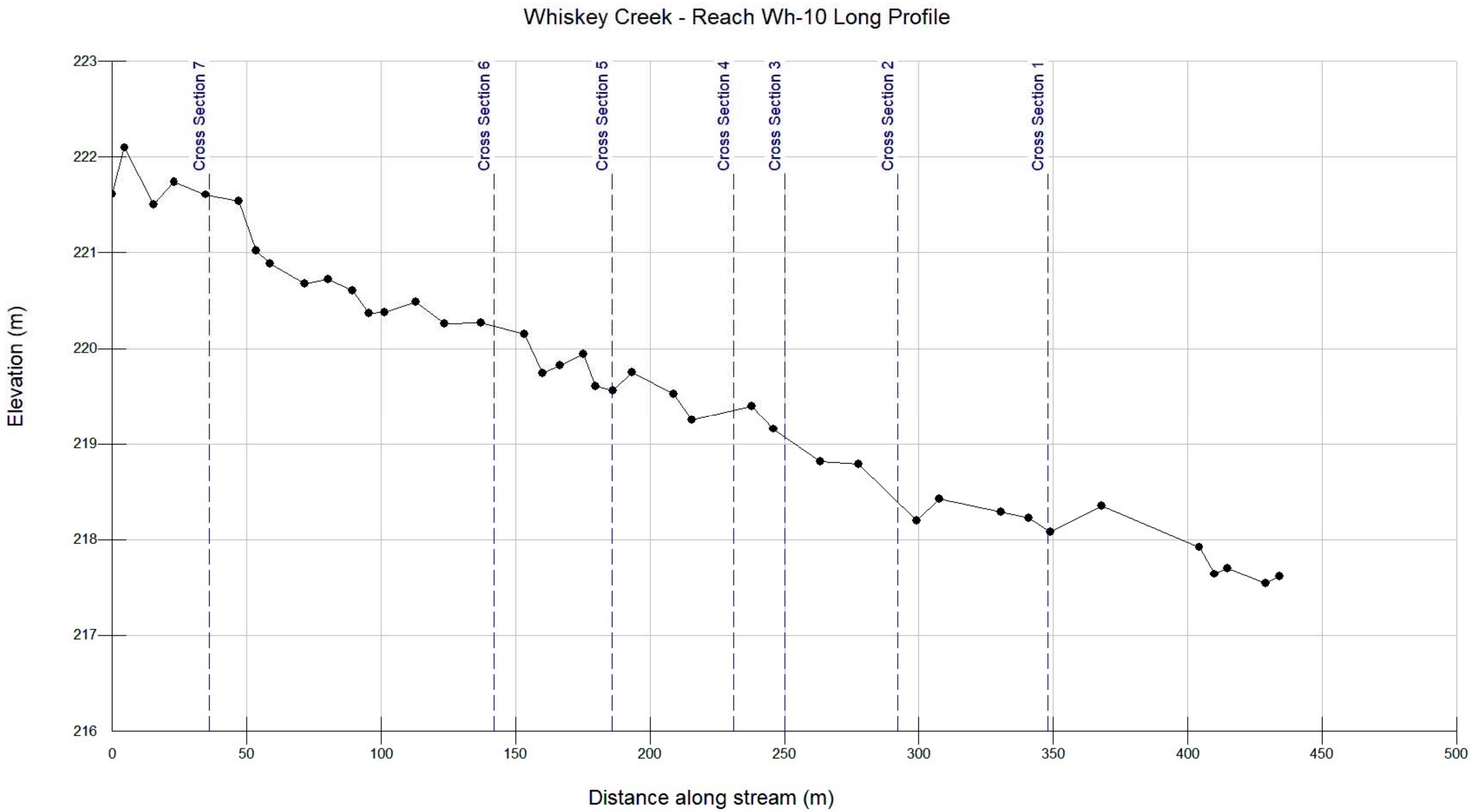


Figure 1: Whiskey Creek Reach Wh-10 Profile

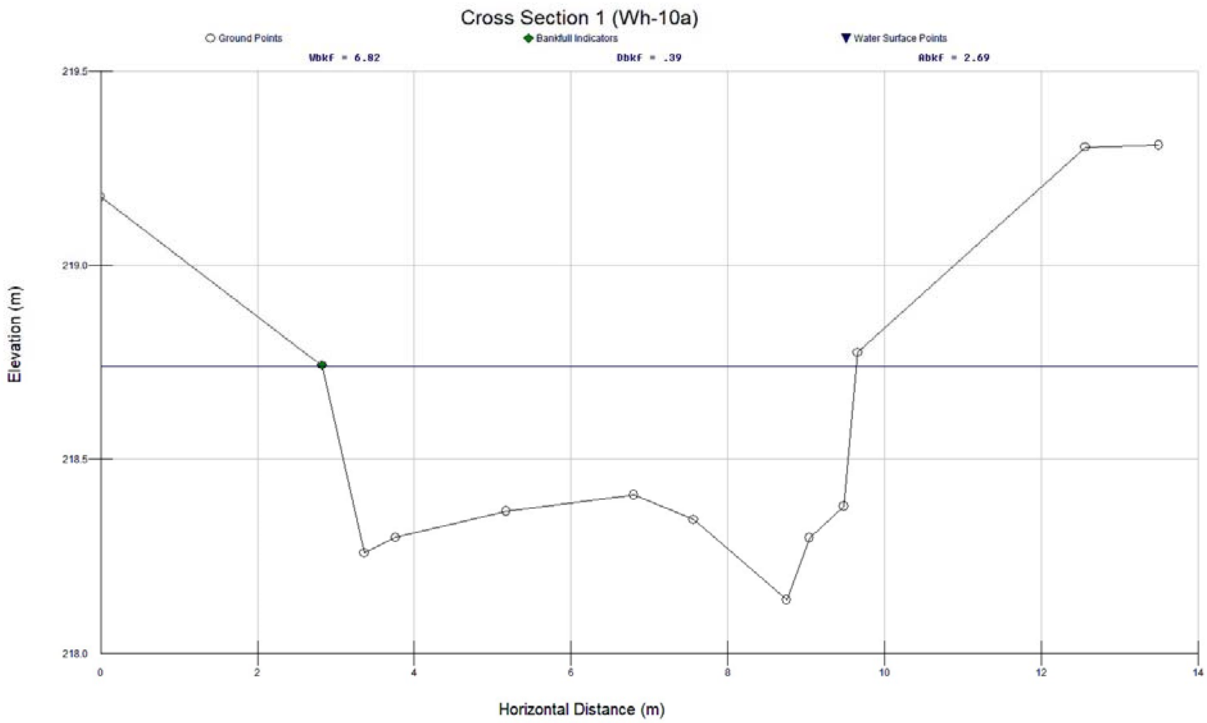


Figure 2: Cross Section 1

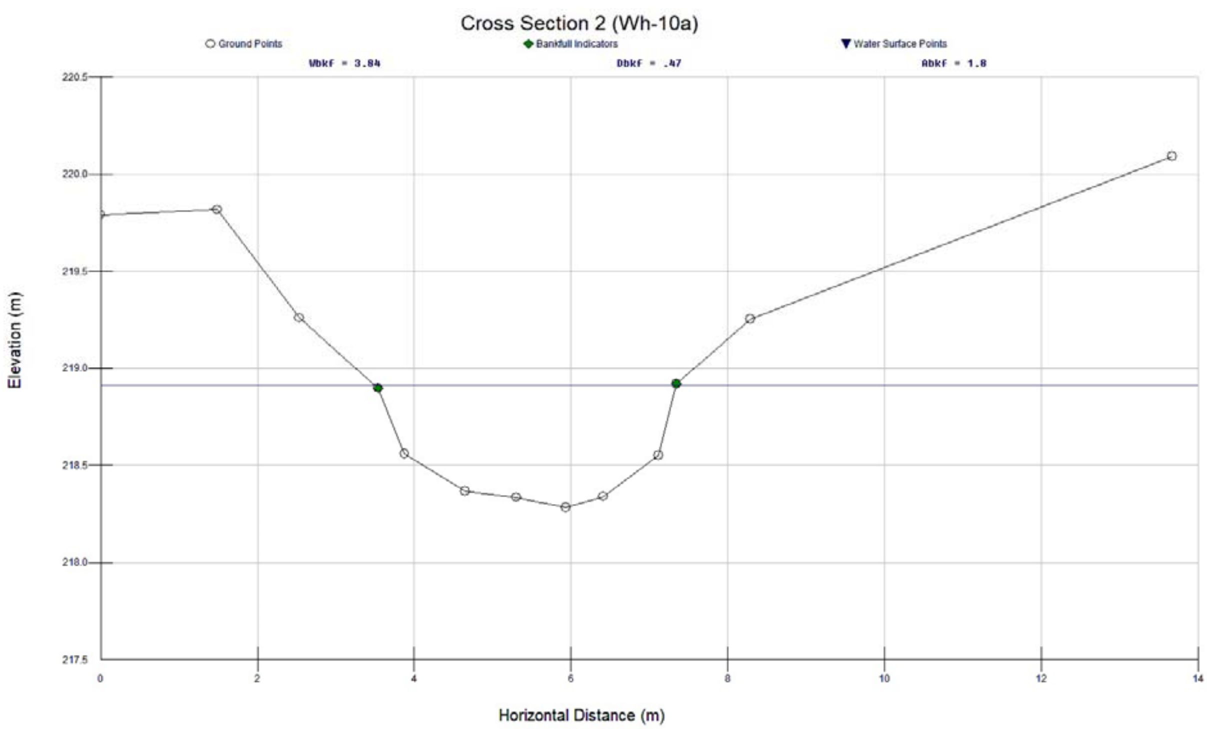


Figure 3: Cross Section 2

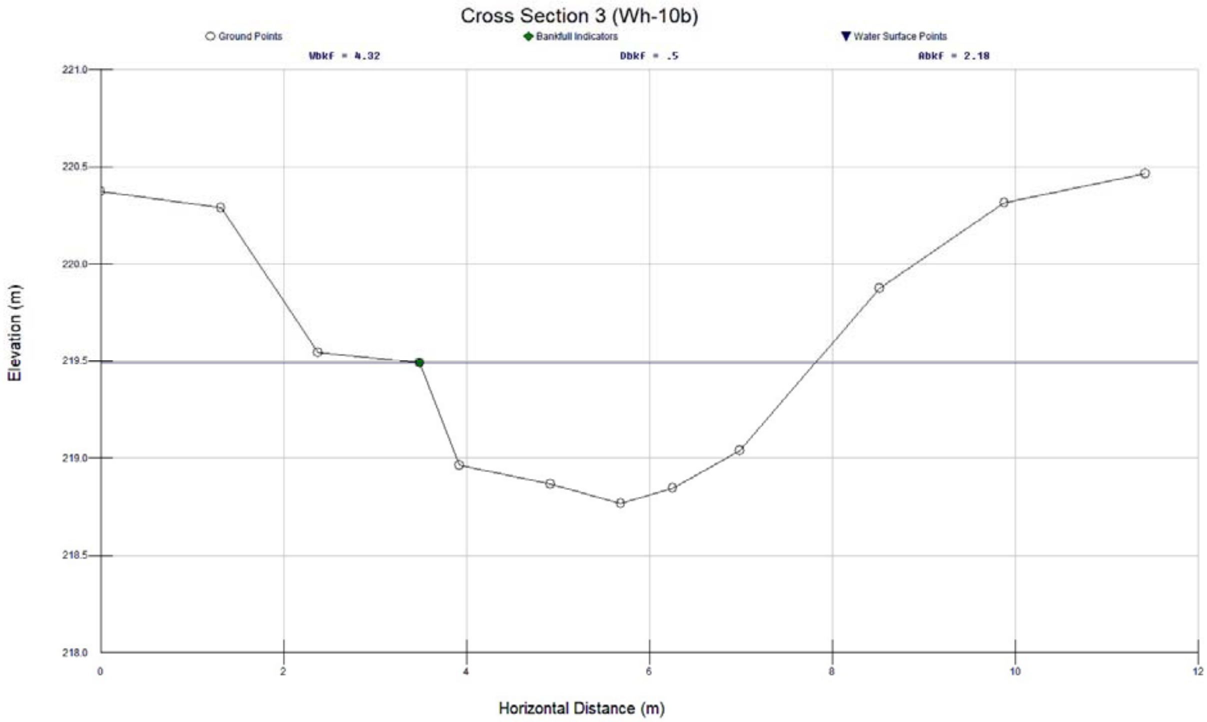


Figure 4: Cross Section 3

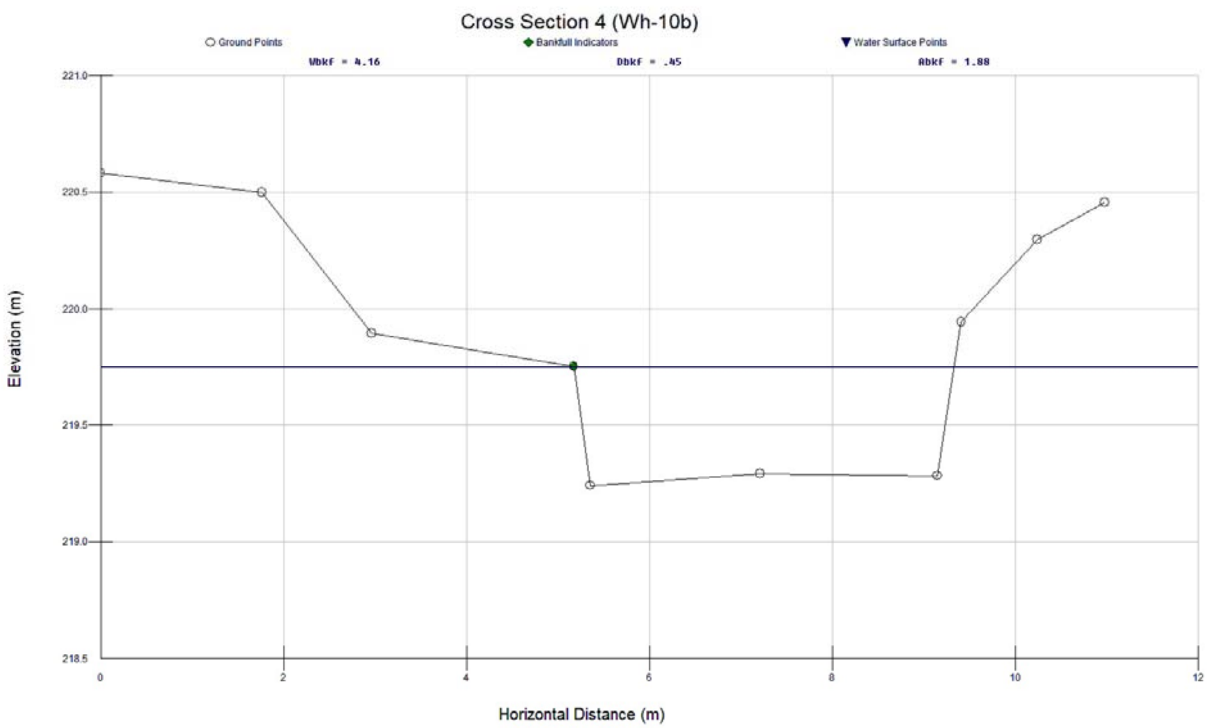


Figure 5: Cross Section 4

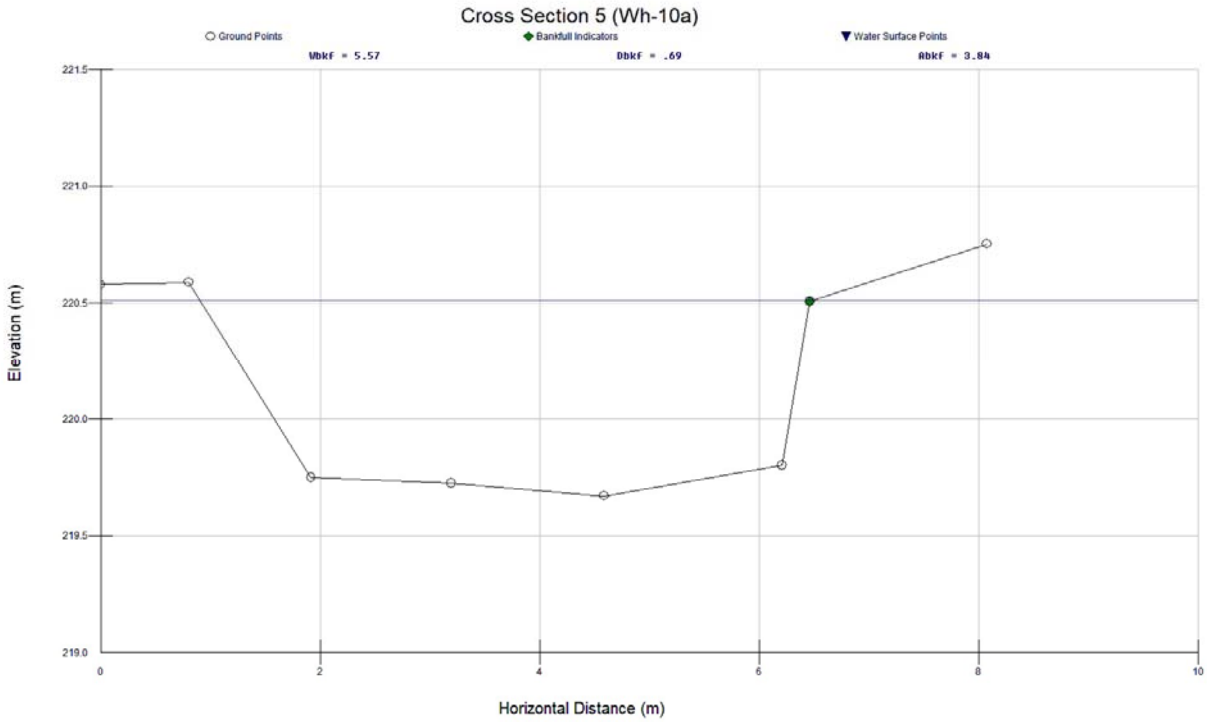


Figure 6: Cross Section 5

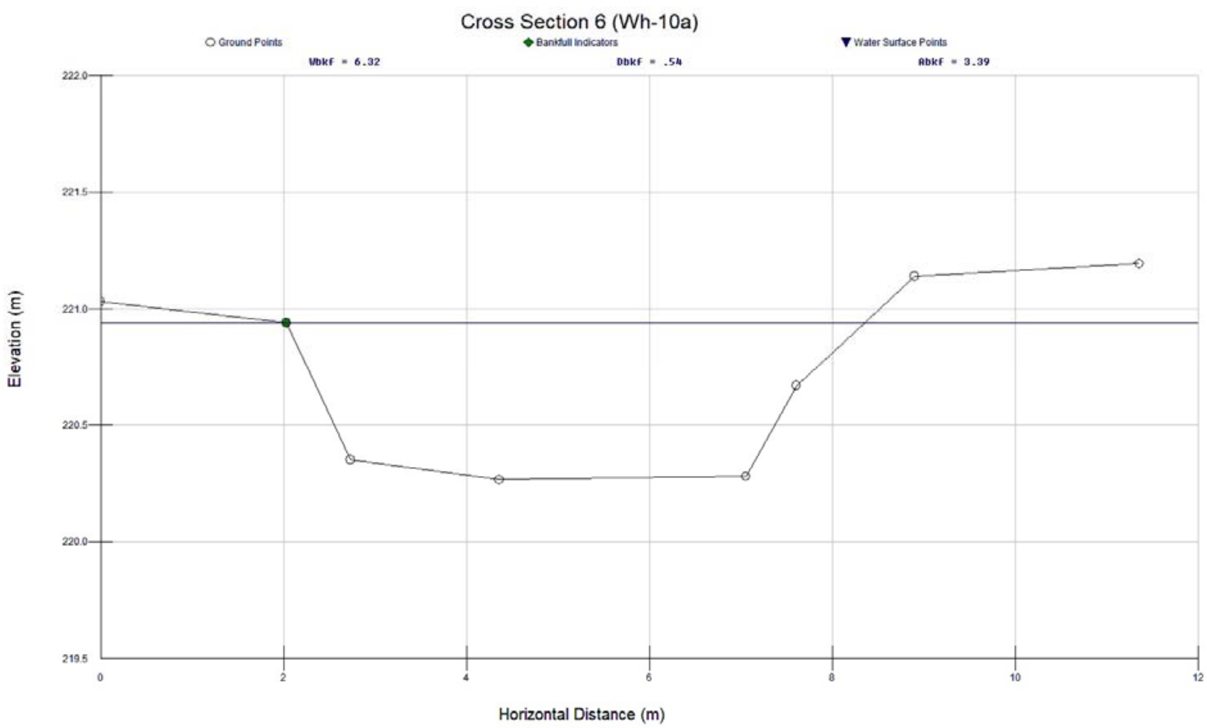


Figure 7: Cross Section 6

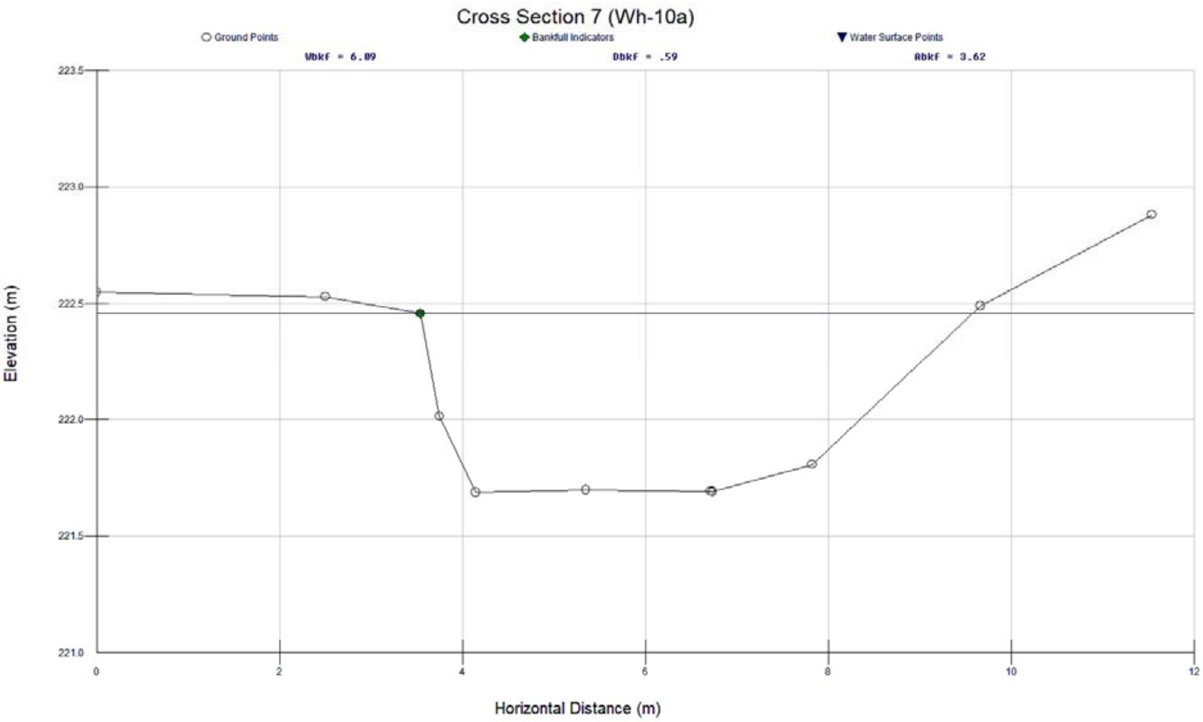


Figure 8: Cross Section 7