

Upper Blackfoot Mining Complex Restoration Project

Reference Reach Geomorphic Data Summary Report



Submitted To:

State of Montana
Department of Justice
Natural Resource Damage Program
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Executive Summary

Currently, remedial actions related to removal of the Mike Horse Dam and impoundments, and removal of mining tailings associated with the Upper Blackfoot Mining Complex (UBMC), are in the planning stages. In 2011, the State of Montana Natural Resource Damage Program (NRDP) developed preliminary restoration design concepts for streams and floodplains that will be impacted by remedial actions. The purpose of the preliminary design was to define the restoration vision for the site so removal and remediation actions can support a desired restoration outcome. The final report, *Conceptual Restoration Plan for the Upper Blackfoot Mining Complex* (River Design Group, Inc., Geum Environmental Consulting, Inc., WestWater Consultants, Inc. 2011), identified additional data needs that would be required to support feasibility analysis, alternative development, and preliminary design. Among the recommendations was to identify and study geomorphic reference reaches to support the development of natural channel design criteria. In cooperation with NRDP and Montana Fish, Wildlife and Parks (FWP), River Design Group, Inc. (RDG) completed surveys in August 2012 on four main tributaries to the Blackfoot River near Lincoln, Montana, including Anaconda Creek, Arrastra Creek, Copper Creek and Snowbank Creek (Figure 1-1). The selected river segments represented a wide range of stream and floodplain morphologies including lower gradient, riffle-pool stream types developed within terraced alluvial valleys (i.e. C stream types) to steep, confined step-pool stream types bracketed by terraces (i.e. B stream types). Channel gradients ranged from 0.8% on Copper Creek to 3.3% on Anaconda Creek.

Eight cross-sections and a longitudinal profile were completed in each river segment. To obtain a range of values, two cross-sections were completed on riffle, run, pool and glide habitat units. Surveyed features included channel thalweg, water surface, bankfull and terrace elevations. The longitudinal profiles began and terminated at top of riffle features and included channel thalweg, water surface and top of bank or bankfull elevations. Channel planform was assessed to determine sinuosity and to characterize the range of natural variability for select planform dimensions including meander belt width, meander length and radius of curvature.

Channel substrate analyses were completed on riffle features and pavement and sub-pavement analyses were conducted on depositional features associated with the lower gradient stream reaches. Large woody debris, both single pieces and aggregates, were inventoried throughout each reach. All qualifying wood within the bankfull channel margins were inventoried, including dead standing trees. Copper Creek and Snowbank Creek have been impacted by wildfire, while Anaconda Creek and Arrastra Creek remain heavily forested. The morphological data were analyzed and developed into dimensionless ratios, stratified by stream type, to support near-term project planning and design efforts for stream reaches of similar potential morphology in the UBMC project area. This document satisfies an important data gap identified in the 2011 conceptual restoration plan and will be supplemented with other data as necessary.

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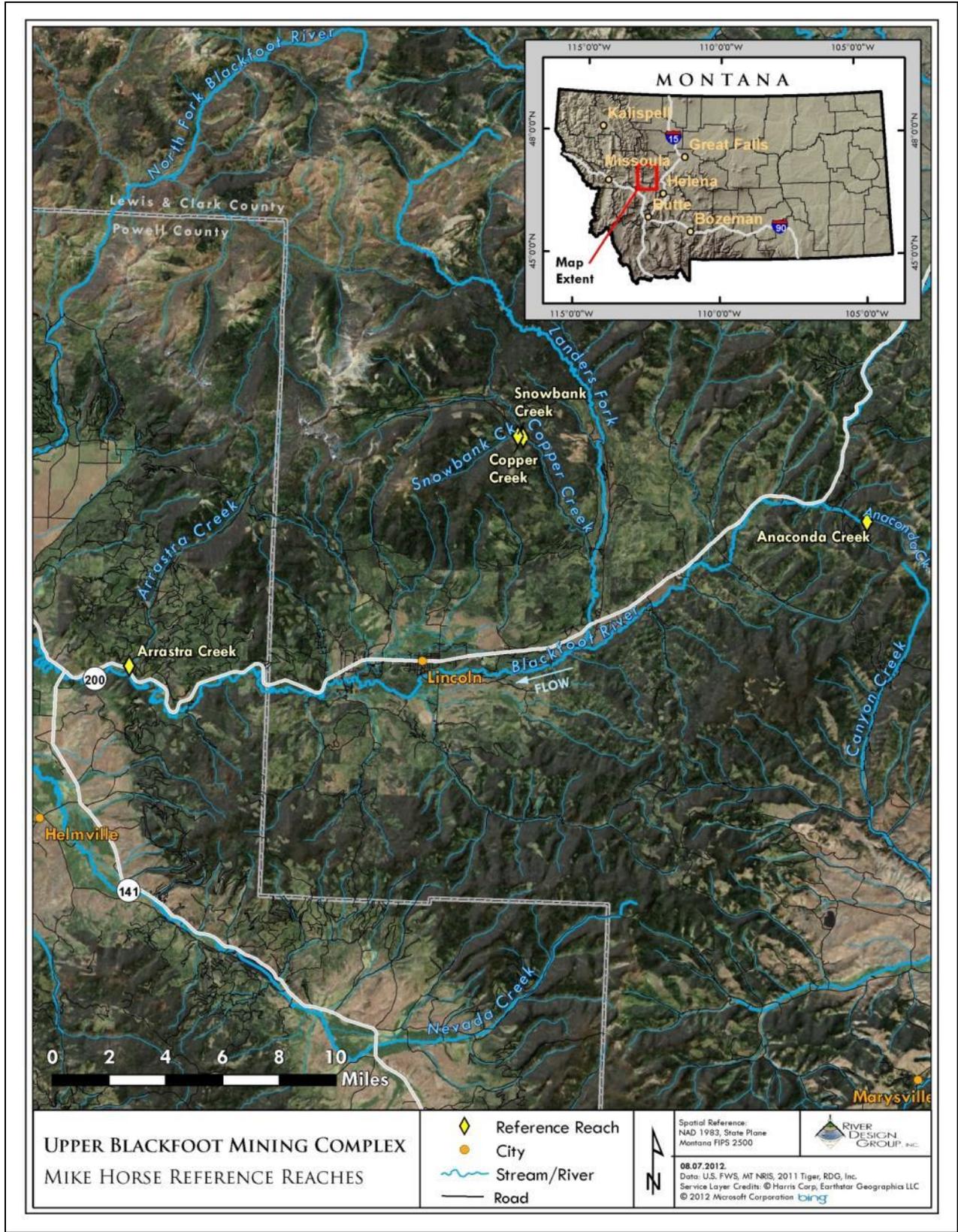


Figure 1-1. Reference reach data collection locations.

1 Data Collection Methods

Geomorphic channel data were collected with a Trimble 3303DR Total Station and a two-person survey crew in August 2012. A Trimble R8 Model 2 survey grade Global Positioning System (GPS) was also utilized where feasible.

Data collection parameters and methods are summarized in Table 1-1.

Parameter	Method
Channel cross-section	Harrelson et al., 1994
Longitudinal channel profile	Harrelson et al., 1994
Planform geometry	Langbein and Leopold, 1966
Substrate characterization	Wolman, 1954
Riffle Stability Index	Kappeser, 1992
Aquatic habitat characterization	Overton et al., 1997
Level I and II classification	Rosgen, 1996
Hydraulic Analyses	Dunne and Leopold, 1978

Total station survey data was processed and analyzed in RIVERMorph[®] version 4.2 (RIVERMorph LLC, 2005). RIVERMorph[®], a software program that facilitates stream channel assessment and data storage, merged all aspects of the surveys by transcribing the total station data from x, y and z coordinates to station and elevation formats. The software was used to process data and produce channel reach summaries and statistics.

Level I metrics for the surveyed stream reaches are summarized in Table 1-2. Detailed reach descriptions are provided in Section 2.

Table 1-2. Level I summary metrics.

Reach ID	Valley Type	Stream Type	Channel Pattern	Channel Gradient (ft/ft)	Reach Condition
Anaconda Creek	2	B4	Single Thread	0.0325	Reference
Arrastra Creek	5	C4	Single Thread	0.0129	Reference
Copper Creek	5	C3c-	Single Thread	0.0078	Reference
Snowbank Creek	2	C4b	Single Thread	0.0228	Reference

2 Anaconda Creek: B4 Reference Reach

Anaconda Creek occurs as the steepest of the four reference reaches surveyed and is a tributary to the upper Blackfoot River in the UBMC project area (Figure 2-1). The surveyed reach included 394 feet of channel. Anaconda Creek occurs in Valley Type 2, characterized by valley floor slopes less than 4%, and soils derived from older residual soils, alluvium and colluvium. The primarily single-thread channel in Anaconda Creek exhibits characteristics of a Rosgen B4 stream type with an average slope of 3.3%, an average width to depth ratio of 10.7, and an average entrenchment ratio of 1.8. Within the surveyed reach, the active channel displays step-pool sequences, limited floodplain extents, and a slightly meandering planform with a sinuosity of 1.04. The average riffle substrate consists of approximately 3% sand, 51% gravel-sized particles with 45% cobble with erratic boulders. The particles were considered sub-angular. The confined valley morphology and coarse parent material promote vertical and lateral channel stability. The forested riparian community within the surveyed reach provides shading and inputs of large woody debris to the channel. Estimated bankfull discharge is 38 cfs.

Anaconda Creek supports the highest frequency of pools of the four surveyed reference reaches, averaging 6.7 pools per 100 meters with an average spacing of 47 feet or every 4.1 bankfull widths. Maximum pool depths range from 1.9 feet to 3.4 feet. Within the bankfull channel, eleven qualifying single pieces of large woody debris and four aggregates were inventoried. This equates to 6.2 and 3.3 singles and aggregates per 100 meters, respectively.

The Riffle Stability Index, a general indicator of bed mobility, indicates that the geometric mean of the 30 largest point bar particles constitutes the D80 of the riffle substrate particle size distribution at cross-sections 5. As the value is below the D85 threshold, this implies that the riffle features are vertically stable and not mobilized during average annual flow events.

Anaconda Creek occurs as a reference reach and may represent the pre-disturbance potential condition for impaired reaches of similar morphology in the UBMC project area. The channel in Anaconda Creek is moderately confined and occupies a limited floodplain and meander belt width compared to the other surveyed reference reaches.

Table 2-1. Select Level II variables for Anaconda Creek.

Reach ID	Stream Type	Bankfull Slope (ft/ft)	Sinuosity	Entrenchment Ratio ¹	Width to Depth Ratio ¹	Riffle Width ¹ (ft)	Riffle D50 ¹ (mm)
Anaconda Creek	B4	0.0325	1.04	1.8	10.7	11.4	60

¹Mean value. n=2.

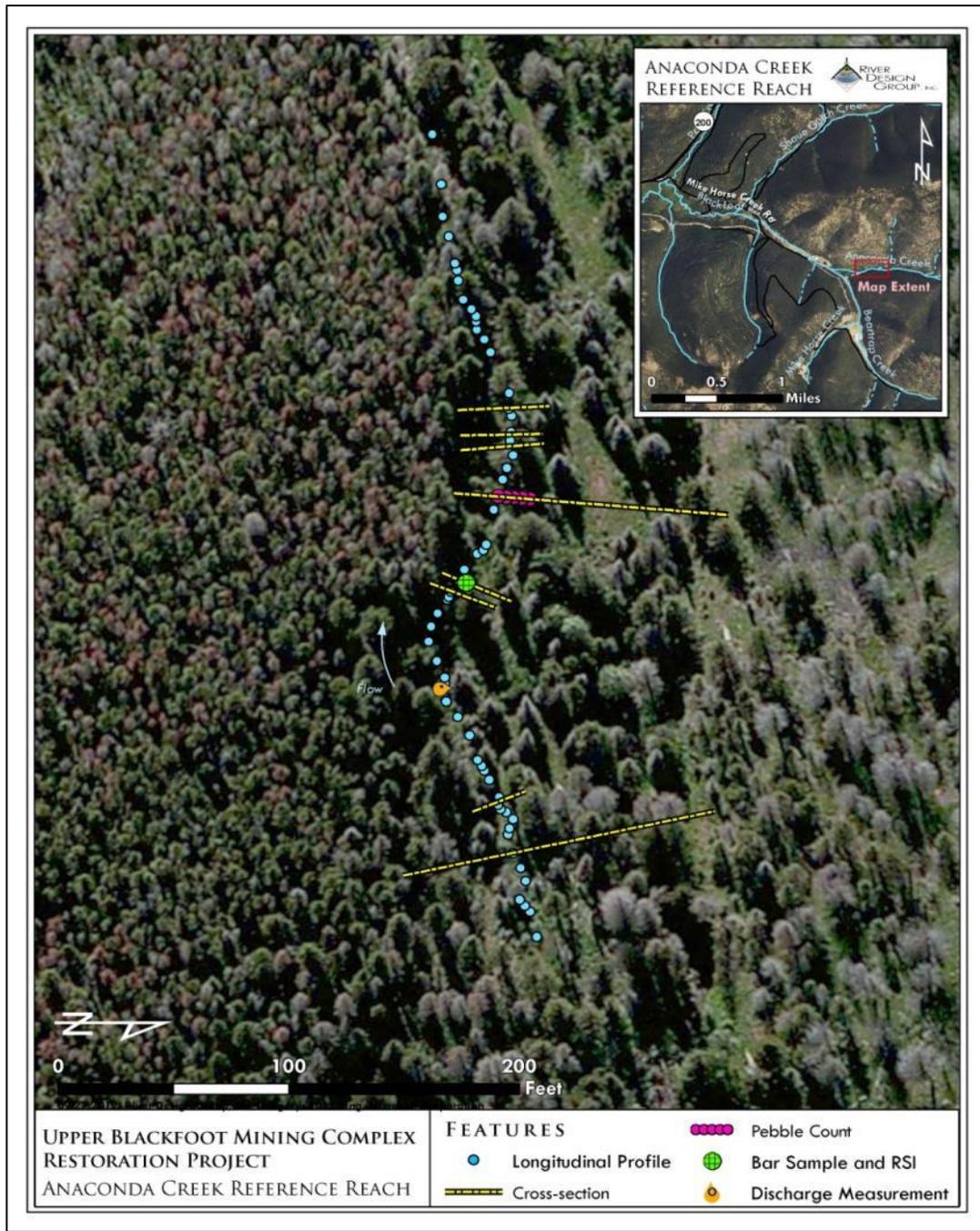


Figure 2-1. Anaconda Creek vicinity map.

2.1.1 Survey Planview

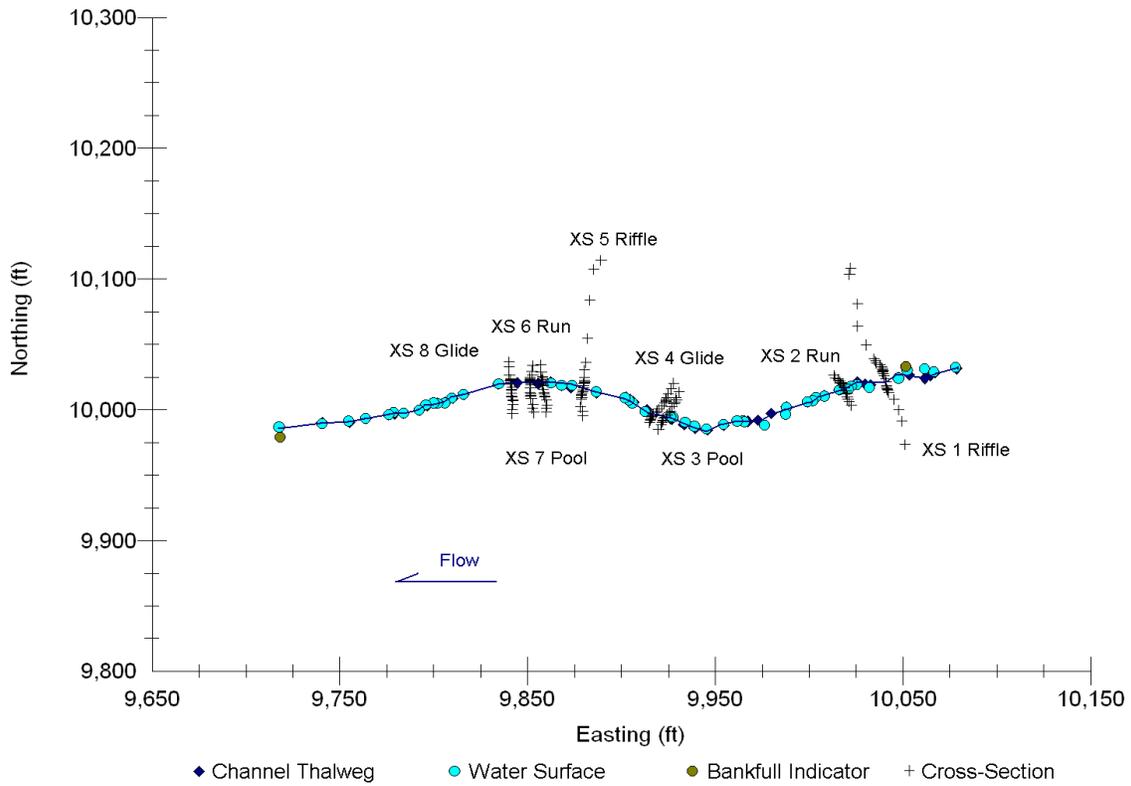


Figure 2-2. Planview of the surveyed points in Anaconda Creek.



Figure 2-3. View of upper (left) middle (inset) and lower (right) survey extents in Anaconda Creek.

2.1.2 Longitudinal Profile

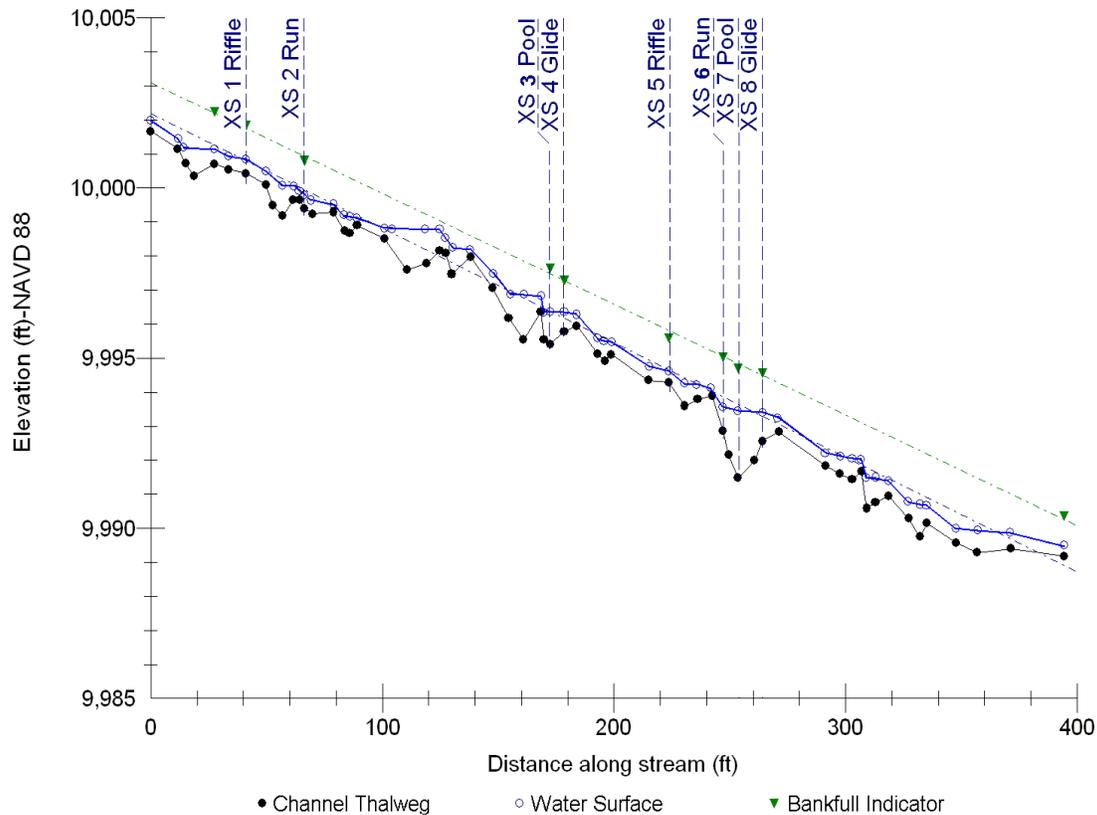


Figure 2-4. Anaconda Creek longitudinal profile.

Table 2-2. Longitudinal profile dimensions for Anaconda Creek.

Profile Dimensions Metric	Min	Mean	Max	Profile Dimensionless Ratios ¹ Metric	Min	Mean	Max
WS Slope (ft/ft)		0.0337		Bankfull Slope (ft/ft)		0.0325	
S Riffle (ft/ft)	0.0213	0.0459	0.0696	S Riffle / Sbkf (ft/ft)	0.65	1.41	2.14
S Pool (ft/ft)	0.0007	0.0027	0.0041	S Pool / Sbkf (ft/ft)	0.02	0.08	0.13
S Run (ft/ft)	0.0141	0.0229	0.0294	S Run / Sbkf (ft/ft)	0.43	0.71	0.91
S Glide (ft/ft)	0.0048	0.0137	0.0213	S Glide / Sbkf (ft/ft)	0.15	0.42	0.65
Pool - Pool (ft)	11.6	47.0	80.4	Pool - Pool / Wbkf (ft)	1.02	4.13	7.08
Pool Length (ft)	8.8	13.3	18.7	Pool Length / Wbkf (ft)	0.77	1.17	1.65
Riffle Length (ft)	8.9	13.5	20.0	Riffle Length / Wbkf (ft)	0.79	1.19	1.76
Dmax Riffle (ft)	1.3	1.6	2.1	Dmax Riffle / Dbkf (ft)	1.22	1.48	1.99
Dmax Pool (ft)	1.9	2.3	3.4	Dmax Pool / Dbkf (ft)	1.80	2.21	3.20
Dmax Run (ft)	1.7	2.0	2.7	Dmax Run / Dbkf (ft)	1.56	1.92	2.55
Dmax Glide (ft)	1.3	1.7	2.1	Dmax Glide / Dbkf (ft)	1.19	1.57	1.99
Low Bank Ht (ft)	1.3	1.6	2.1	Low Bank Ht / Dmax Riff (ft)	0.81	0.99	1.34

¹Sbkf=0.0325 ft/ft, Wbkf=11.4 ft, Dbkf=1.1 ft, Dmax=1.6 ft.

2.1.3 Planform Geometry

Table 2-3. Planform geometry summary table for Anaconda Creek.

Meander Location (ft)	Meander Wave Length (ft)	Meander Belt Width (ft)	Radius of Curvature (ft)	Lm / Wbkf ¹	Wblt / Wbkf ¹ (MWR)	Rc / Wbkf ¹
1+20	305	73.7	125	26.8	6.5	11.0
2+50	326	78.9	105	28.6	6.9	9.2
Minimum	305	73.7	105	26.8	6.5	9.2
Mean	316	76.0	115	27.7	6.7	10.1
Maximum	326	78.9	125	28.6	6.9	11.0
Standard Deviation	14.9	3.7	14.0	1.3	0.3	1.3
Coefficient of Variance	0.05	0.05	0.12	0.05	0.04	0.13
Sinuosity	1.04					

¹ Wbkf=11.4 ft

2.1.4 Cross-Section Dimensions

Table 2-4. Cross-section dimensions for Anaconda Creek.

Cross-Section Dimensions Metric	Min	Mean	Max	Cross-Section Dimensionless Ratios ¹			
				Metric	Min	Mean	Max
Floodprone Width (ft)	14.2	20.6	27.0	Wfpa / Wbkf	1.25	1.81	2.37
Riffle Area (ft ²)	8.4	12.2	15.9	Riffle Area / Abkf	0.69	1.00	1.31
Max Riffle Depth (ft)	1.3	1.4	1.4	Max Riffle Depth / Dbkf	1.23	1.28	1.33
Mean Riffle Depth (ft)	1.0	1.1	1.1	Mean Riffle Depth / Dbkf	0.97	1.00	1.03
Riffle Width (ft)	8.2	11.4	14.6	Riffle Width / Wbkf	0.72	1.00	1.28
Entrenchment Ratio	1.7	1.8	1.8	Entrenchment Ratio/ER	0.97	1.00	1.03
Width/Depth Ratio	7.9	10.7	13.4	Width/Depth / W/D	0.74	1.00	1.26
Pool Area (ft ²)	14.1	19.7	25.4	Pool Area / Abkf	1.16	1.62	2.09
Max Pool Depth (ft)	2.0	2.6	3.2	Max Pool Depth / Dbkf	1.89	2.47	3.05
Mean Pool Depth (ft)	1.0	1.6	2.1	Mean Pool Depth / Dbkf	0.95	1.46	1.97
Pool Width (ft)	12.2	13.0	13.9	Pool Width / Wbkf	1.07	1.15	1.22
Run Area (ft ²)	8.7	11.1	13.4	Run Area / Abkf	0.72	0.91	1.10
Max Run Depth (ft)	1.4	1.7	1.9	Max Run Depth / Dbkf	1.32	1.56	1.78
Mean Run Depth (ft)	0.9	1.0	1.0	Mean Run Depth / Dbkf	0.86	0.90	0.93
Run Width (ft)	9.5	11.5	13.5	Run Width / Wbkf	0.84	1.01	1.19
Glide Area (ft ²)	11.6	12.7	13.9	Glide Area / Abkf	0.95	1.05	1.14
Max Glide Depth (ft)	1.5	1.8	2.0	Max Glide Depth / Dbkf	1.43	1.67	1.90
Mean Glide Depth (ft)	0.8	1.0	1.2	Mean Glide Depth /Dbkf	0.75	0.92	1.09
Glide Width (ft)	12.0	13.3	14.6	Glide Width / Wbkf	1.06	1.17	1.28

¹ Abkf=12.2 ft², Wbkf=11.4 ft, W/D=10.7, ER= 1.8, Dbkf=1.1 ft.

2.1.5 Surveyed Cross-Sections

Riffle Cross-Sections

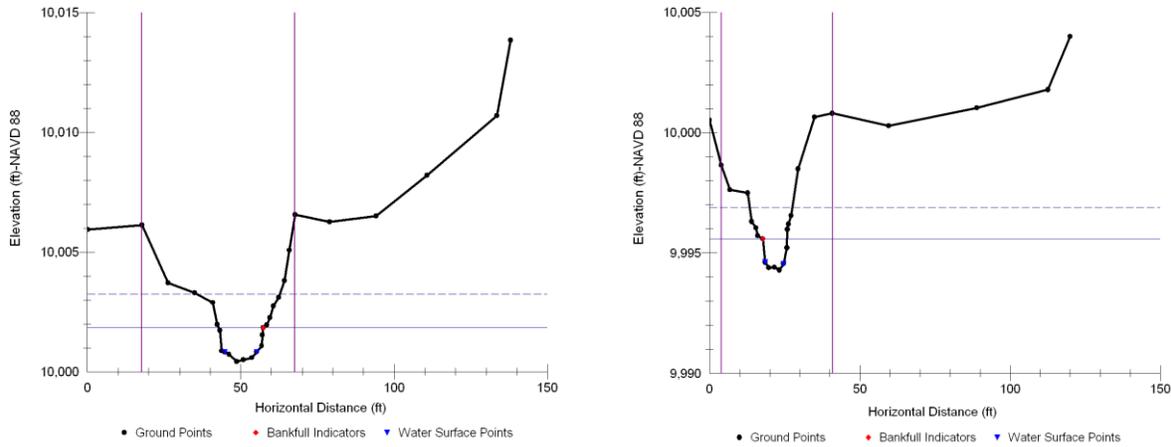


Figure 2-5. Riffle cross-sections 1 (left) and 5 (right).

Table 2-5. Riffle channel dimensions in Anaconda Creek.

Metric	XS 1	XS 5
Floodprone Width (ft)	27.0	14.2
Bankfull Width (ft)	14.6	8.2
Entrenchment Ratio	1.9	1.7
Mean Depth (ft)	1.1	1.0
Maximum Depth (ft)	1.4	1.3
Width/Depth Ratio	13.4	7.9
Bankfull Area (ft ²)	15.9	8.4
Wetted Perimeter (ft)	15.5	9.1
Hydraulic Radius (ft)	1.0	0.9



Figure 2-6. View upstream of cross-section 1 (left) and of cross-section 5 (right).

Run Cross-Sections

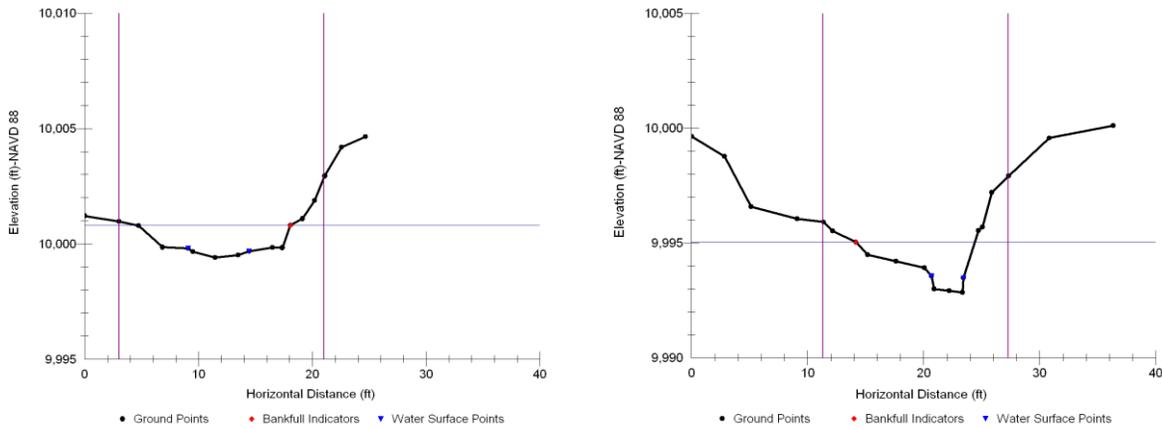


Figure 2-7. Run cross-sections 2 (left) and 6 (right).

Table 2-6. Run channel dimensions in Anaconda Creek.

Metric	XS 2	XS 6
Floodprone Width (ft)	N/A	N/A
Bankfull Width (ft)	13.5	9.5
Entrenchment Ratio	N/A	N/A
Mean Depth (ft)	1.0	0.9
Maximum Depth (ft)	1.4	1.9
Width/Depth Ratio	13.7	10.5
Bankfull Area (ft ²)	13.4	8.7
Wetted Perimeter (ft)	14.3	11.3
Hydraulic Radius (ft)	0.9	0.8



Figure 2-8. View upstream of cross-section 2 (left) and of cross-section 6 (right).

Pool Cross-Sections

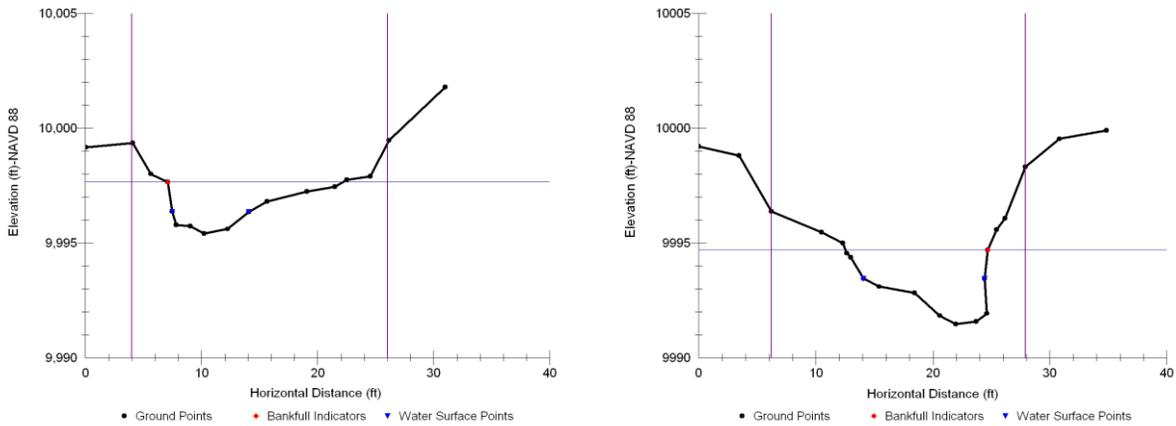


Figure 2-9. Pool cross-sections 3 (left) and 7 (right).

Table 2-7. Pool channel dimensions in Anaconda Creek.

Metric	XS 3	XS 7
Floodprone Width (ft)	N/A	N/A
Bankfull Width (ft)	13.9	12.2
Entrenchment Ratio	N/A	N/A
Mean Depth (ft)	1.0	2.1
Maximum Depth (ft)	2.0	3.2
Width/Depth Ratio	13.8	5.8
Bankfull Area (ft ²)	14.1	25.4
Wetted Perimeter (ft)	15.3	15.7
Hydraulic Radius (ft)	0.9	1.6



Figure 2-10. View upstream of cross-section 3 (left) and of cross-section 7 (right).

Glide Cross-Sections

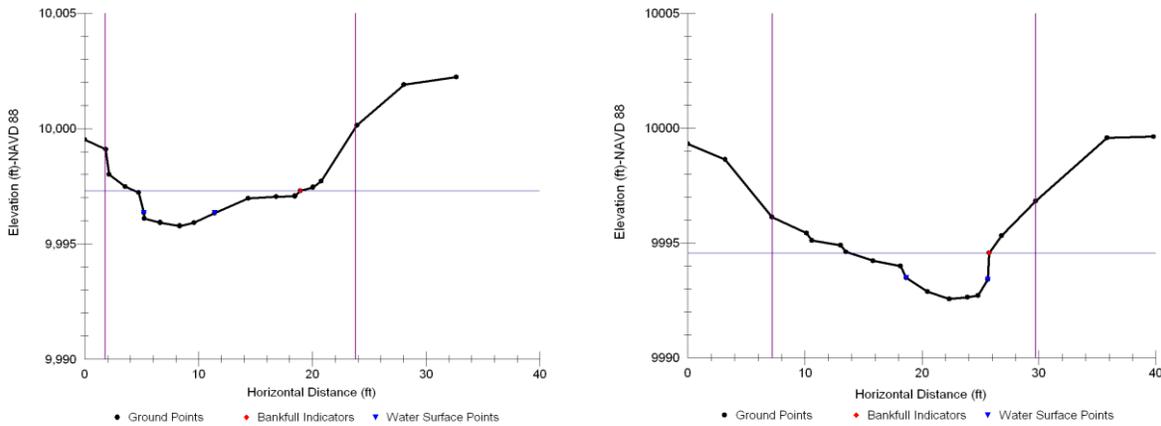


Figure 2-11. Glide cross-sections 4 (left) and 8 (right).

Table 2-8. Glide channel dimensions in Anaconda Creek.

Metric	XS 4	XS 8
Floodprone Width (ft)	N/A	N/A
Bankfull Width (ft)	14.6	12.0
Entrenchment Ratio	N/A	N/A
Mean Depth (ft)	0.8	1.2
Maximum Depth (ft)	1.5	2.0
Width/Depth Ratio	18.5	10.3
Bankfull Area (ft ²)	11.6	13.9
Wetted Perimeter (ft)	15.5	13.7
Hydraulic Radius (ft)	0.8	1.0



Figure 2-12. View upstream of cross-section 4 (left) and of cross-section 8 (right).

2.1.6 Substrate Particle Size Distributions

Riffle Substrate

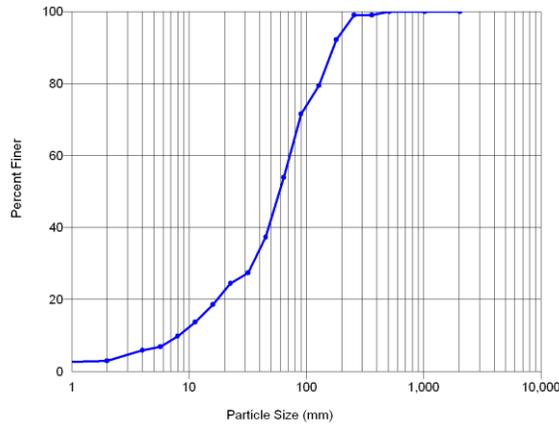


Figure 2-13. Riffle particle size distribution at cross-sections 5.

Table 2-9. Particle size distribution at cross-section 5.

Metric	mm	Metric	%
D16	13	Silt/Clay	0
D35	42	Sand	3
D50	60	Gravel	51
D84	147	Cobble	45
D95	211	Boulder	1
D100	512	Bedrock	0

Riffle Stability Index

Table 2-10. Riffle Stability Index values for Anaconda Creek.

		RSI Score
Reach Condition	Geometric Mean (mm)	XS 5
Reference	131	D80

2.1.7 Hydraulic Analysis

Table 2-11. Measured and estimated discharge (cfs) for riffle cross-sections in Anaconda Creek (August 2011). D50=60mm, D84=147mm.

XS ID	Area (ft ²)	Local Slope (ft/ft)	Manning's	Relative Roughness	Darcy-Weisbach	U/U*	Average	Measured
XS 1	2.6	0.0368	2.1	1.5	1.5	1.5	1.7	0.8
XS 5	1.3	0.0347	0.8	0.5	0.5	0.5	0.6	0.8

Table 2-12. Estimated bankfull discharge (cfs) for riffle cross-sections in Anaconda Creek.

XS ID	Area (ft ²)	Bankfull Slope (ft/ft)	Manning's	Relative Roughness	Darcy-Weisbach	U/U*	Average
XS 1	15.9	0.0325	84.1	76.7	79.5	77.1	79.4
XS 5	8.4	0.0325	40.2	36.5	39.0	36.4	38.0

Bold=value utilized as Anaconda Creek estimate for project-scale hydraulic analysis.

2.1.8 Aquatic Habitat Characterization

Table 2-13. Characterization of large wood observed in Anaconda Creek.

R1/R4 Variable Outputs	Singles	Aggregates	Rootfans
Total Number (count)	11	4	7 / 2 ¹
Number / 100 m	9.2	3.3	5.8 / 2.3 ²
Mean Diameter of Single Pieces (m)	0.34		
Mean Length of Single Pieces (m)	12.0		
Total Volume of Single Pieces (m ³)	24.2		
Total Volume of Single Pieces (m ³) / 100 m	20.1		
Percent Submerged Volume of Single Pieces (%)	0		
Number of Pieces in Aggregates	11.5 ³		2

¹ Total number of rootwads occurring as singles / or in aggregates.

² Number of rootwads occurring as single pieces / or in aggregates, per 100 meters.

³ Represents the number of single pieces identified in aggregates.

Table 2-14. Characterization of existing pool habitats surveyed in Anaconda Creek.

Reach ID	Number of Pools (#/100 m)	Pool to Pool Spacing (m) (mean)	Pool to Pool Spacing / Wbkf ¹ (mean)	Maximum Pool Depths (m) (mean)	Discrete Residual Pool Volume (m ³) (mean)	Cumulative Residual Pool Volume (m ³) (m ³ /100 m)
Anaconda Creek	8.0 (6.7)	3.5-24.5 (14.3)	1.0-7.1 (4.1)	0.5-1.0 (0.7)	0.5-3.5 (1.4)	9.4 (7.8)

¹Wbkf=3.5 m.

3 Arrastra Creek: C4 Reference Reach

Arrastra Creek occurs as the third lowest gradient system of the four reference reaches (Figure 3-1). The reach includes 641 feet of channel and classified as a C4 stream type (Rosgen 1996). Arrastra Creek, at the survey location, occurs in Valley Type 5, characterized by valley floor slopes of less than 4%, glacial moraines, terraces and floodplains and/or more recent alluvium deposits. The primarily single-thread channel in Arrastra Creek exhibits characteristics of a Rosgen C4 stream type with an average slope of 1.3%, an average width to depth ratio of 15.9, and an average entrenchment ratio of 6.7. Channel bedforms are characterized by riffle-pool sequences. The floodplain is well-developed and a meandering planform characterizes the reach with a sinuosity of 1.3. The average riffle substrate consists of approximately 1% sand, 64% gravel-sized particles with 35% cobble and 0% boulders. The particles were considered sub-rounded. The valley type and topography permit some channel adjustment and lateral migration or bank erosion at the outside of meander bends was observed during the survey. The forested riparian community provides shading and inputs of large woody debris to the channel. Estimated bankfull discharge is 225 cfs.

Arrastra Creek supports the third lowest frequency of pools of the four reference reaches, averaging 3.6 pools per 100 meters with an average spacing of 103 feet or every 4.1 bankfull widths. Maximum pool depths range from 3.4 feet to 4.5 feet. Within the bankfull channel, eighteen qualifying single pieces of large woody debris and seven aggregates were inventoried in the surveyed reach. This equates to 9.2 and 3.6 singles and aggregates per 100 meters, respectively.

The Riffle Stability Index, a general indicator of bed mobility, indicates that the geometric mean of the 30 largest point bar particles constitutes the D85 of the riffle substrate particle size distribution at cross-sections 5. As the value is at the D85 threshold, this implies that the riffle armor layer is likely mobilized during average annual flow events.

Arrastra Creek occurs as a reference reach and may represent the pre-disturbance potential condition for impaired reaches in the UBMC project area of similar dimension, pattern and profile.

Table 3-1. Select Level II variables for Arrastra Creek.

Reach ID	Stream Type	Bankfull Slope (ft/ft)	Sinuosity	Entrenchment Ratio ¹	Width to Depth Ratio ¹	Riffle Width ¹ (ft)	Riffle D50 ¹ (mm)
Arrastra Creek	C4	0.0129	1.3	6.7	15.9	25.1	51

¹Mean value. n=2.

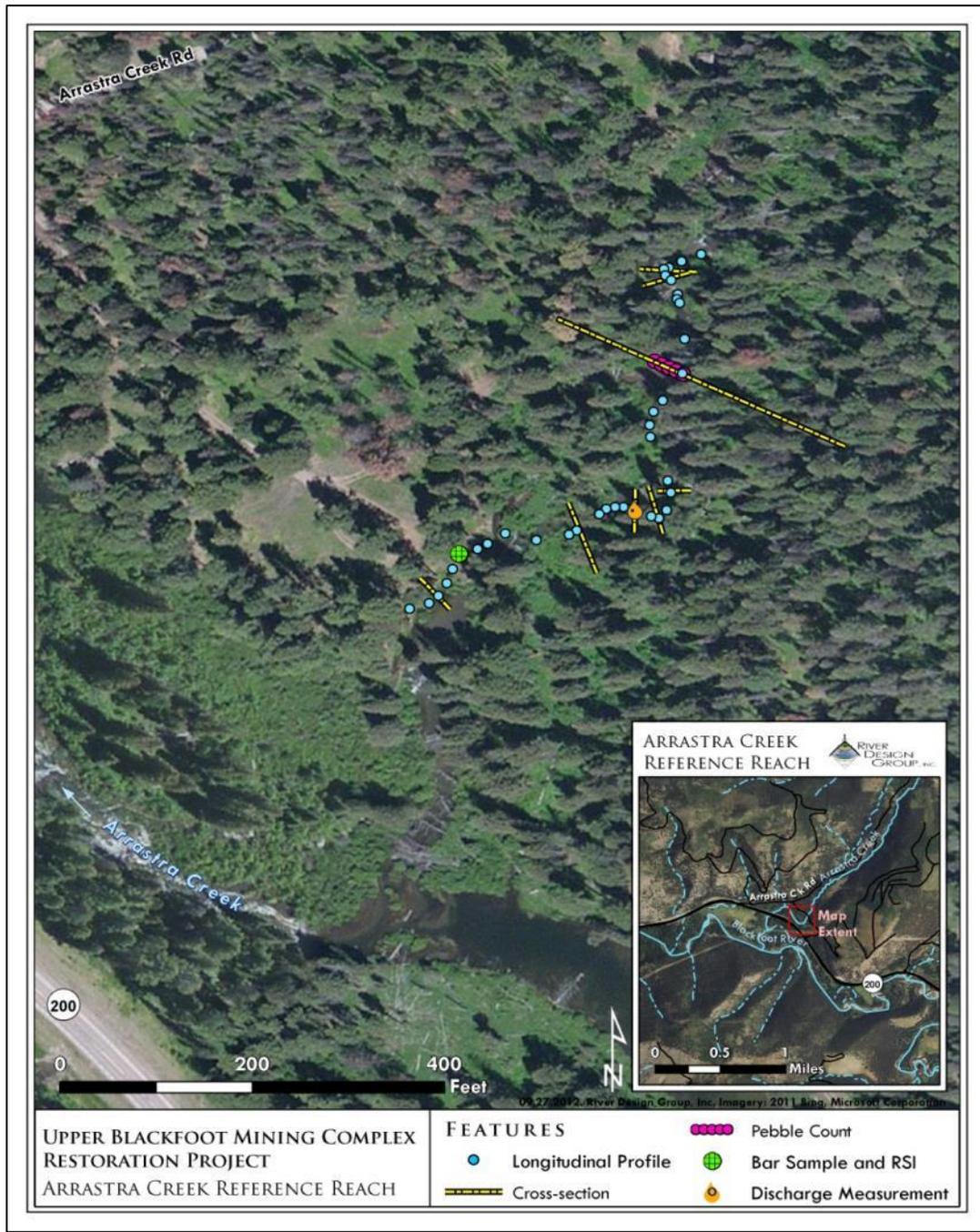


Figure 3-1. Arrastra Creek vicinity map.

3.1.1 Survey Planview

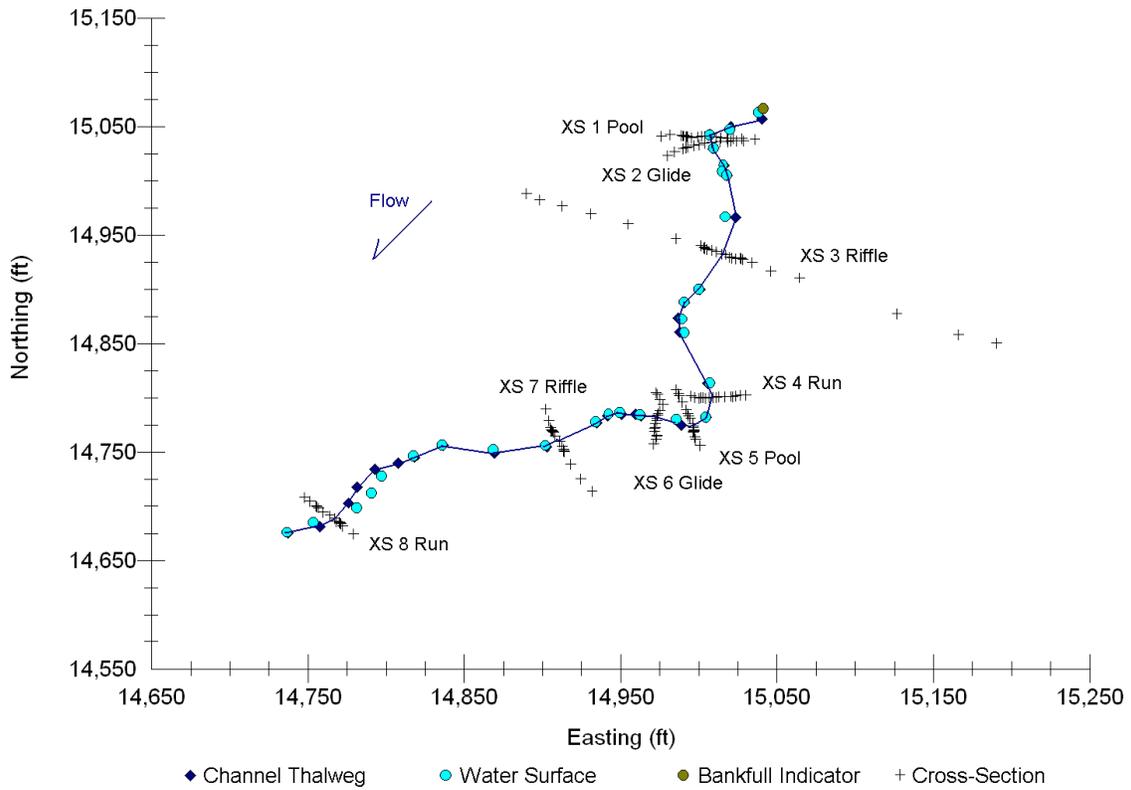


Figure 3-2. Planview of the surveyed points in Arrastra Creek.



Figure 3-3. View of upper (left) middle (inset) and lower (right) survey extents in Arrastra Creek.

3.1.2 Longitudinal Profile

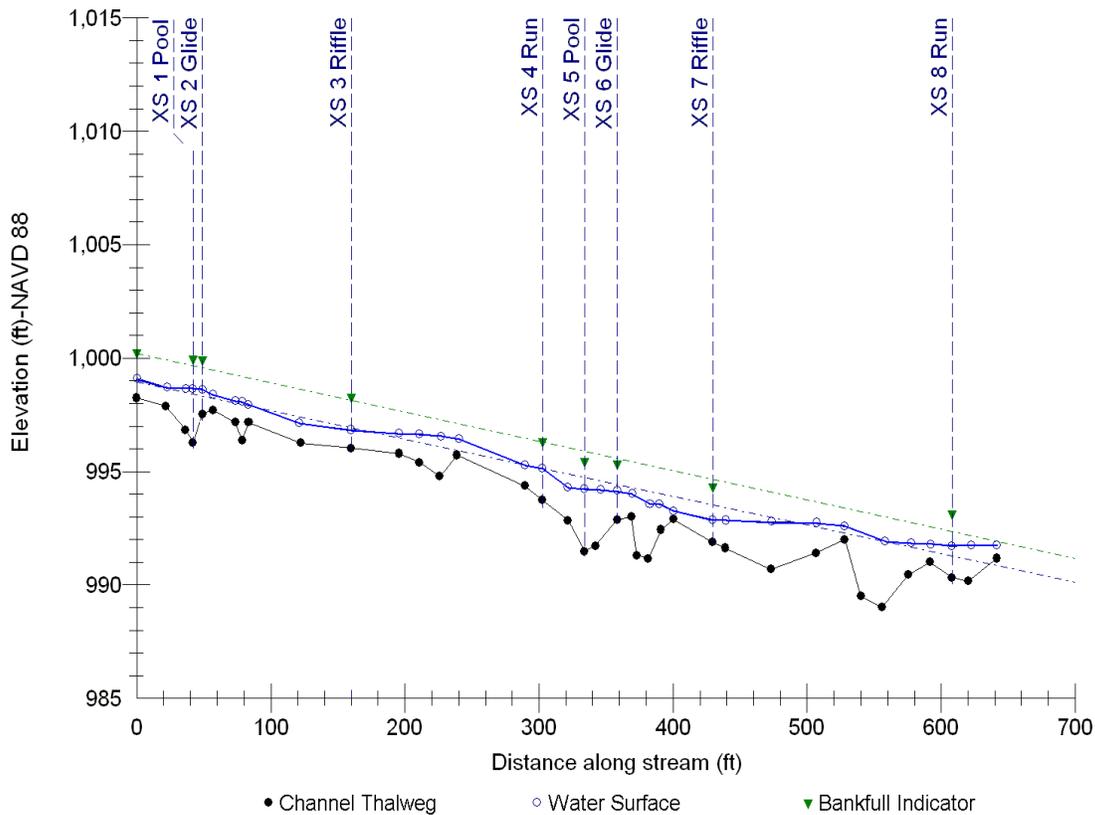


Figure 3-4. Arrastra Creek longitudinal profile.

Table 3-2. Longitudinal profile dimensions for Arrastra Creek.

Profile Dimensions Metric	Min	Mean	Max	Profile Dimensionless Ratios ¹ Metric	Min	Mean	Max
WS Slope (ft/ft)		0.0126		Bankfull Slope (ft/ft)		0.0129	
S Riffle (ft/ft)	0.0076	0.0174	0.0237	S Riffle / Sbkf (ft/ft)	0.59	1.35	1.84
S Pool (ft/ft)	0.0016	0.0023	0.0027	S Pool / Sbkf (ft/ft)	0.13	0.18	0.21
S Run (ft/ft)	0.0039	0.0067	0.0095	S Run / Sbkf (ft/ft)	0.30	0.52	0.74
S Glide (ft/ft)	0.0054	0.0066	0.0093	S Glide / Sbkf (ft/ft)	0.42	0.51	0.72
Pool - Pool (ft)	47.1	103	183	Pool - Pool / Wbkf (ft)	1.88	4.12	7.29
Pool Length (ft)	20.0	35.2	59.2	Pool Length / Wbkf (ft)	0.80	1.40	2.36
Riffle Length (ft)	23.5	50.2	103	Riffle Length / Wbkf (ft)	0.94	2.00	4.13
Dmax Riffle (ft)	1.9	2.1	2.5	Dmax Riffle / Dbkf (ft)	1.18	1.33	1.58
Dmax Pool (ft)	3.4	3.9	4.5	Dmax Pool / Dbkf (ft)	2.16	2.47	2.83
Dmax Run (ft)	2.2	2.7	3.4	Dmax Run / Dbkf (ft)	1.39	1.70	2.15
Dmax Glide (ft)	1.9	2.3	2.8	Dmax Glide / Dbkf (ft)	1.21	1.47	1.75
Low Bank Ht (ft)	1.9	2.2	2.5	Low Bank Ht / Dmax Riff (ft)	0.91	1.03	1.18

¹Sbkf=0.0129ft/ft, Wbkf=25.1 ft, Dbkf=1.6 ft, Dmax=2.1 ft.

3.1.3 Planform Geometry

Table 3-3. Planform geometry summary table for Arrastra Creek.

Meander Location (ft)	Meander Wave Length (ft)	Meander Belt Width (ft)	Radius of Curvature (ft)	Lm / Wbkf ¹	Wblt / Wbkf ¹ (MWR)	Rc / Wbkf ¹
0+42	125	88	51	5.0	3.5	2.0
2+20	213	81	70	8.5	3.2	2.8
3+33	163	100	51	6.5	4.0	2.0
5+51	150	75	86	6.0	3.0	3.4
Minimum	125	75.0	50.8	5.0	3.0	2.0
Mean	163	86.0	64	6.5	3.4	2.6
Maximum	213	100	85.9	8.5	4.0	3.4
Standard Deviation	1.47	10.7	17.0	1.47	0.43	17.0
Coefficient of Variance	0.23	0.12	0.26	0.23	0.12	0.26
Sinuosity	1.3					

¹ Wbkf=25.1 ft

3.1.4 Cross-Section Dimensions

Table 3-4. Cross-section dimensions for Arrastra Creek.

Cross-Section Dimensions Metric	Min	Mean	Max	Cross-Section Dimensionless Ratios ¹			
				Metric	Min	Mean	Max
Floodprone Width (ft)	73.8	169	264	Wfpa / Wbkf	2.95	6.74	10.54
Riffle Area (ft ²)	37.9	39.4	40.9	Riffle Area / Abkf	0.96	1.00	1.04
Max Riffle Depth (ft)	2.2	2.3	2.4	Max Riffle Depth / Dbkf	1.39	1.44	1.49
Mean Riffle Depth (ft)	1.6	1.6	1.6	Mean Riffle Depth / Dbkf	0.99	1.00	1.01
Riffle Width (ft)	24.4	25.1	25.7	Riffle Width / Wbkf	0.97	1.00	1.03
Entrenchment Ratio	3.2	6.7	10.3	Entrenchment Ratio/ER	2.9	6.7	10.5
Width/Depth Ratio	15.6	15.9	16.2	Width/Depth / W/D	0.98	1.00	1.02
Pool Area (ft ²)	55.4	59.0	62.5	Pool Area / Abkf	1.40	1.49	1.59
Max Pool Depth (ft)	3.6	3.8	3.9	Max Pool Depth / Dbkf	2.29	2.38	2.47
Mean Pool Depth (ft)	1.4	1.6	1.9	Mean Pool Depth / Dbkf	0.87	1.04	1.20
Pool Width (ft)	33.1	36.6	40.1	Pool Width / Wbkf	1.32	1.46	1.60
Run Area (ft ²)	31.8	38.7	45.6	Run Area / Abkf	0.81	0.98	1.16
Max Run Depth (ft)	2.5	2.7	2.8	Max Run Depth / Dbkf	1.61	1.68	1.75
Mean Run Depth (ft)	1.3	1.6	1.9	Mean Run Depth / Dbkf	0.83	1.02	1.21
Run Width (ft)	23.9	24.0	24.2	Run Width / Wbkf	0.95	0.96	0.96
Glide Area (ft ²)	36.5	41.0	45.6	Glide Area / Abkf	0.93	1.04	1.15
Max Glide Depth (ft)	2.3	2.4	2.4	Max Glide Depth / Dbkf	1.48	1.51	1.53
Mean Glide Depth (ft)	1.2	1.4	1.6	Mean Glide Depth /Dbkf	0.77	0.88	0.99
Glide Width (ft)	29.1	29.6	30.0	Glide Width / Wbkf	1.16	1.18	1.20

¹ Abkf=39.4 ft², Wbkf=25.1 ft, W/D=15.9, ER= 6.7, Dbkf=1.6 ft.

3.1.5 Surveyed Cross-Sections

Riffle Cross-Sections

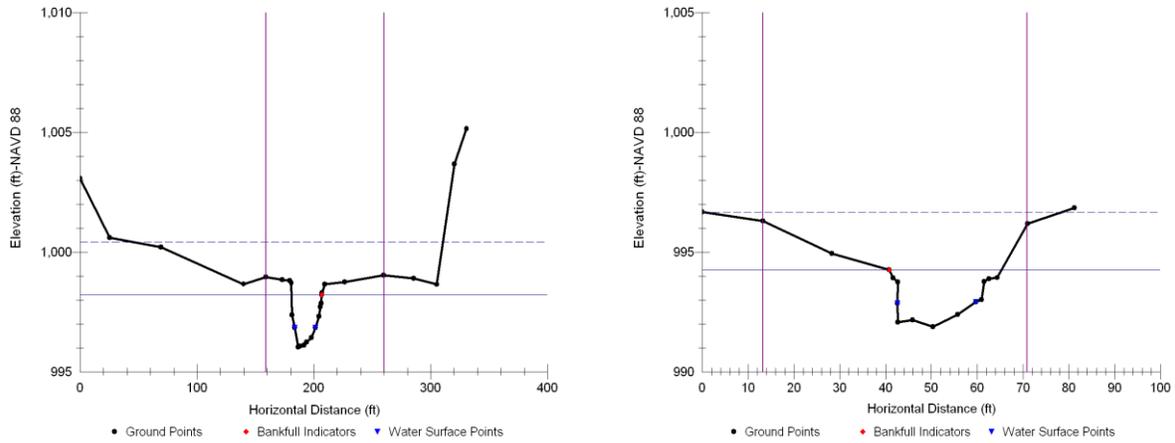


Figure 3-5. Riffle cross-sections 3 (left) and 7 (right).

Table 3-5. Riffle channel dimensions in Arrastra Creek.

Metric	XS 3	XS 7
Floodprone Width (ft)	264	73.8
Bankfull Width (ft)	25.7	24.4
Entrenchment Ratio	10.3	3.0
Mean Depth (ft)	1.6	1.6
Maximum Depth (ft)	2.2	2.4
Width/Depth Ratio	16.2	15.6
Bankfull Area (ft ²)	40.9	37.9
Wetted Perimeter (ft)	26.7	26.6
Hydraulic Radius (ft)	1.5	1.4



Figure 3-6. View upstream of cross-section 3 (left) and of cross-section 7 (right).

Run Cross-Sections

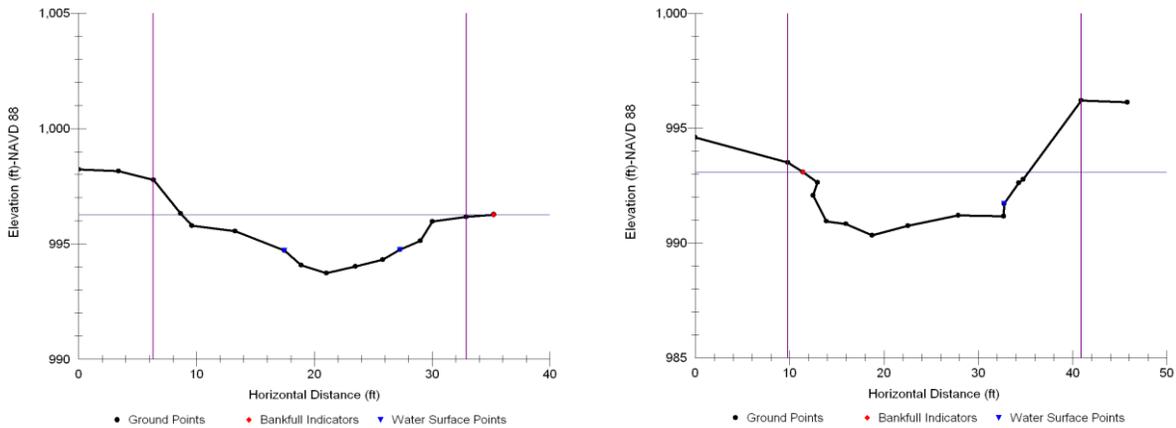


Figure 3-7. Run cross-sections 4 (left) and 8 (right).

Table 3-6. Run channel dimensions in Arrastra Creek.

Metric	XS 4	XS 8
Floodprone Width (ft)	N/A	N/A
Bankfull Width (ft)	24.2	23.9
Entrenchment Ratio	N/A	N/A
Mean Depth (ft)	1.3	1.9
Maximum Depth (ft)	2.5	2.8
Width/Depth Ratio	18.4	12.5
Bankfull Area (ft ²)	31.8	45.6
Wetted Perimeter (ft)	25.1	26.6
Hydraulic Radius (ft)	1.3	1.7



Figure 3-8. View upstream of cross-section 4 (left) and of cross-section 8 (right).

Pool Cross-Sections

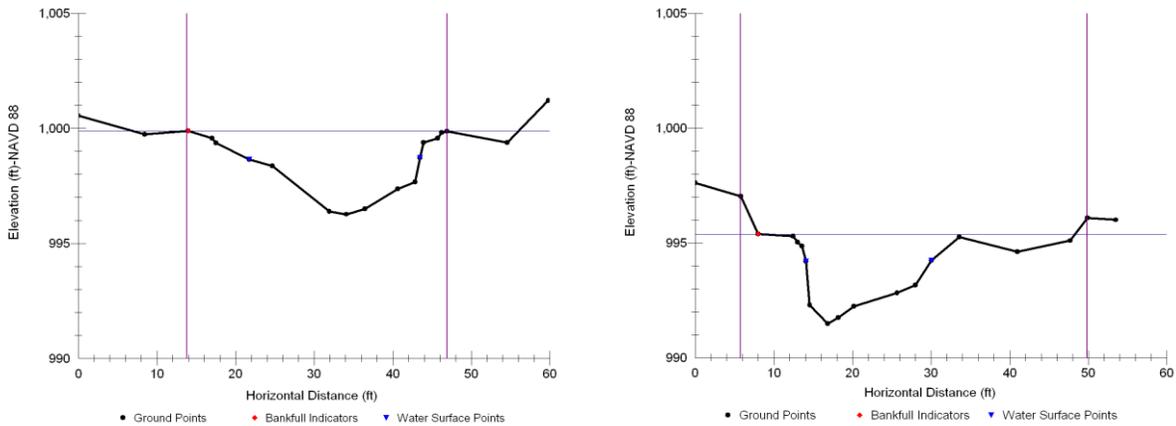


Figure 3-9. Pool cross-sections 1 (left) and 5 (right).

Table 3-7. Pool channel dimensions in Arrastra Creek.

Metric	XS 1	XS 5
Floodprone Width (ft)	N/A	N/A
Bankfull Width (ft)	33.1	40.1
Entrenchment Ratio	N/A	N/A
Mean Depth (ft)	1.9	1.4
Maximum Depth (ft)	3.6	3.9
Width/Depth Ratio	17.5	29.0
Bankfull Area (ft ²)	62.5	55.4
Wetted Perimeter (ft)	34.7	42.8
Hydraulic Radius (ft)	1.8	1.3



Figure 3-10. View downstream of cross-section 1 (left) and upstream of cross-section 5 (right).

Glide Cross-Sections

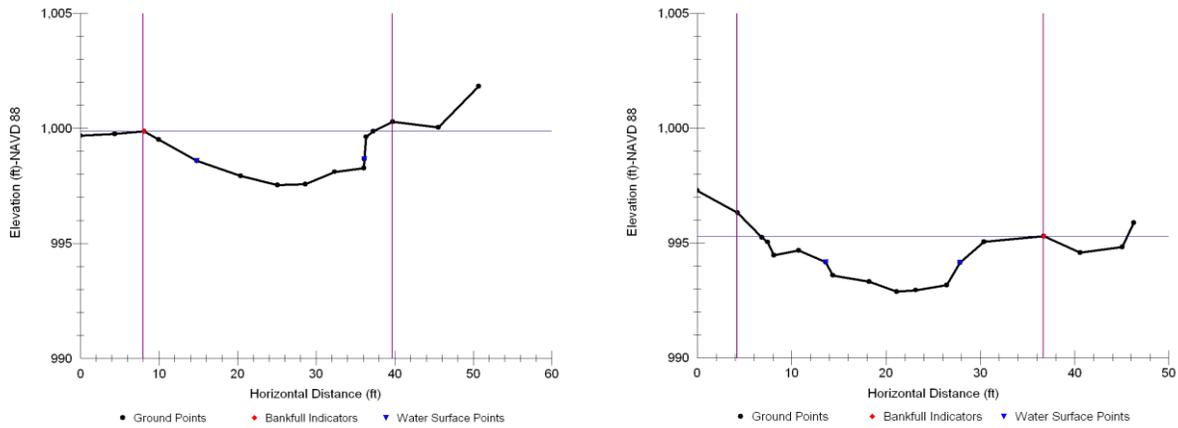


Figure 3-11. Glide cross-sections 2 (left) and 6 (right).

Table 3-8. Glide channel dimensions in Arrastra Creek.

Metric	XS 2	XS 6
Floodprone Width (ft)	N/A	N/A
Bankfull Width (ft)	29.1	30.0
Entrenchment Ratio	N/A	N/A
Mean Depth (ft)	1.6	1.2
Maximum Depth (ft)	2.3	2.4
Width/Depth Ratio	18.7	24.6
Bankfull Area (ft ²)	45.6	36.5
Wetted Perimeter (ft)	30.5	31.0
Hydraulic Radius (ft)	1.5	1.2



Figure 3-12. View downstream of cross-section 2 (left) and of cross-section 6 (right).

3.1.6 Substrate Particle Size Distributions

Riffle Substrate

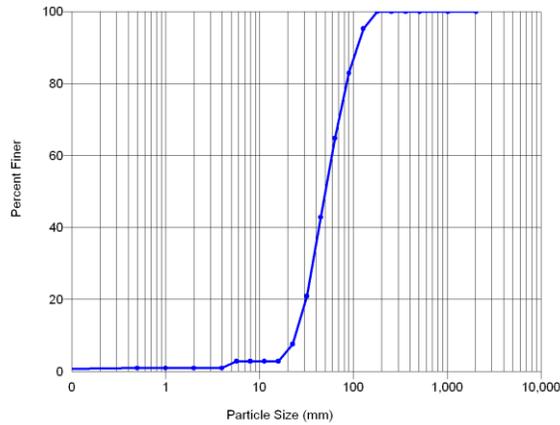


Figure 3-13. Riffle particle size distribution at cross-sections 3.

Table 3-9. Particle size distribution at cross-section 3.

Metric	mm	Metric	%
D16	29	Silt/Clay	0
D35	40	Sand	1
D50	51	Gravel	64
D84	94	Cobble	35
D95	127	Boulder	0
D100	180	Bedrock	0

Point Bar Material

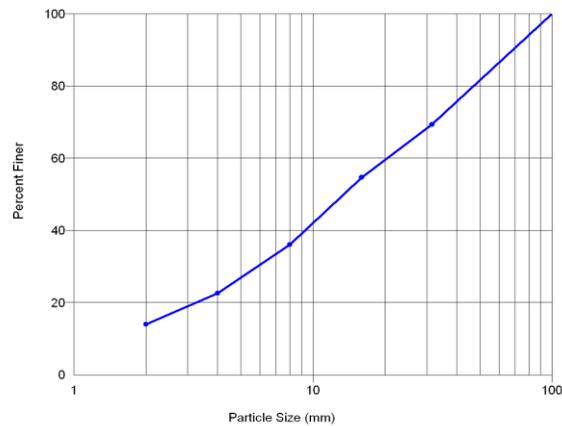


Figure 3-14. Representative point bar particle size distribution for Arrastra Creek.

Table 3-10. Bar Sample particle size distribution for Arrastra Creek.

Metric	mm	Metric	%
D16	2	Silt/Clay	0
D35	8	Sand	14
D50	14	Gravel	74
D84	64	Cobble	12
D95	89	Boulder	0
D100	100	Bedrock	0

Riffle Stability Index

Table 3-11. Riffle Stability Index values for Arrastra Creek.

		RSI Score
Reach Condition	Geometric Mean (mm)	XS 5
Reference	97.6	D85

3.1.7 Hydraulic Analysis

Table 3-12. Measured and estimated discharge (cfs) for riffle cross-sections in Arrastra Creek (August 2011). D50=51mm, D84=94mm.

XS ID	Area (ft ²)	Local Slope (ft/ft)	Manning's	Relative Roughness	Darcy-Weisbach	U/U*	Average	Measured
XS 3	9.4	0.0143	20.6	18.5	18.8	19.1	19.3	19.6
XS 7	11.9	0.0094	27.2	24.8	25.5	25.0	25.6	19.6

Table 3-13. Estimated bankfull discharge (cfs) for riffle cross-sections in Arrastra Creek.

XS ID	Area (ft ²)	Bankfull Slope (ft/ft)	Manning's	Relative Roughness	Darcy-Weisbach	U/U*	Average
XS 3	40.9	0.0129	235	220	225	221	225
XS 7	38.9	0.0129	213	200	208	200	205

Bold=value utilized as Arrastra Creek estimate for project-scale hydraulic analysis.

3.1.8 Aquatic Habitat Characterization

Table 3-14. Characterization of large wood observed in Arrastra Creek.

R1/R4 Variable Outputs	Singles	Aggregates	Rootfans
Total Number (count)	18	7	4 / 17 ¹
Number / 100 m	9.2	3.6	2.0 / 8.7 ²
Mean Diameter of Single Pieces (m)	0.24		
Mean Length of Single Pieces (m)	6.9		
Total Volume of Single Pieces (m ³)	7.6		
Total Volume of Single Pieces (m ³) / 100 m	4.0		
Percent Submerged Volume of Single Pieces (%)	10		
Number of Pieces in Aggregates	70 ³		17

¹ Total number of rootwads occurring as singles / or in aggregates.

² Number of rootwads occurring as single pieces / or in aggregates, per 100 meters.

³ Represents the number of single pieces identified in aggregates.

Table 3-15. Characterization of existing pool habitats surveyed in Arrastra Creek.

Reach ID	Number of Pools (#/100 m)	Pool to Pool Spacing (m) (mean)	Pool to Pool Spacing / Wbkf ¹ (mean)	Maximum Pool Depths (m) (mean)	Discrete Residual Pool Volume (m ³) (mean)	Cumulative Residual Pool Volume (m ³) (m ³ /100 m)
Arrastra Creek	7.0 (3.6)	14.4-55.8 (31.4)	1.9-7.3 (4.1)	1.1-1.2 (1.2)	6.3-23.1 (13.1)	91.4 (46.8)

¹Wbkf=7.7 m.

4 Copper Creek: C3 Reference Reach

Copper Creek occurs as the lowest gradient system of the four reference reaches (Figure 4-1). The reach includes 1,017 feet of channel and classifies as a C3 stream type. Copper Creek within the survey reach occurs in Valley Type 5, characterized by valley floor slopes of less than 4%, glacial moraines, terraces and floodplains and/or more recent alluvium deposits. The primarily single-thread channel in Copper Creek exhibits characteristics of a Rosgen C3 stream type with a slope of 0.8%, an average width to depth ratio of 23, and an average entrenchment ratio of 2.6. Within Copper Creek the active channel displays riffle-pool sequences, is bracketed by a well-developed floodplain, and is characterized by a meandering planform with a sinuosity of 1.3. The average riffle substrate consists of approximately 9% sand, 40% gravel-sized particles with 46% cobble and 6% boulders. The particles were considered sub-rounded. The valley type and topography permit lateral channel migration and bank erosion at the outside of the upstream meander bend was observed during the survey. The downstream meander abuts road fillslope which precludes channel migration. Riparian and floodplain vegetation communities have been affected by wildfires and are in early successional stages. Estimated bankfull discharge is 316 cfs.

Copper Creek supports the lowest frequency of pools of the four reference reaches, averaging 2.6 pools per 100 meters with an average spacing of 193 feet or every 5.2 bankfull widths. Maximum pool depths range from 2.4 feet to 4.4 feet. Within the bankfull channel, fifty-five qualifying single pieces of large woody debris and fifteen aggregates were inventoried in the surveyed reach. This equates to 17.4 and 4.8 singles and aggregates per 100 meters, respectively. Copper Creek has the largest distribution and volume of large woody debris of the reference reaches. As the adjacent forest and riparian vegetation have been impacted by wildfire, dead standing trees within the bankfull margins serve as a supply of coarse wood to the active channel.

The Riffle Stability Index, a general indicator of bed mobility, indicates that the geometric mean of the 30 largest point bar particles constitutes the D82 of the riffle substrate particle size distribution at cross-sections 5. As the value is under the D85 threshold, this implies that the riffle features are vertically stable and not mobilized during average annual flood events.

Copper Creek occurs as a reference reach and may represent the pre-disturbance potential condition for stream reaches in the UBMC project area of similar dimension, pattern and profile.

Table 4-1. Select Level II variables for Copper Creek.

Reach ID	Stream Type	Bankfull Slope (ft/ft)	Sinuosity	Entrenchment Ratio ¹	Width to Depth Ratio ¹	Riffle Width ¹ (ft)	Riffle D50 ¹ (mm)
Copper Creek	C3	0.0078	1.3	2.6	21.8	36.8	66

¹Mean value. n=2.

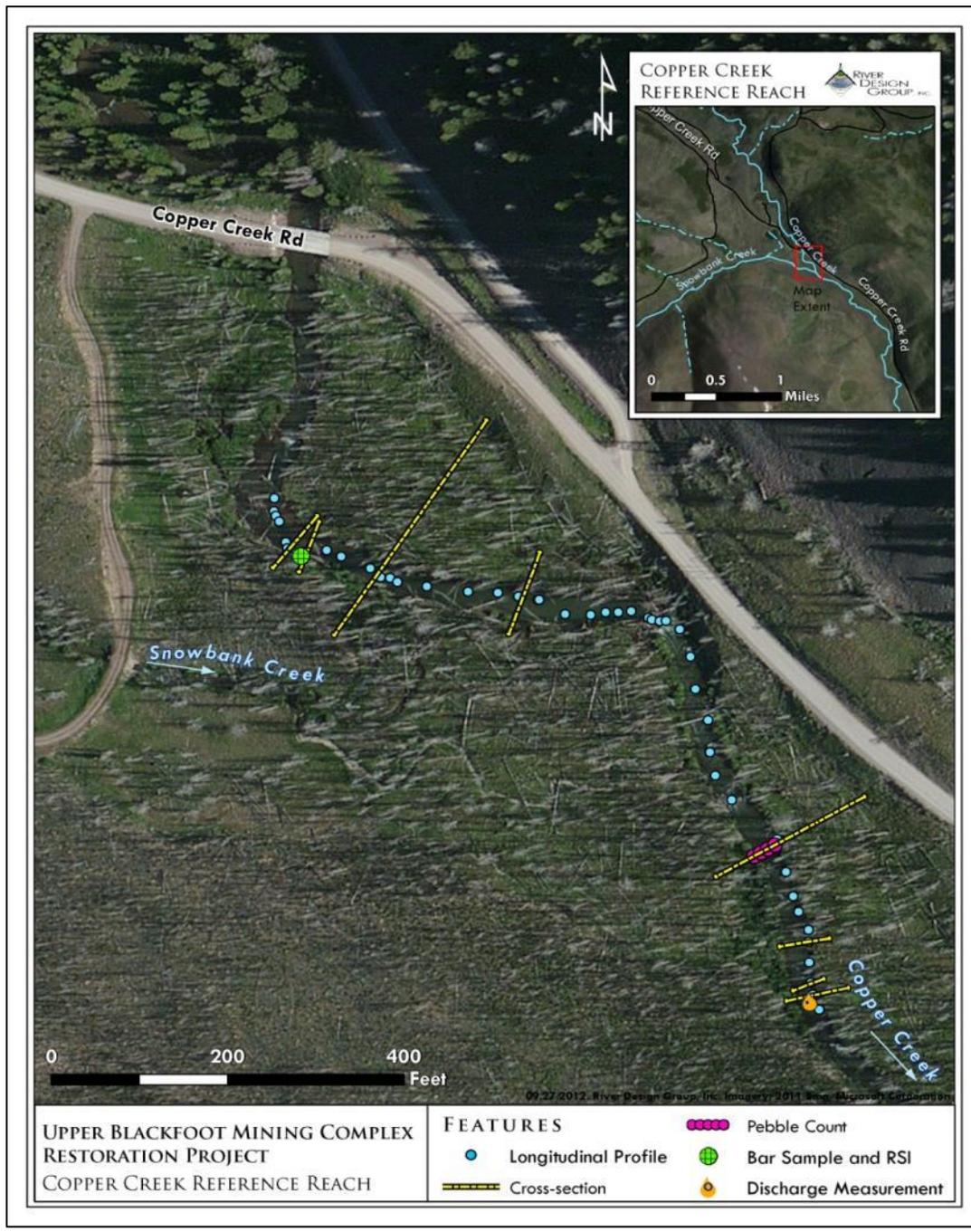


Figure 4-1. Copper Creek vicinity map.

4.1.1 Survey Planview

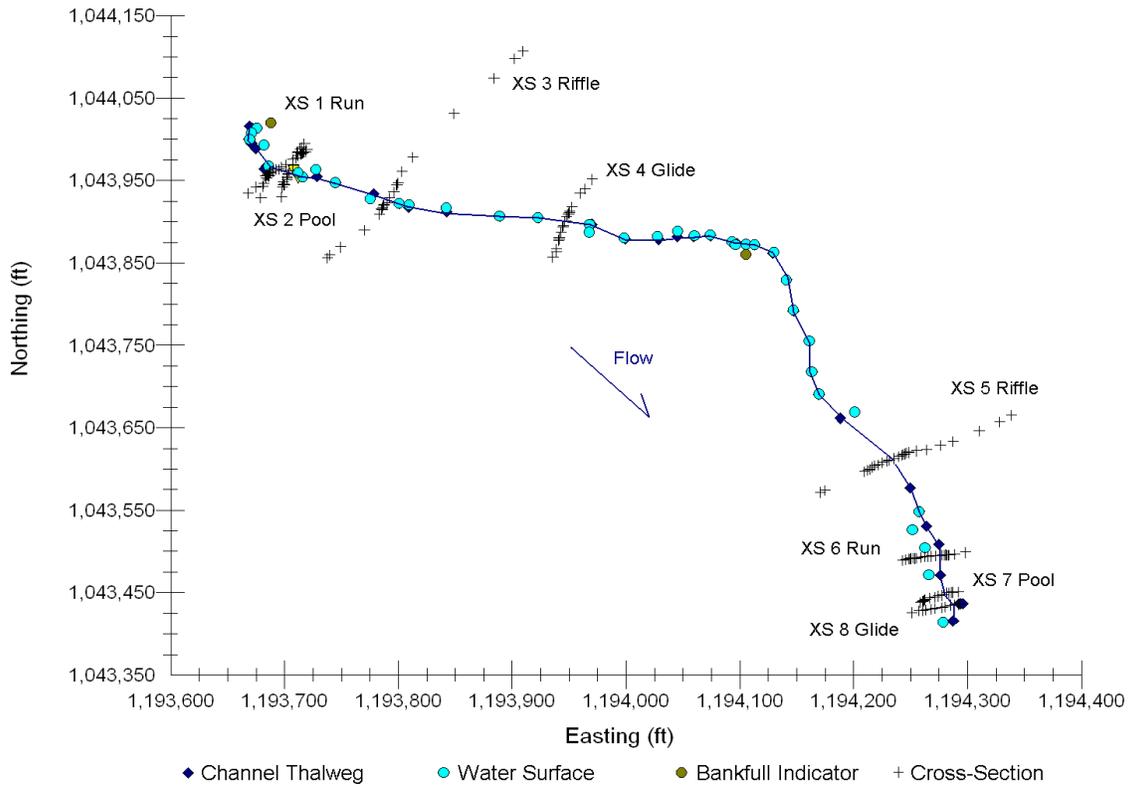


Figure 4-2. Planview of the surveyed points in Copper Creek.



Figure 4-3. View of upper (left) middle (inset) and lower (right) survey extents in Copper Creek.

4.1.2 Longitudinal Profile

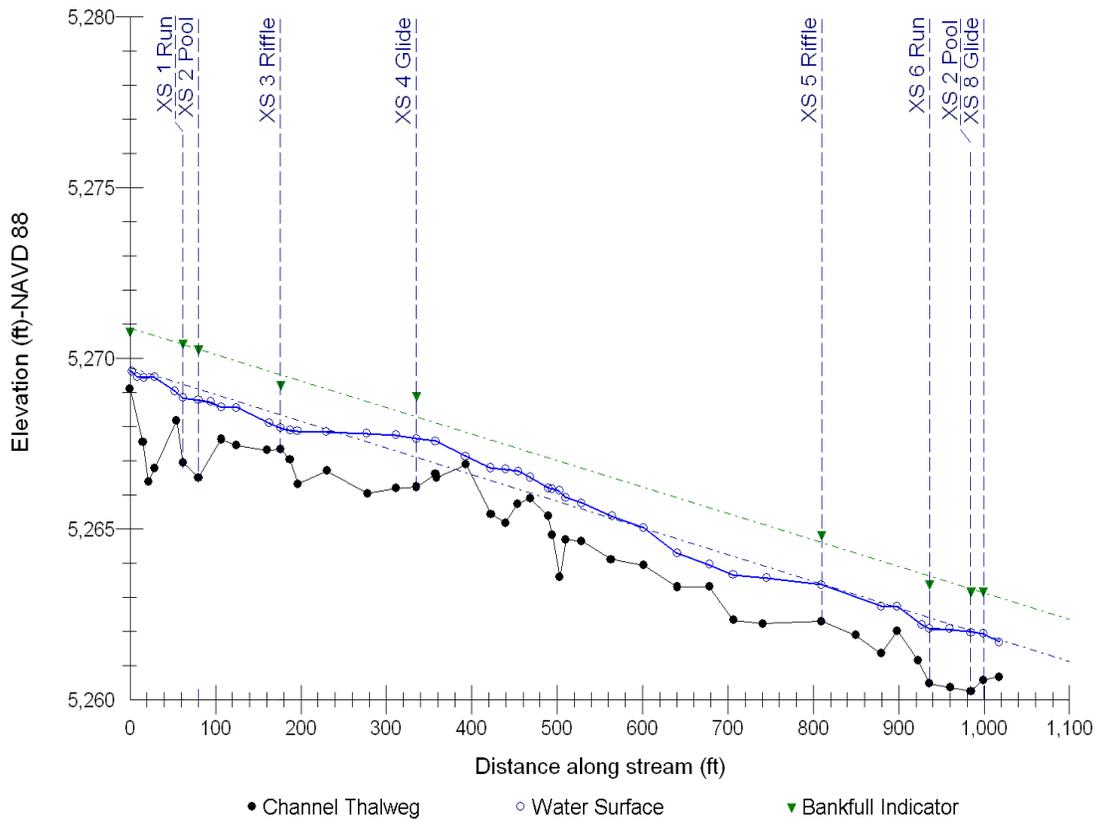


Figure 4-4. Copper Creek longitudinal profile.

Table 4-2. Longitudinal profile dimensions for Copper Creek.

Profile Dimensions Metric	Min	Mean	Max	Profile Dimensionless Ratios ¹ Metric	Min	Mean	Max
WS Slope (ft/ft)		0.0078		Bankfull Slope (ft/ft)		0.0078	
S Riffle (ft/ft)	0.0053	0.0121	0.0185	S Riffle / Sbkf (ft/ft)	0.68	1.55	2.37
S Pool (ft/ft)	0.0003	0.0013	0.0021	S Pool / Sbkf (ft/ft)	0.04	0.17	0.27
S Run (ft/ft)	0.0038	0.0060	0.0094	S Run / Sbkf (ft/ft)	0.49	0.77	1.20
S Glide (ft/ft)	0.0037	0.0043	0.0056	S Glide / Sbkf (ft/ft)	0.48	0.56	0.72
Pool - Pool (ft)	58.0	193	274	Pool - Pool / Wbkf (ft)	1.58	5.24	7.44
Pool Length (ft)	41.7	59.0	94.6	Pool Length / Wbkf (ft)	1.13	1.60	2.57
Riffle Length (ft)	24.4	130	369	Riffle Length / Wbkf (ft)	0.66	3.53	10.02
Dmax Riffle (ft)	2.3	2.4	2.4	Dmax Riffle / Dbkf (ft)	1.36	1.37	1.40
Dmax Pool (ft)	2.4	3.3	4.4	Dmax Pool / Dbkf (ft)	1.40	1.92	2.58
Dmax Run (ft)	2.7	2.9	3.1	Dmax Run / Dbkf (ft)	1.60	1.70	1.79
Dmax Glide (ft)	2.0	2.5	2.8	Dmax Glide / Dbkf (ft)	1.19	1.46	1.64
Low Bank Ht (ft)	2.3	2.4	2.4	Low Bank Ht / Dmax Riff (ft)	0.99	1.01	1.03

¹Sbkf=0.0078ft/ft, Wbkf=36.8 ft, Dbkf=2.2 ft, Dmax=2.4ft.

4.1.3 Planform Geometry

Table 4-3. Planform geometry summary table for Copper Creek.

Meander Location (ft)	Meander Wave Length (ft)	Meander Belt Width (ft)	Radius of Curvature (ft)	Lm / Wbkf ¹	Wblt / Wbkf ¹ (MWR)	Rc / Wbkf ¹
0+72	565	217	103	15.4	5.9	2.8
4+97	574	191	92	15.6	5.2	2.5
Minimum	565	191	92.4	15.4	5.2	2.5
Mean	570	204	98.0	15.5	5.6	2.7
Maximum	574	217	103	15.6	5.9	2.8
Standard Deviation	6.1	18.4	7.7	0.17	0.50	0.21
Coefficient of Variance	0.01	0.09	0.08	0.01	0.09	0.08
Sinuosity	1.3					

¹ Wbkf=36.8 ft

4.1.4 Cross-Section Dimensions

Table 4-4. Cross-section dimensions for Copper Creek.

Cross-Section Dimensions Metric	Min	Mean	Max	Cross-Section Dimensionless Ratios ¹			
				Metric	Min	Mean	Max
Floodprone Width (ft)	70.8	98.0	125	Wfpa / Wbkf	1.92	2.66	3.40
Riffle Area (ft ²)	50.1	63.6	77.0	Riffle Area / Abkf	0.79	1.00	1.21
Max Riffle Depth (ft)	1.9	2.2	2.5	Max Riffle Depth / Dbkf	1.09	1.28	1.46
Mean Riffle Depth (ft)	1.5	1.7	1.9	Mean Riffle Depth / Dbkf	0.88	1.00	1.12
Riffle Width (ft)	33.4	36.8	40.2	Riffle Width / Wbkf	0.91	1.00	1.09
Entrenchment Ratio	2.1	1.6	3.1	Entrenchment Ratio/ER	1.92	2.66	3.40
Width/Depth Ratio	21.1	21.8	22.6	Width/Depth / W/D	0.96	1.00	1.04
Pool Area (ft ²)	55.8	56.1	56.5	Pool Area / Abkf	0.88	0.88	0.89
Max Pool Depth (ft)	2.9	3.3	3.8	Max Pool Depth / Dbkf	1.69	1.94	2.19
Mean Pool Depth (ft)	1.4	1.7	2.1	Mean Pool Depth / Dbkf	0.80	1.00	1.20
Pool Width (ft)	27.1	34.3	41.5	Pool Width / Wbkf	0.74	0.93	1.13
Run Area (ft ²)	48.8	56.0	63.2	Run Area / Abkf	0.77	0.88	0.99
Max Run Depth (ft)	2.9	3.2	3.5	Max Run Depth / Dbkf	1.69	1.85	2.02
Mean Run Depth (ft)	1.4	1.5	1.6	Mean Run Depth / Dbkf	0.81	0.87	0.92
Run Width (ft)	31.0	38.3	45.6	Run Width / Wbkf	0.84	1.04	1.24
Glide Area (ft ²)	50.7	53.6	56.4	Glide Area / Abkf	0.80	0.84	0.89
Max Glide Depth (ft)	2.6	2.6	2.6	Max Glide Depth / Dbkf	1.51	1.53	1.54
Mean Glide Depth (ft)	1.4	1.5	1.7	Mean Glide Depth /Dbkf	0.80	0.90	0.99
Glide Width (ft)	33.3	35.1	36.9	Glide Width / Wbkf	0.90	0.95	1.00

¹ Abkf=63.6 ft², Wbkf=36.8 ft, W/D=21.8, ER= 1.6, Dbkf=2.2 ft.

4.1.5 Surveyed Cross-Sections

Riffle Cross-Sections

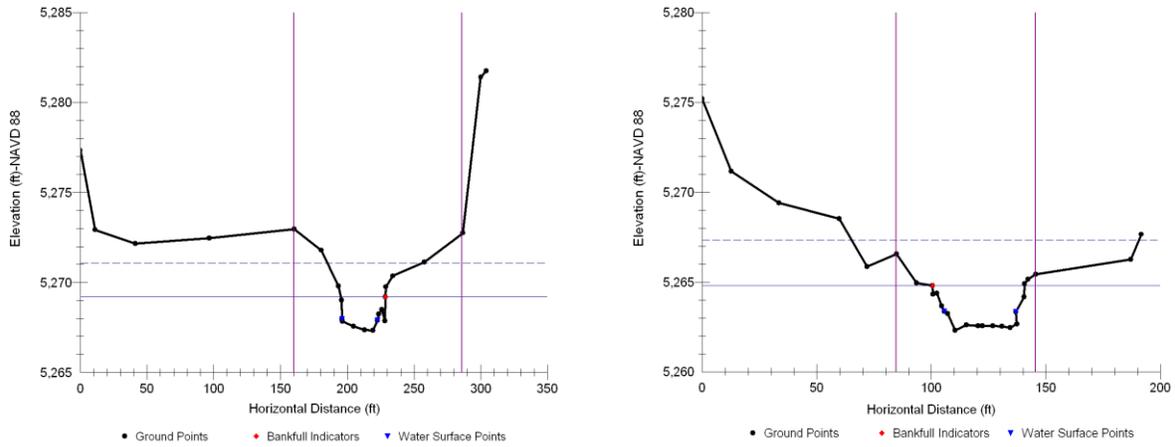


Figure 4-5. Riffle cross-sections 3 (left) and 5 (right).

Table 4-5. Riffle channel dimensions in Copper Creek.

Metric	XS 3	XS 5
Floodprone Width (ft)	70.8	125
Bankfull Width (ft)	33.4	40.2
Entrenchment Ratio	2.1	3.1
Mean Depth (ft)	1.5	1.9
Maximum Depth (ft)	1.9	2.5
Width/Depth Ratio	22.3	21.1
Bankfull Area (ft ²)	50.1	77.0
Wetted Perimeter (ft)	35.4	42.9
Hydraulic Radius (ft)	1.4	1.8



Figure 4-6. View downstream of cross-section 3 (left) and upstream of cross-section 5 (right).

Run Cross-Sections

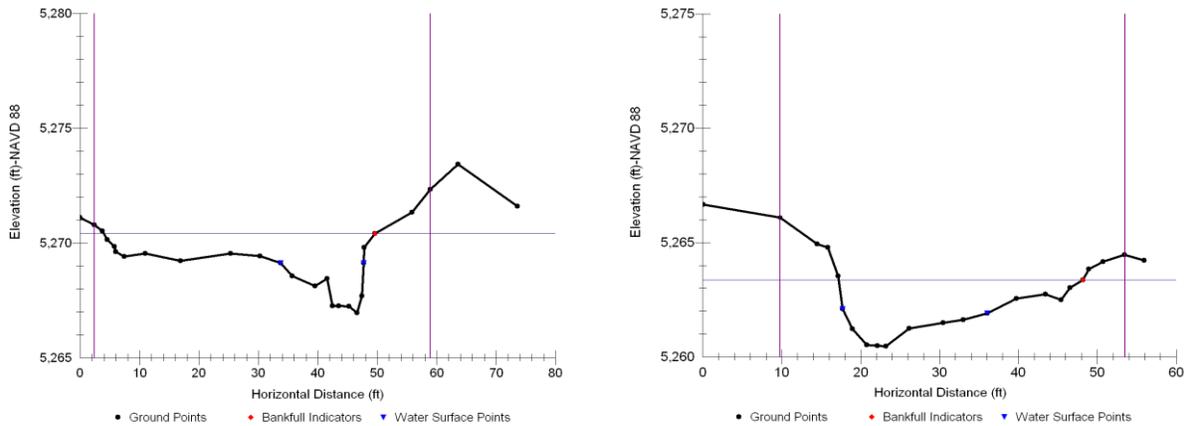


Figure 4-7. Run cross-sections 1 (left) and 6 (right).

Table 4-6. Run channel dimensions in Copper Creek.

Metric	XS 1	XS 6
Floodprone Width (ft)	N/A	N/A
Bankfull Width (ft)	45.6	31.0
Entrenchment Ratio	N/A	N/A
Mean Depth (ft)	1.4	1.6
Maximum Depth (ft)	3.5	2.9
Width/Depth Ratio	32.8	19.7
Bankfull Area (ft ²)	63.2	48.8
Wetted Perimeter (ft)	48.7	32.6
Hydraulic Radius (ft)	1.3	1.5



Figure 4-8. View downstream of cross-section 1 (left) and of cross-section 6 (right).

Pool Cross-Sections

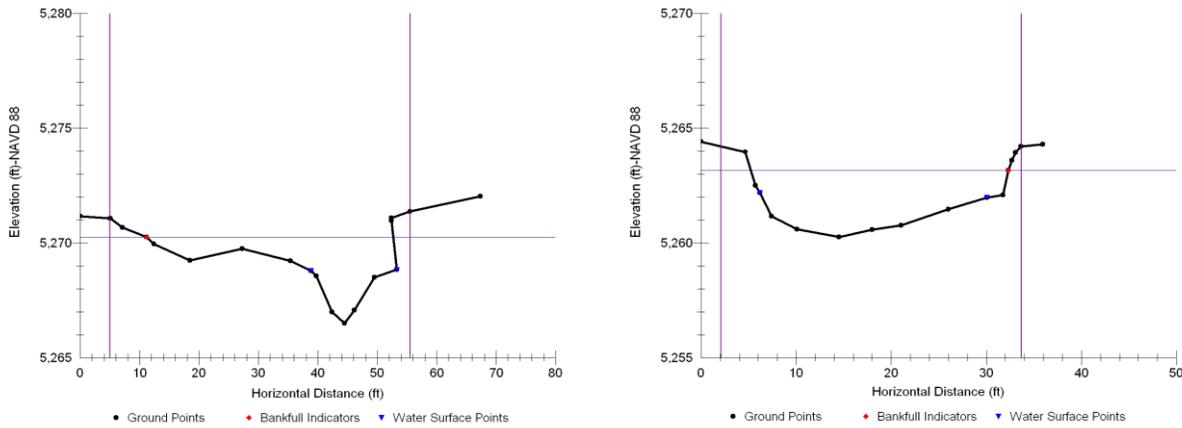


Figure 4-9. Pool cross-sections 2 (left) and 7 (right).

Table 4-7. Pool channel dimensions within Copper Creek.

Metric	XS 2	XS 7
Floodprone Width (ft)	N/A	N/A
Bankfull Width (ft)	41.5	27.1
Entrenchment Ratio	N/A	N/A
Mean Depth (ft)	1.4	2.1
Maximum Depth (ft)	3.8	2.9
Width/Depth Ratio	30.5	13.2
Bankfull Area (ft ²)	56.5	55.8
Wetted Perimeter (ft)	44.7	28.7
Hydraulic Radius (ft)	1.3	1.9



Figure 4-10. View downstream of cross-section 2 (left) and of cross-section 7 (right).

Glide Cross-Sections

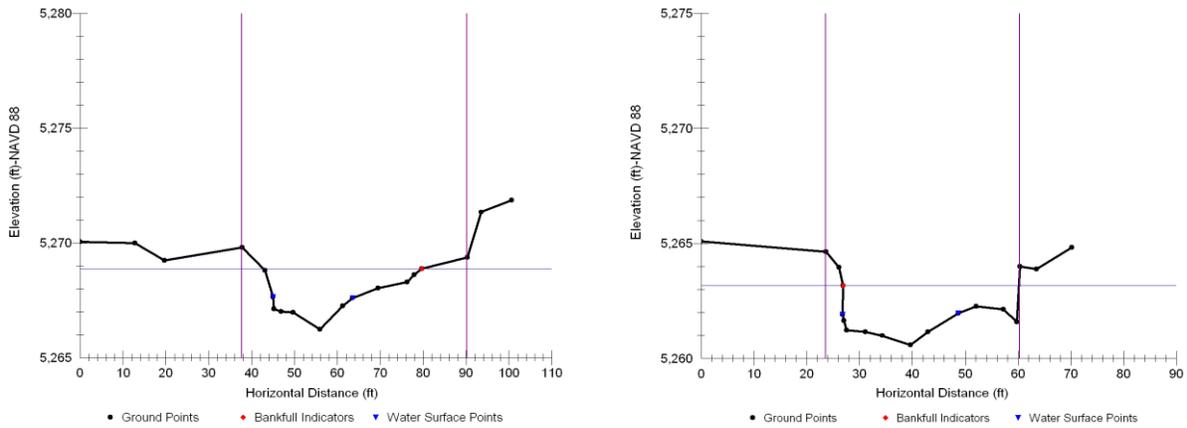


Figure 4-11. Glide cross-sections 4 (left) and 8 (right).

Table 4-8. Glide channel dimensions in Copper Creek.

Metric	XS 4	XS 8
Floodprone Width (ft)	N/A	N/A
Bankfull Width (ft)	36.9	33.3
Entrenchment Ratio	N/A	N/A
Mean Depth (ft)	1.4	1.7
Maximum Depth (ft)	2.6	2.6
Width/Depth Ratio	26.9	19.6
Bankfull Area (ft ²)	50.7	56.4
Wetted Perimeter (ft)	37.8	36.3
Hydraulic Radius (ft)	1.3	1.6



Figure 4-12. View downstream of cross-section 4 (left) and of upstream cross-section 8 (right).

4.1.6 Substrate Particle Size Distributions

Riffle Substrate

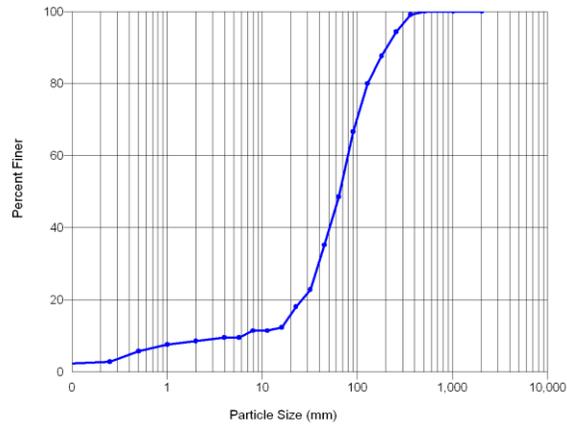


Figure 4-13. Riffle particle size distribution at cross-sections 3.

Table 4-9. Particle size distribution at cross-section 3.

Metric	mm	Metric	%
D16	20	Silt/Clay	0
D35	45	Sand	9
D50	66	Gravel	40
D84	155	Cobble	46
D95	272	Boulder	6
D100	512	Bedrock	0

Point Bar Material

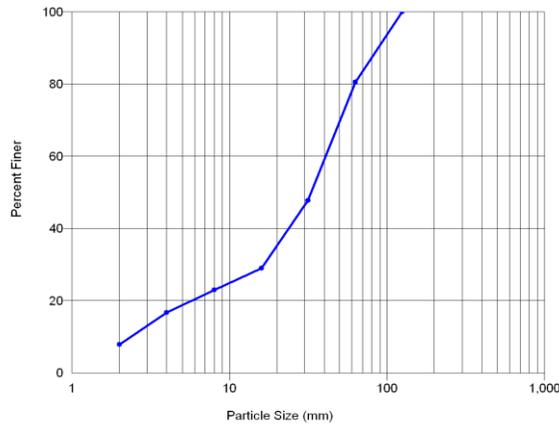


Figure 4-14. Representative point bar particle size distribution for Copper Creek.

Table 4-10. Bar Sample particle size distribution for Copper Creek.

Metric	mm	Metric	%
D16	4	Silt/Clay	0
D35	21	Sand	8
D50	34	Gravel	73
D84	74	Cobble	19
D95	109	Boulder	0
D100	125	Bedrock	0

Riffle Stability Index

Table 4-11. Riffle Stability Index values for Copper Creek.

		RSI Score
Reach Condition	Geometric Mean (mm)	XS 3
Reference	143	D82

4.1.7 Hydraulic Analysis

Table 4-12. Measured and estimated discharge (cfs) for riffle cross-sections in Copper Creek (August 2011). D50=66mm, D84=155mm.

XS ID	Area (ft ²)	Local Slope (ft/ft)	Manning's	Relative Roughness	Darcy-Weisbach	U/U*	Average	Measured
XS 3	11.7	0.0120	13.3	11.2	11.2	11.5	11.8	23.9
XS 5	24.9	0.0029	27.6	24.7	25.5	25.1	25.7	23.9

Table 4-13. Estimated bankfull discharge (cfs) for riffle cross-sections in Copper Creek.

XS ID	Area (ft ²)	Bankfull Slope (ft/ft)	Manning's	Relative Roughness	Darcy-Weisbach	U/U*	Average
XS 3	50.1	0.0078	173	160	165	160	165
XS 5	77.0	0.0078	331	307	317	307	316

Bold=value utilized as Copper Creek estimate for project-scale hydraulic analysis.

4.1.8 Aquatic Habitat Characterization

Table 4-14. Characterization of large wood observed in Copper Creek.

R1/R4 Variable Outputs	Singles	Aggregates	Rootfans
Total Number (count)	55	15	35 / 50 ¹
Number / 100 m	17.4	4.8	11.3 / 16.0 ²
Mean Diameter of Single Pieces (m)	0.24		
Mean Length of Single Pieces (m)	14.8		
Total Volume of Single Pieces (m ³)	52.8		
Total Volume of Single Pieces (m ³) / 100 m	17.0		
Percent Submerged Volume of Single Pieces (%)	3.3		
Number of Pieces in Aggregates	251 ³		49.5

¹ Total number of rootwads occurring as singles / or in aggregates.

² Number of rootwads occurring as single pieces / or in aggregates, per 100 meters.

³ Represents the number of single pieces identified in aggregates.

Table 4-15. Characterization of existing pool habitats surveyed in Copper Creek.

Reach ID	Number of Pools (#/100 m)	Pool to Pool Spacing (m) (mean)	Pool to Pool Spacing / Wbkf ¹ (mean)	Maximum Pool Depths (m) (mean)	Discrete Residual Pool Volume (m ³) (mean)	Cumulative Residual Pool Volume (m ³) (ft ³ /100 m)
Copper Creek	8.0 (2.6)	17.7-83.5 (58.8)	1.6-7.4 (5.2)	0.7-1.3 (1.0)	0.8-9.0 (4.0)	31.7 (10.2)

¹Wbkf=11.2 m.

5 Snowbank Creek: C4b Reference Reach

Snowbank Creek occurs as the second highest gradient system of the four reference reaches (Figure 5-1). The reach includes 383 feet of channel and classified as a C4b stream type (Rosgen 1996). Snowbank Creek within the survey reach occurs in Valley Type 2, characterized by valley floor slopes of less than 4%, and soils derived from older residual soils, alluvium and colluvium. The primarily single-thread channel exhibits characteristics of a Rosgen C4b stream type with a slope of 2.3%, an average width to depth ratio of 12.1, and an average entrenchment ratio of 6.6. The active channel displays riffle-pool and step-pool sequences and is developed within a terraced alluvial valley. The channel is relatively straight with a sinuosity of 1.0. The average riffle substrate consists of approximately 7% sand, 57% gravel-sized particles with 36% cobble and 0% boulders. The particles were considered sub-rounded. Estimated bankfull discharge is 136 cfs.

Snowbank Creek supports the second highest frequency of pools among the four reference reaches, averaging 5.1 pools per 100 meters with an average spacing of 58 feet or every 3.8 bankfull widths. Maximum pool depths range from 2.4 feet to 3.0 feet. Within the bankfull channel, twenty-one qualifying single pieces of large woody debris and four aggregates were inventoried in the surveyed reach. This equates to 17.9 and 3.4 singles and aggregates per 100 meters, respectively. Snowbank Creek has the second largest distribution of large woody debris of the surveyed reference reaches. As the adjacent forest and riparian vegetation has been impacted by wildfire, dead standing trees within the bankfull margins provide a source of coarse wood to the channel.

The Riffle Stability Index, a general indicator of bed mobility, indicates that the geometric mean of the 30 largest point bar particles constitutes the D86 of the riffle substrate particle size distribution at cross-section 8. As the value is over the D85 threshold, this implies that the riffle features are likely mobilized during average annual flow events.

Snowbank Creek occurs as a reference reach and may represent the pre-disturbance potential condition for impaired reaches in the UBMC project area of similar dimension, pattern and profile.

Table 5-1. Select Level II variables for Snowbank Creek.

Reach ID	Stream Type	Bankfull Slope (ft/ft)	Sinuosity	Entrenchment Ratio ¹	Width to Depth Ratio ¹	Riffle Width ¹ (ft)	Riffle D50 ¹ (mm)
Snowbank Creek	C4b	0.0228	1.0	6.6	12.1	15.2	53

¹Mean value. n=2.

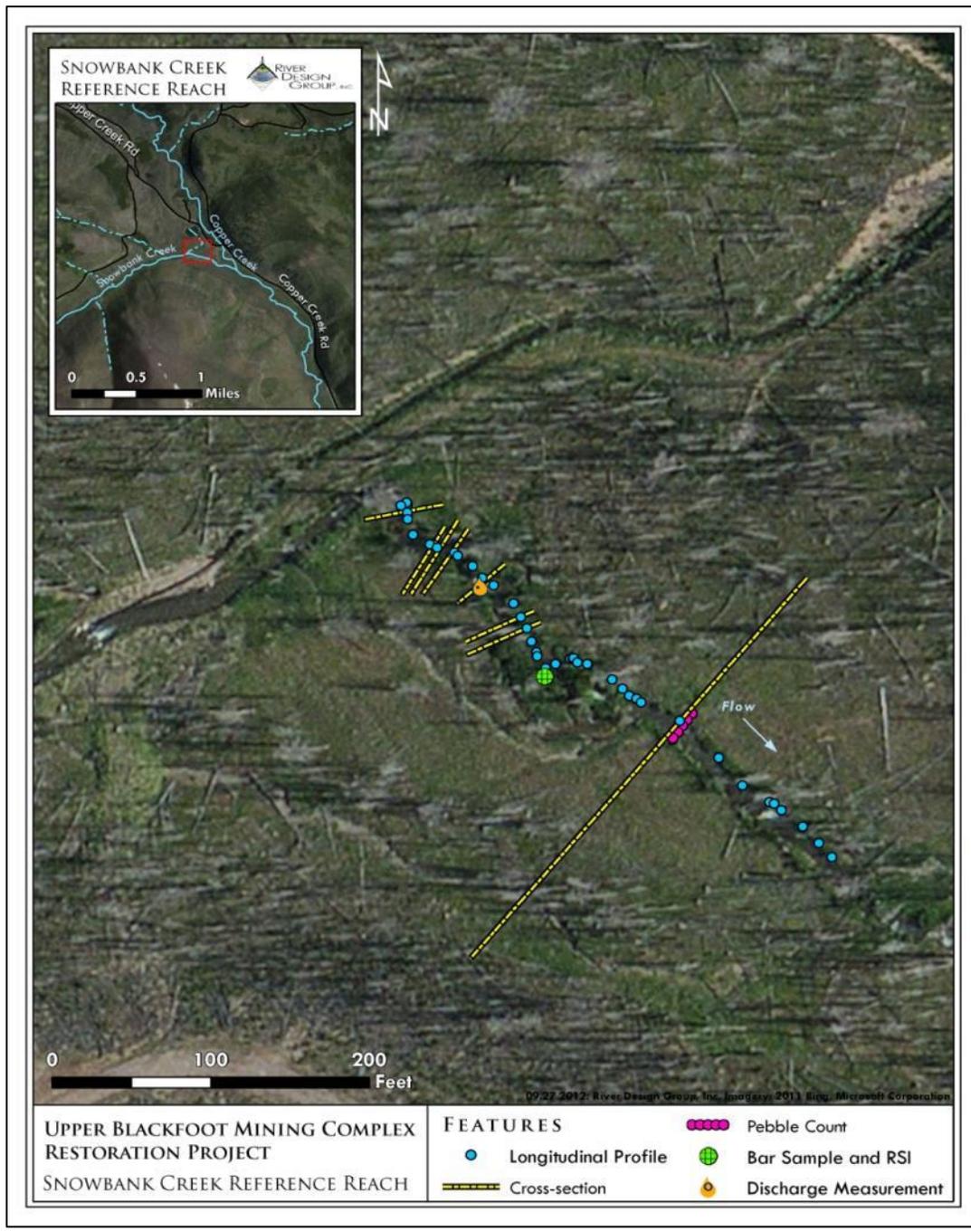


Figure 5-1. Snowbank Creek vicinity map.

5.1.1 Survey Planview

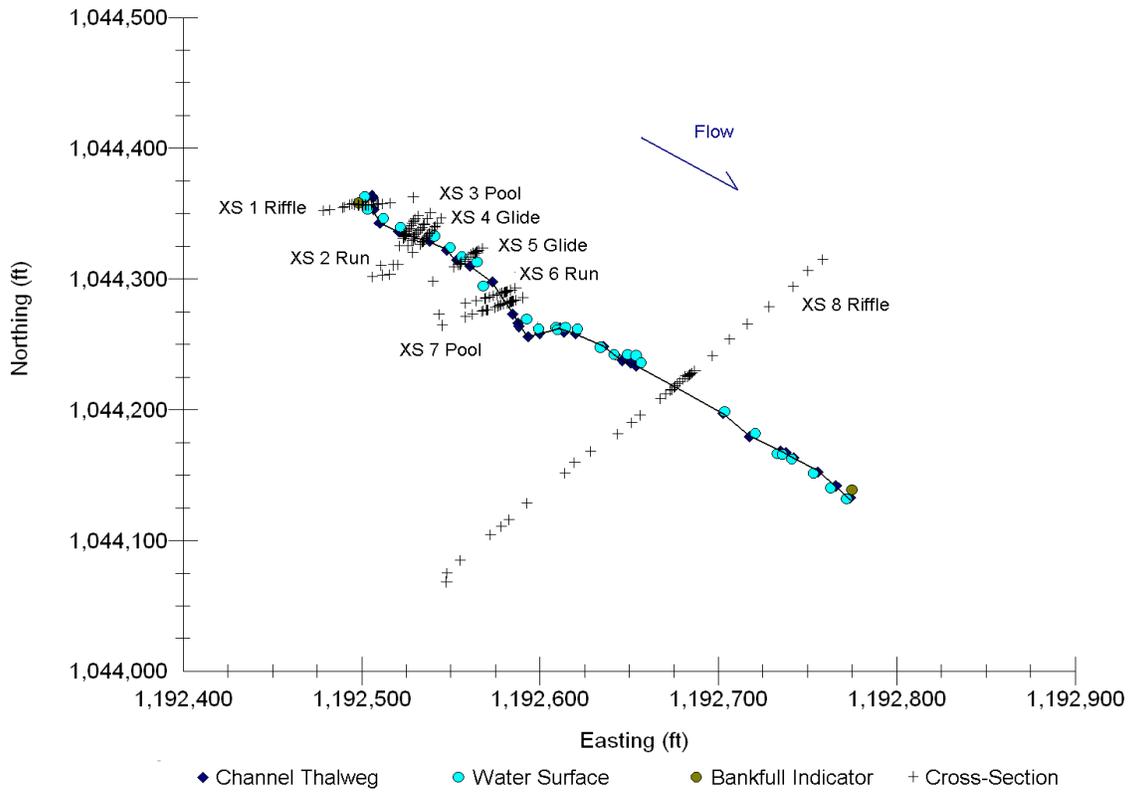


Figure 5-2. Planview of the surveyed points in Snowbank Creek.



Figure 5-3. View of upper (left) middle (inset) and lower (right) survey extents in Snowbank Creek.

5.1.2 Longitudinal Profile

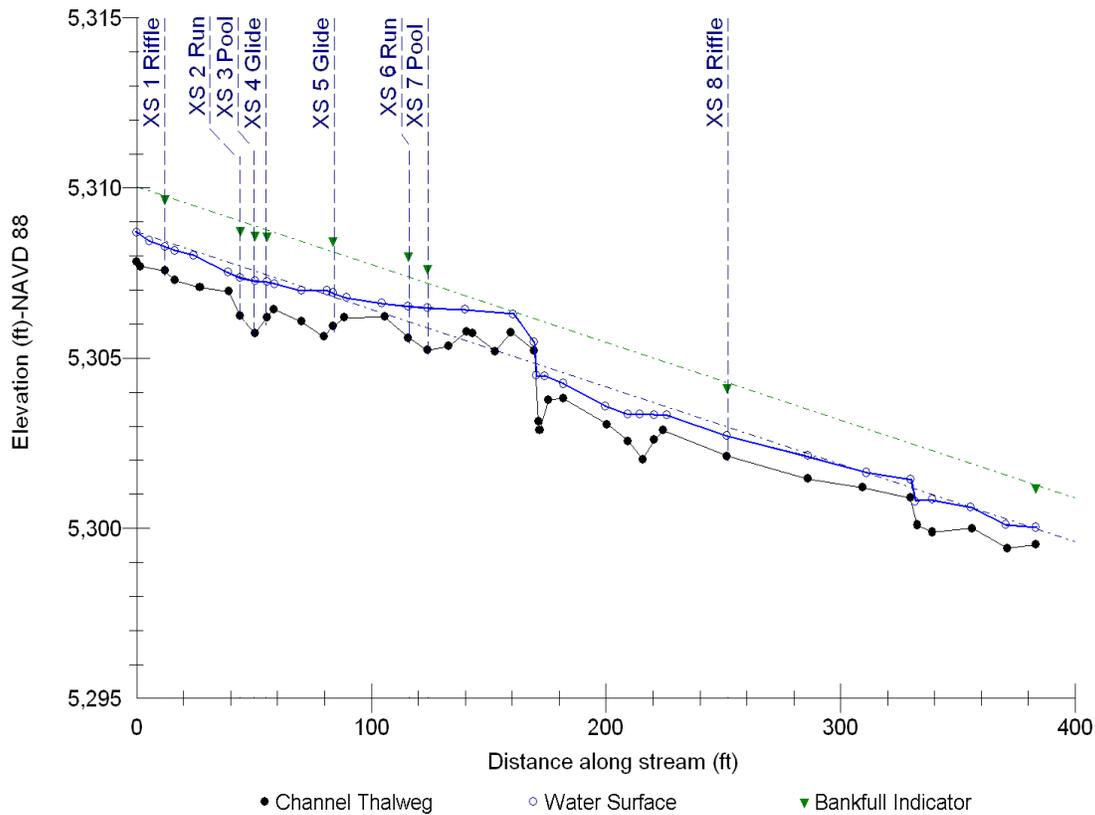


Figure 5-4. Snowbank Creek longitudinal profile.

Table 5-2. Longitudinal profile dimensions for Snowbank Creek.

Profile Dimensions Metric	Min	Mean	Max	Profile Dimensionless Ratios ¹ Metric	Min	Mean	Max
WS Slope (ft/ft)		0.0228		Bankfull Slope (ft/ft)		0.0228	
S Riffle (ft/ft)	0.0154	0.0252	0.0366	S Riffle / Sbkf (ft/ft)	0.67	1.10	1.60
S Pool (ft/ft)	0.0019	0.0040	0.0078	S Pool / Sbkf (ft/ft)	0.08	0.18	0.34
S Run (ft/ft)	0.0091	0.0108	0.0135	S Run / Sbkf (ft/ft)	0.40	0.47	0.59
S Glide (ft/ft)	0.0079	0.0093	0.0110	S Glide / Sbkf (ft/ft)	0.34	0.41	0.48
Pool - Pool (ft)	30.2	57.8	123	Pool - Pool / Wbkf (ft)	1.99	3.81	8.09
Pool Length (ft)	5.7	16.2	26.4	Pool Length / Wbkf (ft)	0.38	1.07	1.74
Riffle Length (ft)	16.4	37.5	99.4	Riffle Length / Wbkf (ft)	1.08	2.47	6.55
Dmax Riffle (ft)	1.9	2.1	2.3	Dmax Riffle / Dbkf (ft)	1.50	1.66	1.84
Dmax Pool (ft)	2.4	2.7	3.0	Dmax Pool / Dbkf (ft)	1.88	2.15	2.41
Dmax Run (ft)	2.3	2.3	2.4	Dmax Run / Dbkf (ft)	1.82	1.86	1.90
Dmax Glide (ft)	1.9	2.2	2.4	Dmax Glide / Dbkf (ft)	1.54	1.73	1.90
Low Bank Ht (ft)	1.9	2.1	2.2	Low Bank Ht / Dmax Riff (ft)	0.92	0.99	1.06

¹Sbkf=0.0228ft/ft, Wbkf=15.2 ft, Dbkf=1.3 ft, Dmax=2.1ft.

5.1.3 Planform Geometry

Table 5-3. Planform geometry summary table for Snowbank Creek.

Meander Location (ft)	Meander Wave Length (ft)	Meander Belt Width (ft)	Radius of Curvature (ft)	L_m / W_{bkf}^1	W_{bt} / W_{bkf}^1 (MWR)	R_c / W_{bkf}^1
No meanders occurred within the surveyed reach.						
Minimum						
Mean						
Maximum						
Standard Deviation						
Coefficient of Variance						
Sinuosity	1.0					

¹ $W_{bkf}=15.2$ ft

5.1.4 Cross-Section Dimensions

Table 5-4. Cross-section dimensions for Snowbank Creek.

Cross-Section Dimensions Metric	Min	Mean	Max	Cross-Section Dimensionless Ratios ¹			
				Metric	Min	Mean	Max
Floodprone Width (ft)	57.0	104	151	Wfpa / Wbkf	3.76	6.86	9.96
Riffle Area (ft ²)	15.0	19.1	23.3	Riffle Area / Abkf	0.78	1.00	1.22
Max Riffle Depth (ft)	2.0	2.0	2.1	Max Riffle Depth / Dbkf	1.58	1.62	1.66
Mean Riffle Depth (ft)	1.1	1.3	1.4	Mean Riffle Depth / Dbkf	0.90	1.00	1.09
Riffle Width (ft)	13.2	15.2	17.1	Riffle Width / Wbkf	0.87	1.00	1.13
Entrenchment Ratio	4.3	6.6	8.8	Entrenchment Ratio/ER	3.75	6.84	9.93
Width/Depth Ratio	11.7	12.1	12.6	Width/Depth / W/D	0.96	1.00	1.04
Pool Area (ft ²)	23.2	26.5	29.8	Pool Area / Abkf	1.21	1.38	1.56
Max Pool Depth (ft)	2.4	2.9	3.5	Max Pool Depth / Dbkf	1.89	2.35	2.81
Mean Pool Depth (ft)	1.2	1.7	2.2	Mean Pool Depth / Dbkf	0.94	1.34	1.74
Pool Width (ft)	13.7	16.6	19.5	Pool Width / Wbkf	0.91	1.10	1.29
Run Area (ft ²)	15.2	22.2	29.3	Run Area / Abkf	0.79	1.16	1.53
Max Run Depth (ft)	2.4	2.4	2.5	Max Run Depth / Dbkf	1.90	1.94	1.98
Mean Run Depth (ft)	1.2	1.2	1.2	Mean Run Depth / Dbkf	0.98	0.98	0.98
Run Width (ft)	12.5	18.2	23.9	Run Width / Wbkf	0.82	1.20	1.57
Glide Area (ft ²)	18.3	23.1	27.9	Glide Area / Abkf	0.96	1.21	1.46
Max Glide Depth (ft)	2.4	2.4	2.5	Max Glide Depth / Dbkf	1.90	1.94	1.98
Mean Glide Depth (ft)	1.3	1.6	1.8	Mean Glide Depth /Dbkf	1.07	1.25	1.42
Glide Width (ft)	13.6	14.7	15.8	Glide Width / Wbkf	0.90	0.97	1.04

¹ Abkf=19.1 ft², Wbkf=15.2 ft, W/D=12.1, ER= 6.6, Dbkf=1.3 ft.

5.1.5 Surveyed Cross-Sections

Riffle Cross-Sections

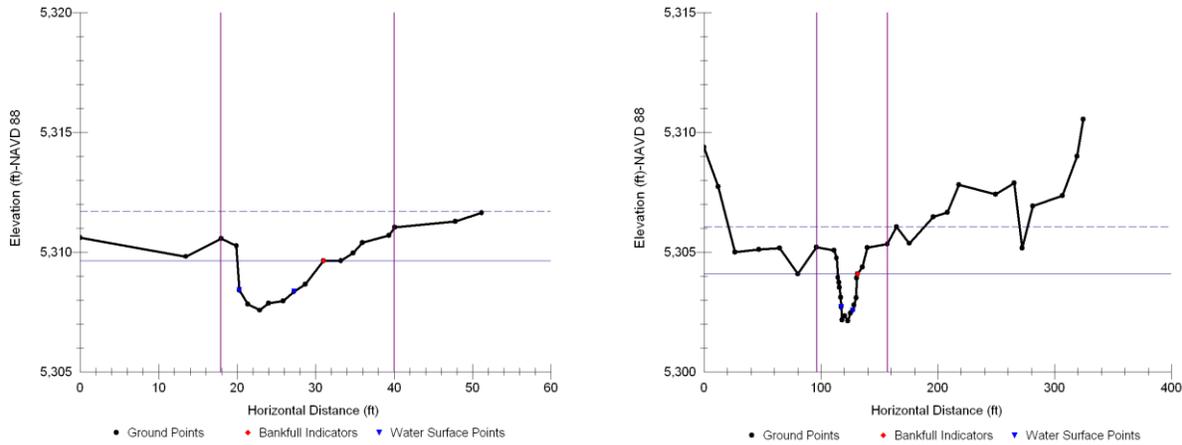


Figure 5-5. Riffle cross-sections 1 (left) and 8 (right).

Table 5-5. Riffle channel dimensions in Snowbank Creek.

Metric	XS 1	XS 8
Floodprone Width (ft)	57.0	151
Bankfull Width (ft)	13.2	17.1
Entrenchment Ratio	4.3	8.8
Mean Depth (ft)	1.1	1.4
Maximum Depth (ft)	2.1	2.0
Width/Depth Ratio	11.7	12.6
Bankfull Area (ft ²)	15.0	23.3
Wetted Perimeter (ft)	14.7	18.5
Hydraulic Radius (ft)	1.0	1.3



Figure 5-6. View downstream of cross-section 1 (left) and of cross-section 8 (right).

Run Cross-Sections

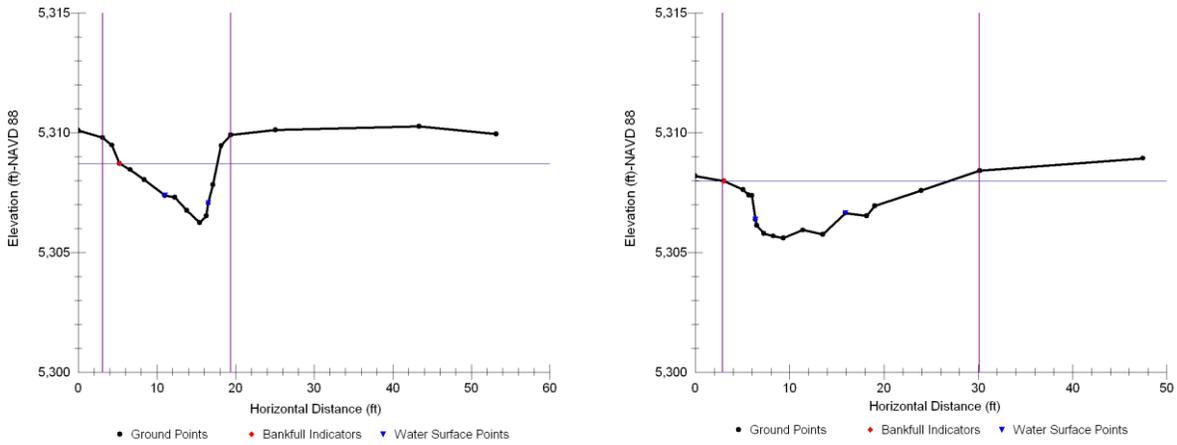


Figure 5-7. Run cross-sections 2 (left) and 6 (right).

Table 5-6. Run channel dimensions in Snowbank Creek.

Metric	XS 2	XS 6
Floodprone Width (ft)	N/A	N/A
Bankfull Width (ft)	12.5	23.9
Entrenchment Ratio	N/A	N/A
Mean Depth (ft)	1.2	1.2
Maximum Depth (ft)	2.5	2.4
Width/Depth Ratio	10.2	19.4
Bankfull Area (ft ²)	15.2	29.3
Wetted Perimeter (ft)	14.1	25.2
Hydraulic Radius (ft)	1.1	1.2



Figure 5-8. View downstream of cross-section 2 (left) and of cross-section 6 (right).

Pool Cross-Sections

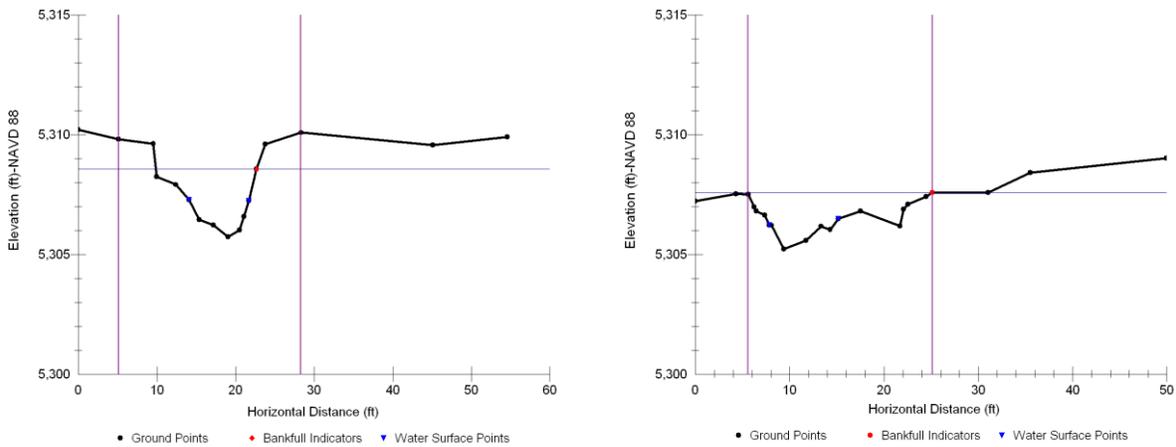


Figure 5-9. Pool cross-sections 3 (left) and 7 (right).

Table 5-7. Pool channel dimensions within Snowbank Creek.

Metric	XS 3	XS 7
Floodprone Width (ft)	N/A	N/A
Bankfull Width (ft)	13.7	19.5
Entrenchment Ratio	N/A	N/A
Mean Depth (ft)	2.2	1.2
Maximum Depth (ft)	3.5	2.4
Width/Depth Ratio	6.3	16.6
Bankfull Area (ft ²)	29.8	23.2
Wetted Perimeter (ft)	16.5	21.2
Hydraulic Radius (ft)	1.8	1.1



Figure 5-10. View downstream of cross-section 3 (left) and of cross-section 7 (right).

Glide Cross-Sections

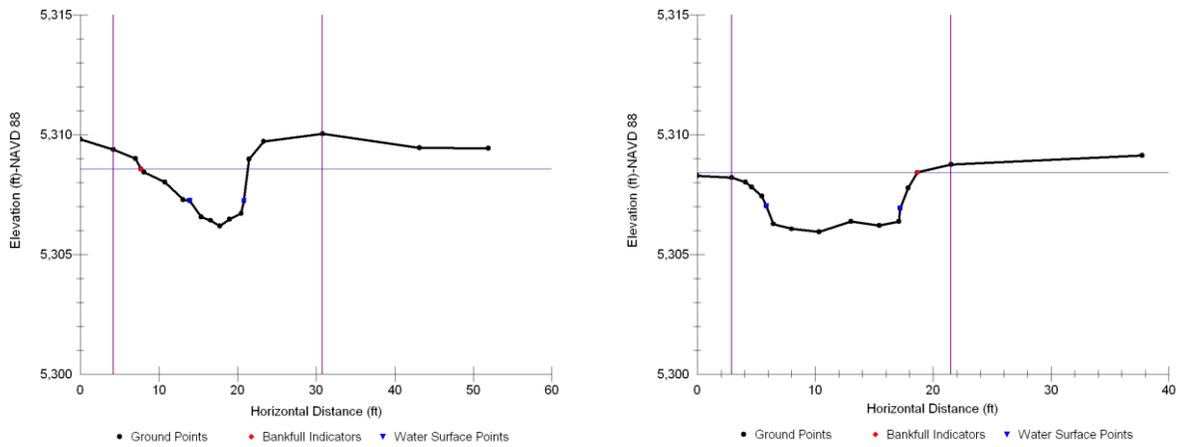


Figure 5-11. Glide cross-sections 4 (left) and 5 (right).

Table 5-8. Glide channel dimensions in Snowbank Creek.

Metric	XS 4	XS 5
Floodprone Width (ft)	N/A	N/A
Bankfull Width (ft)	13.6	15.8
Entrenchment Ratio	N/A	N/A
Mean Depth (ft)	1.3	1.8
Maximum Depth (ft)	2.4	2.5
Width/Depth Ratio	10.2	8.9
Bankfull Area (ft ²)	18.3	27.9
Wetted Perimeter (ft)	15.2	17.8
Hydraulic Radius (ft)	1.2	1.6



Figure 5-12. View downstream of cross-section 4 (left) and upstream of cross-section 5 (right).

5.1.6 Substrate Particle Size Distributions

Riffle Substrate

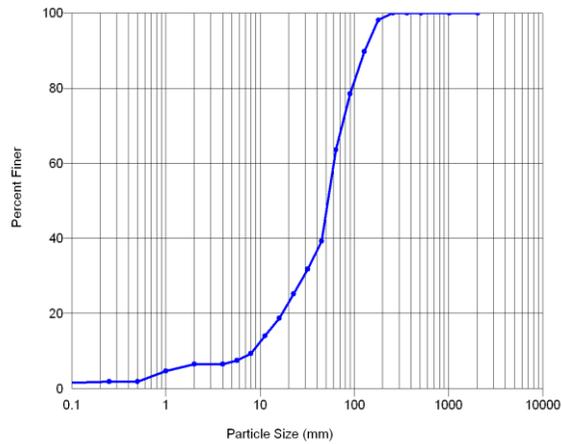


Figure 5-13. Riffle particle size distribution at cross-sections 8.

Table 5-9. Particle size distribution at cross-section 8.

Metric	mm	Metric	%
D16	13	Silt/Clay	0
D35	38	Sand	7
D50	53	Gravel	57
D84	109	Cobble	36
D95	161	Boulder	0
D100	256	Bedrock	0

Point Bar Material

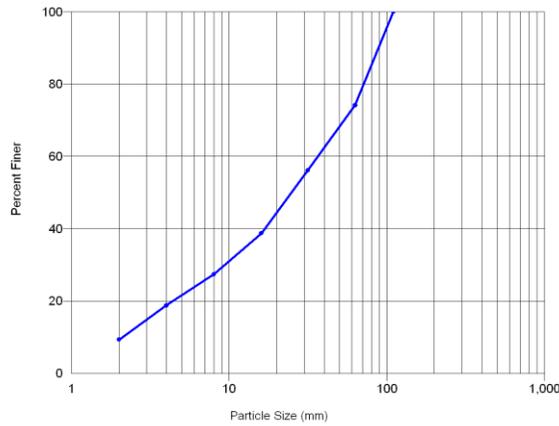


Figure 5-14. Representative point bar particle size distribution for Snowbank Creek.

Table 5-10. Bar Sample particle size distribution for Snowbank Creek.

Metric	mm	Metric	%
D16	3	Silt/Clay	0
D35	13	Sand	9
D50	26	Gravel	66
D84	81	Cobble	25
D95	101	Boulder	0
D100	110	Bedrock	0

Riffle Stability Index

Table 5-11. Riffle Stability Index values for Snowbank Creek.

		RSI Score
Reach Condition	Geometric Mean (mm)	XS 3
Reference	116	D86

5.1.7 Hydraulic Analysis

Table 5-12. Measured and estimated discharge (cfs) for riffle cross-sections in Snowbank Creek (August 2011). D50=53mm, D84=109mm.

XS ID	Area (ft ²)	Local Slope (ft/ft)	Manning's	Relative Roughness	Darcy-Weisbach	U/U*	Average	Measured
XS 1	3.5	0.0256	8.5	7.6	7.8	7.5	7.9	3.4
XS 8	4.0	0.0167	3.9	3.3	3.4	3.3	3.5	3.4

Table 5-13. Estimated bankfull discharge (cfs) for riffle cross-sections in Snowbank Creek.

XS ID	Area (ft ²)	Bankfull Slope (ft/ft)	Manning's	Relative Roughness	Darcy-Weisbach	U/U*	Average
XS 1	15.0	0.0228	83.8	77.6	82.4	70.2	78.5
XS 8	23.3	0.0228	142	132	137	133	136

Bold=value utilized as Snowbank Creek estimate for project-scale hydraulic analysis.

5.1.8 Aquatic Habitat Characterization

Table 5-14. Characterization of large wood observed in Snowbank Creek.

R1/R4 Variable Outputs	Singles	Aggregates	Rootfans
Total Number (count)	21	4	11 / 10 ¹
Number / 100 m	17.9	3.4	9.4 / 8.5 ²
Mean Diameter of Single Pieces (m)	0.2		
Mean Length of Single Pieces (m)	7.7		
Total Volume of Single Pieces (m ³)	5.2		
Total Volume of Single Pieces (m ³) / 100 m	4.5		
Percent Submerged Volume of Single Pieces (%)	8.8		
Number of Pieces in Aggregates	39 ³		10

¹ Total number of rootwads occurring as singles / or in aggregates.

² Number of rootwads occurring as single pieces / or in aggregates, per 100 meters.

³ Represents the number of single pieces identified in aggregates.

Table 5-15. Characterization of existing pool habitats surveyed in Snowbank Creek.

Reach ID	Number of Pools (#/100 m)	Pool to Pool Spacing (m) (mean)	Pool to Pool Spacing / Wbkf ¹ (mean)	Maximum Pool Depths (m) (mean)	Discrete Residual Pool Volume (m ³) (mean)	Cumulative Residual Pool Volume (m ³) (ft ³ /100 m)
Snowbank Creek	6.0 (5.1)	9.2-37.5 (17.6)	2.0-8.1 (3.8)	0.7-1.1 (0.9)	0.6-2.2 (1.2)	7.1 (6.1)

¹Wbkf=4.6 m.