Rosgen Classification
Unnamed Creek South of Dunka Road

Prepared for
Poly Met Mining Inc.

September 2013

BARR

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1.0 Introduction

The Minnesota Department of Natural Resources (MDNR), United States Forest Service Region 9 (USFS R9), and the United States Army Corps of Engineers (USACE), collectively known as the Co-Lead Agencies, are in the process of evaluating the environmental impacts of the NorthMet Project (Project). As part of the environmental review process, Poly Met Mining Inc. (PolyMet) has performed an evaluation of the geomorphology of the Unnamed Creek that drains a portion of the Mine Site to the Partridge River (also referred to as the "West Pit Outlet" stream). The purpose of this report is to summarize the findings of the stream geomorphology survey on Unnamed Creek conducted in November 2011 and discuss the sensitivity of the stream to changes in hydrology.

1.1 Description of Unnamed Creek

Unnamed Creek is a perennial stream which drains the western portion of the Mine Site, including the future West Pit, to the Partridge River (Figure 1). This creek is not found on MDNR lists or figures of the public waters of Minnesota. The creek channel varies along its length from rocky riffles to open ponds created by low beaver dams. The headwaters of Unnamed Creek is a deep marsh immediately north of Dunka Road; there is little or no stream channel upstream of this marsh. The existing drainage area to this marsh consists largely of shrub forests, shrub swamps, and marshes. The land adjacent to Unnamed Creek before its confluence with the Partridge River is shrub swamps and shrub forests. The total length of Unnamed Creek is approximately 0.9 miles from its headwaters to the Partridge River. In November 2011, Barr Engineering conducted a survey of approximately 0.4 miles of Unnamed Creek in order to characterize the geomorphic characteristics of the channel and the floodplain.

1.2 Physical Classification of Channels

Physical classification of a stream or river is the process of describing a stream's physical nature based on the relationship of its geometry and hydraulic characteristics. The purpose of a physical classification is to evaluate the stability of a stream under existing conditions, determine its sensitivity to change, and to indicate how restoration may be approached if a portion of the stream becomes unstable. The most commonly accepted system of physical classification is that developed by D.L. Rosgen (Reference (1), Reference (2)). The Rosgen system has eight basic stream types, which are further subdivided according to channel slope and materials. Furthermore, the classification is separated into levels, ranging from Level I (broad level characterization) to Level IV (verification of field measurements). A general description of the Rosgen classification system is presented in Appendix A.

1.3 Previous Studies

Unnamed Creek was included in a hydrologic study performed for the Project in 2008 (Reference (3)) and updated in 2013 (Reference (4)). This study consisted of an XP-SWMM model of the entire Partridge River watershed above USGS gaging station #04015475 (Partridge River above Colby Lake). Unnamed Creek was included in this model, but channel cross-section and floodplain information were derived from aerial photography and GIS tools rather than a field survey. The XP-SWMM modeling, adjusted based on the observed flow record at the USGS gage (Table 4-7 of reference (4)), estimates that the average annual maximum flow rate of Unnamed Creek at the Dunka Road crossing is approximately 24 cfs, and the annual average flow rate is 1.6 cfs. This geomorphic study represents the first field data collected on Unnamed Creek for the NorthMet Project.

2.0 Level I Rosgen Classification

Barr Engineering performed a level I Rosgen Classification on Unnamed Creek in November 2011. The surveyed reaches are shown in Figure 1. A Level I classification consists of a survey of the channel profile and cross-sections of the channel and floodplain. See Appendix A for a general description of the Rosgen classification system and definition of terms used in this classification. The survey made some attempt to describe the substrate and bank materials, but no specific samples were collected.

2.1 Data Collection

Barr conducted the survey of Unnamed Creek on November 16th, 2011. During the field survey, data was collected using survey-grade GPS. Ground photographs were also taken of each cross-section and at various points along the stream. The stream bottom profile was surveyed for a length of approximately 0.3 miles, and three permanent monumented cross-sections were established with 2 to 4 foot rebar stakes or nails in adjacent trees, lath and ribbon. Water surface elevations and bankfull elevation indicators were also surveyed, and the dominant bed material was described by visual inspection and photographs at several locations.

2.2 Unnamed Creek Classification

The surveyed reach of Unnamed Creek is located south of Dunka Road, approximately 0.22 miles downstream of the road crossing and culvert. The measured physical parameters, cross-sections and photographs of this reach are shown in Appendix B, Data Sheet 1. In this area, Unnamed Creek meanders through forested wetlands with occasional low beaver dams that retard flow and increase water levels without creating large drops.

Unnamed Creek is best characterized as a combination of Rosgen types C and E. Cross-section 1 is on the border between C and E classifications. This is due to its width/depth ratio of 10.6, which is near the value of 12 that divides C from E in the Rosgen classification system. Based on width/depth ratio alone, Cross-section 1 is an E channel, but its sinuosity is more typical of a C channel. Cross-section 2 has the width/depth ratio of a C channel, but the sinuosity of an E channel. Finally, Cross-section 3 is characterized as Type E.

Reaches sometimes display characteristics of multiple channel types, and it is also possible for channel type to change along a reach. Changes in channel type are usually accompanied by changes in landscape factors such as slope or bed material. In the case of Unnamed Creek, the changes in substrate and the presence of beaver dams may be controlling influences on channel shape and plan form. In all sections, regardless of specific channel types,Unnamed Creek is considered slightly entrenched and has a moderate to high degree of sinuosity. These characteristics indicate that the stream has an adequate floodplain to dissipate energy during higher-than-bankfull flows, and that it has reasonably frequent access to that floodplain. Baseflow in this creek from groundwater is very low and may occasionally be zero; the hydrologic model of the area estimates the average 30-day minimum flow at Dunka Road at approximately 0.1 cfs (Reference (4)).

The wetland surrounding Unnamed Creek has been classified as an alder thicket (Reference (5)). Bank and floodplain vegetation along Unnamed Creek consists of emergent and wetland grasses and wetland shrubs. There are places where conifers and shrubs grow right up to the banks of the stream, but there is no evidence of significant bank undercutting or other erosion on this reach. The alder thicket wetland along the stream is bordered by a forest on both sides. Stream bed material consists of cobbles in riffles and runs and silty/mucky materials in ponds and pools. The classification of bank material is not well known but based on existing vegetation and previously classified wetland type it is likely to be predominantly silt.

Downstream of the surveyed reach, in the 0.3 miles before its confluence with the Partridge River, Unnamed Creek maintains approximately the same plan view and floodplain characteristics as the surveyed reach. It is reasonable to expect that cross-sectional area increases moving downstream as the watershed area increases, but slope and entrenchment ratios are also likely consistent with that of the surveyed reach.

With characteristics of both C and E channels, Unnamed Creek has moderate to high sensitivity to disturbances of the streambanks or significant changes in stream flow or sediment supply. As indicated in Table A-2, the influence of riparian vegetation on channel stability in all C and E streams is moderate to very high, meaning that streams with extensive vegetative root systems on the banks are more likely to maintain a stable cross-section. Because of the well-developed bank vegetation (100% coverage on the banks) and the noted presence of cobbles in the creek substrate, this reach is expected to be stable under moderate changes in stream flow and sediment supply. The recovery potential of this channel, should the banks be disturbed, is good.

3.0 Conclusions

This survey investigated Unnamed Creek, a tributary to the Partridge River from the NorthMet Mine Site, and found it to be consistent with Rosgen Type C and E streams. There is no evidence of erosion, downcutting, or channel widening at any of the surveyed locations along Unnamed Creek, and the creek has well-developed floodplains, substantial bank vegetation, and cobbles in the steeper riffle sections. Baseflow to Unnamed Creek from groundwater is very low, and water levels during average- and low-flow conditions are likely controlled by low beaver dams scattered throughout the wetlands.

Because of the well-developed floodplains and complete coverage of the stream banks with wetland vegetation, Unnamed Creek is likely able to withstand moderate changes in hydrology with no significant degradation. The need for more detailed classification or monitoring of Unnamed Creek in the future should be based on the degree of proposed hydrologic changes in the creek's watershed.

References

1. **Rosgen, D.L.** A Classification of Natural Rivers. 1994, 22, pp. 169-199.

2. —. Applied River Morphology. Wildland Hydrology. Pogosa Springs, Colorado : s.n., 1996.

3. **Barr Engineering Company.** Streamflow and Lake Level Changes, Hydrologic/Hydraulic Modeling Results for the PolyMet NorthMet Mine Site, RS73B Draft-03. September 2008.

4. **Poly Met Mining Inc.** NorthMet Project Water Modeling Data Package Volume 1 - Mine Site (v12). March 2013.

5. **PolyMet Mining Inc.** NorthMet Project Wetland Data Package. March 2013.

Figures

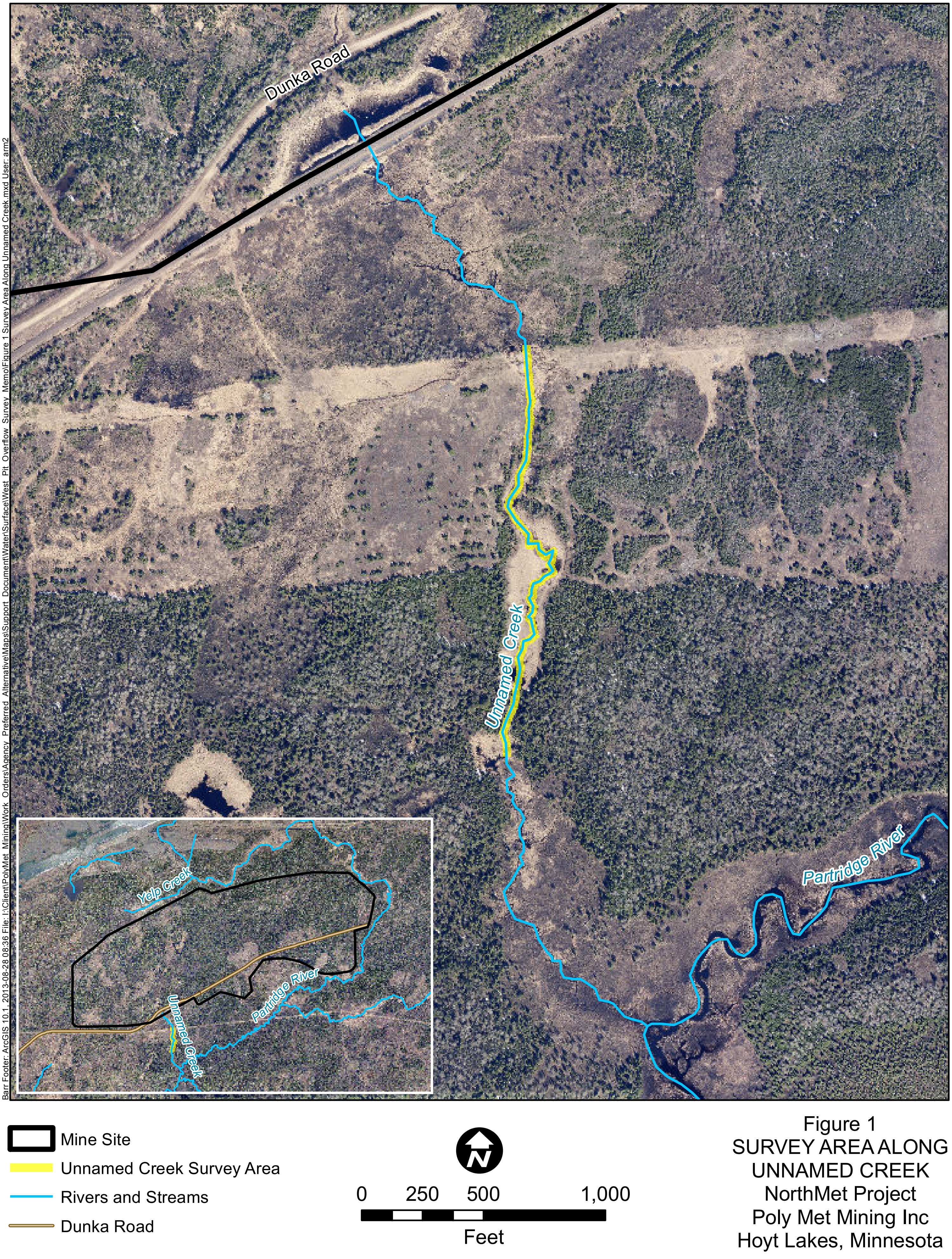


Figure 1
SURVEY AREA ALONG
UNNAMED CREEK
NorthMet Project
Poly Met Mining Inc
Hoyt Lakes, Minnesota

Appendices

Appendix A

Rosgen Classification System

Rosgen Classification System

The classification system used to classify the stream channels was developed by D.L. Rosgen ("A Classification of Natural Rivers", Catena, 1994) Rosgen's classification system describes a stream on a reach-by-reach basis. A single stream can have several different stream types over its length. The system defines a stream type according to the shape, pattern, and profile of the reach. In particular, the following parameters are used to classify a stream type: the degree of entrenchment of the channel, the ratio of width to depth, degree of channel meandering or sinuosity, channel material, and the channel surface slope. Some of these parameters are illustrated on Figure A-1.

The Rosgen classification system specifies seven basic stream types, ranging from A to G as shown on Figure A-2. Each type has six subclasses corresponding to the predominant bed material present in the reach. These subclasses are numbered from 1 to 6: 1 is bedrock, 2 is boulder, 3 is cobble, 4 is gravel, 5 is sand, and 6 is silt. This allows for 42 combinations of stream type. A description of the stream types is given in Table A-1. This table gives a range of values of the criteria used for stream classification. These ranges are those most commonly observed; the actual observed values can lie outside of these ranges to a certain extent, recognizing that as the stream type changes, the criteria will adjust accordingly.

Entrenchment Ratio is defined as the ratio of the width of the flood-prone area to the bankfull surface width of the channel. Flood-prone area is defined by Rosgen as the width measured at an elevation which is determined at twice the maximum bankfull depth. Field observation shows this elevation to be a frequent flood (50 year) or less, rather than a rare flood elevation. The entrenchment ratio describes the interrelationship of the river to its valley and landform features. It is a measure of channel down-cutting compared to its floodplain. This interrelationship determines whether the river (stream) is deeply incised or entrenched in the valley floor or deposit feature. The entrenchment ratio indicates whether the flat area adjacent to the channel is a frequent floodplain, a terrace (abandoned floodplain), or is outside the flood-prone area.

W*idth/Depth Ratio* is the ratio of bankfull channel width to bankfull mean depth; it is used to describe the dimension and shape of the channel.

Sinuosity is the ratio of stream length to valley length. It can also be described as the ratio of valley slope to channel slope. This value typically varies from 1.0 to 2.5, where a value of 1.0 corresponds to a straight channel. Sinuosity can often be determined from aerial photographs, and interpretations can then be made of slope, channel materials, and entrenchment. Values of sinuosity appear to be modified by bedrock control, roads, channel confinement, and vegetation types, among other factors. Generally, as gradient and particle size decrease, there is a corresponding increase in sinuosity. Meander geometry characteristics are directly related to sinuosity following minimum expenditure of energy concepts. Based on these relations and ease of determination, sinuosity is one of the delineative criteria for stream classification.

Water Surface Slope is of major importance to the morphological character of the channel and its sediment, hydraulic, and biological function. It is determined by measuring the difference in water surface elevation per unit stream length. It is typically measured through at least 20 channel widths or two meander wavelengths (Rosgen). In broad level delineations, slope can be estimated by measuring sinuosity from aerial photos and measuring valley slope from topographic maps.

Channel Materials refer to the bed and bank materials of the stream. Channel material is critical for sediment transport and hydraulic influences, and also modifies the form, plan, and profile of the stream. Interpretations of biological function and stability also require this information. The channel materials can often be estimated from soils maps and geologic information. They can also be determined in the field, and at the detailed level the materials are measured and the size plotted on percent distribution paper.

Bankfull Discharge occurs at approximately the 1.5 year recurrence interval and is referenced to as the dominant discharge for the stream. Hydraulic geometry and sediment transport relations rely heavily on the frequency and magnitude of bankfull discharge.

Different types of streams have differing sensitivities to disturbance and varying recovery potential. Sensitivity and recovery potential are interrelated to sediment supply in the stream, bank erosion potential, and the influence of vegetation on controlling bank erosion. These differences are itemized by stream type in Table A-2. The information in this table is best applied when a stream's behavior can be assessed by appearance and by extrapolating information from similar stream types. Knowing the sensitivity of each stream type allows for better management of the stream systems, potential impact assessment, and risk analysis.

Table A-1 Summary of Criteria for General Classification (from Rosgen)

Stream Type	General Description	Entrenchment Ratio	W/D Ratio	Sinuosity	Slope	Landform/Soils/Features
A	Steep, entrenched, debris transport streams.	< 1.4	<12	1.0 to 1.2	0.04 to 0.10	High relief, mountainous environments; entrenched and confined streams with cascading reaches; frequent deep pools
B	Moderately entrenched, moderate gradient, riffle dominated channel with infrequent pools. Very stable.	1.4 to 2.2	>12	>12	0.02 to 0.039	Moderate relief, colluvial deposition and/or residual soils. Moderate entrenchment and W/D ratio. Narrow, gently sloping valleys. Rapids with occasional pools.
C	Low gradient, meandering alluvial channels with broad, well defined floodplain.	>2.2	>12	>1.4	<0.02	Broad valleys with terraces, associated with floodplain, alluvial soils. Slightly entrenched with well-defined meandering channel. Riffle-pool bed morphology.
D	Braided channel; very wide channel with eroding banks.	n/a	>40	n/a	<0.04	Broad valleys with alluvial and colluvial fans. Abundant sediment supply.
E	Low gradient, meandering stream with low width/depth ratio and little deposition. Very efficient and stable.	>2.2	<12	>1.5	<0.02	Broad valley/meadows. Alluvial materials with floodplain. Highly sinuous with stable, well vegetated banks. Riffle-pool morphology with very low width/depth ratio.
F	Entrenched meandering riffle/pool channel on low gradients with high width/depth ratio	<1.4	>12	>1.4	<0.02	Entrenched in highly weathered material. Gentle gradients with high W/D ratio. Meandering, laterally unstable with high bank-erosion rates. Riffle-pool morphology.
G	Entrenched Gully step/pool with low width/depth ration on moderate gradients	<1.4	<12	>1.2	0.02 to 0.039	Gully, step-pool morphology with moderate slopes and low W/D ratio. Narrow valleys, or deeply incised in alluvial or colluvial materials. Unstable, with grade control problems and high bank erosion rates.

Table A-2. Management Interpretations of various stream types (from Rosgen, 1996)

Stream Type	Sensitivity to Disturbance[a]	Recovery Potential[b]	Sediment Supply[c]	Streambank Erosion Potential	Vegetation Controlling Influence[d]
A1	Very low	Excellent	Very low	Very low	Negligible
A2	Very low	Excellent	Very low	Very low	Negligible
A3	Very high	Very poor	Very high	Very high	Negligible
A4	Extreme	Very poor	Very high	Very high	Negligible
A5	Extreme	Very poor	Very high	Very high	Negligible
A6	High	Poor	High	High	Negligible
B1	Very low	Excellent	Very low	Very low	Negligible
B2	Very low	Excellent	Very low	Very low	Negligible
B3	Low	Excellent	Low	Low	Moderate
B4	Moderate	Excellent	Moderate	Low	Moderate
B5	Moderate	Excellent	Moderate	Moderate	Moderate
B6	Moderate	Excellent	Moderate	Low	Moderate
C1	Low	Very good	Very low	Low	Moderate
C2	Low	Very good	Low	Low	Moderate
C3	Moderate	Good	Moderate	Moderate	Very high
C4	Very high	Good	High	Very high	Very high
C5	Very high	Fair	Very high	Very high	Very high
C6	Very high	Good	High	High	Very high
D3	Very high	Poor	Very high	Very high	Moderate
D4	Very high	Poor	Very high	Very high	Moderate
D5	Very high	Poor	Very high	Very high	Moderate
D6	High	Poor	High	High	moderate
Da4	Moderate	Good	Very low	Low	Very high
DA5	Moderate	Good	Low	Low	Very high
DA6	Moderate	Good	Very low	Very low	Very high
E3	High	Good	Low	Moderate	Very high
E4	Very high	Good	Moderate	High	Very high
E5	Very high	Good	Moderate	High	Very high
E6	Very high	Good	Low	Moderate	Very high
F1	Low	Fair	Low	Moderate	Low
F2	Low	Fair	Moderate	Moderate	Low
F3	Moderate	Poor	Very high	Very high	Moderate
F4	Extreme	Poor	Very high	Very high	Moderate
F5	Very high	Poor	Very high	Very high	Moderate
F6	Very high	Fair	High	Very high	Moderate
G1	Low	Good	Low	Low	Low
G2	Moderate	Fair	Moderate	Moderate	Low
G3	Very high	Poor	Very high	Very high	High
G4	Extreme	Very poor	Very high	Very high	High
G5	Extreme	Very poor	Very high	Very high	High
G6	Very high	Poor	High	High	High

[a] Includes increases in streamflow magnitude and timing and/or sediment increases.
[b] Assumes natural recovery once cause of instability is corrected.
[c] Includes suspended and bedload from channel derived sources and/or from stream adjacent slopes.
[d] Vegetation that influences width/depth ratio-stability.

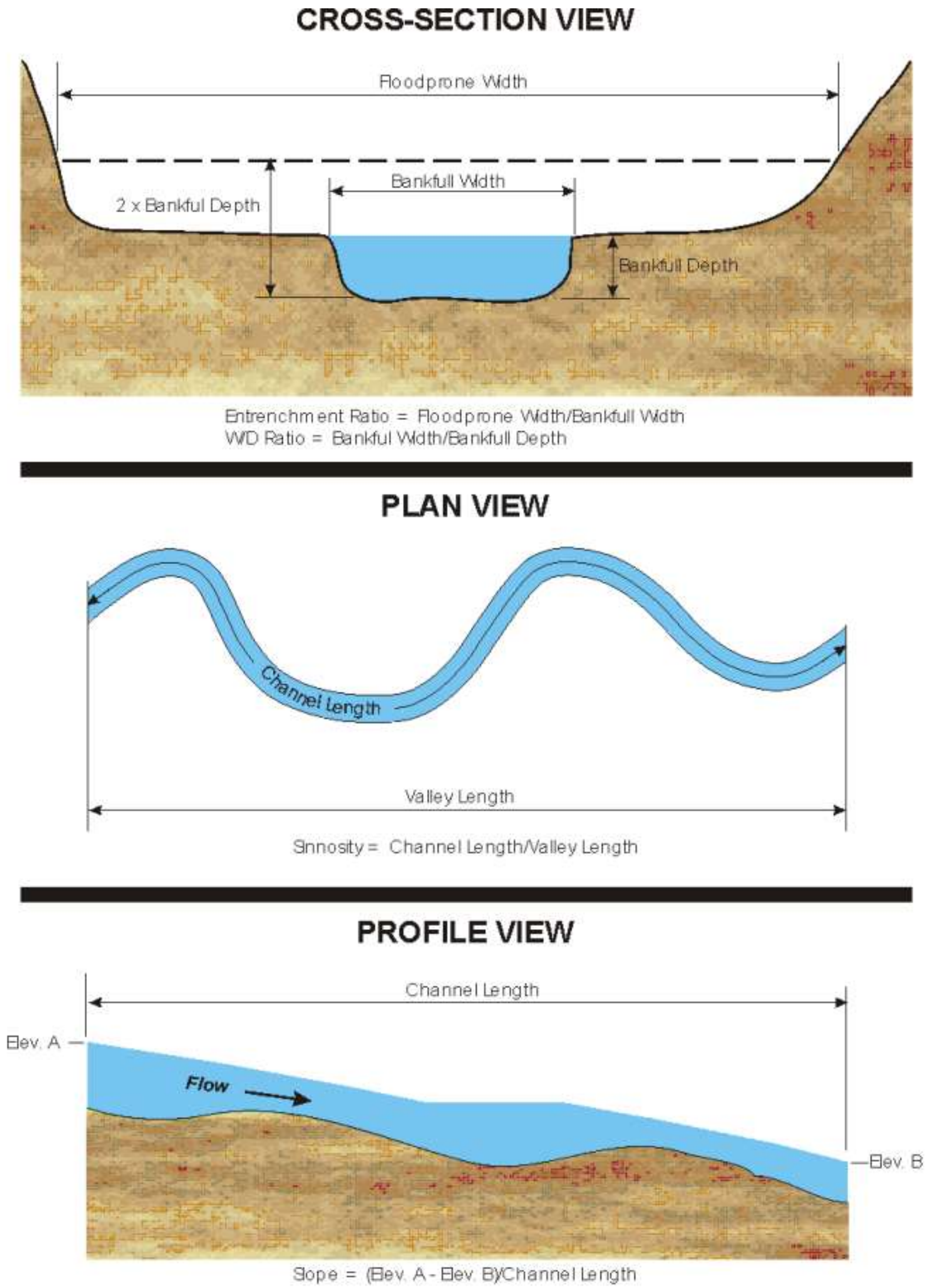


Figure A-1. Channel Parameters Defined (from Rosgen 1996)

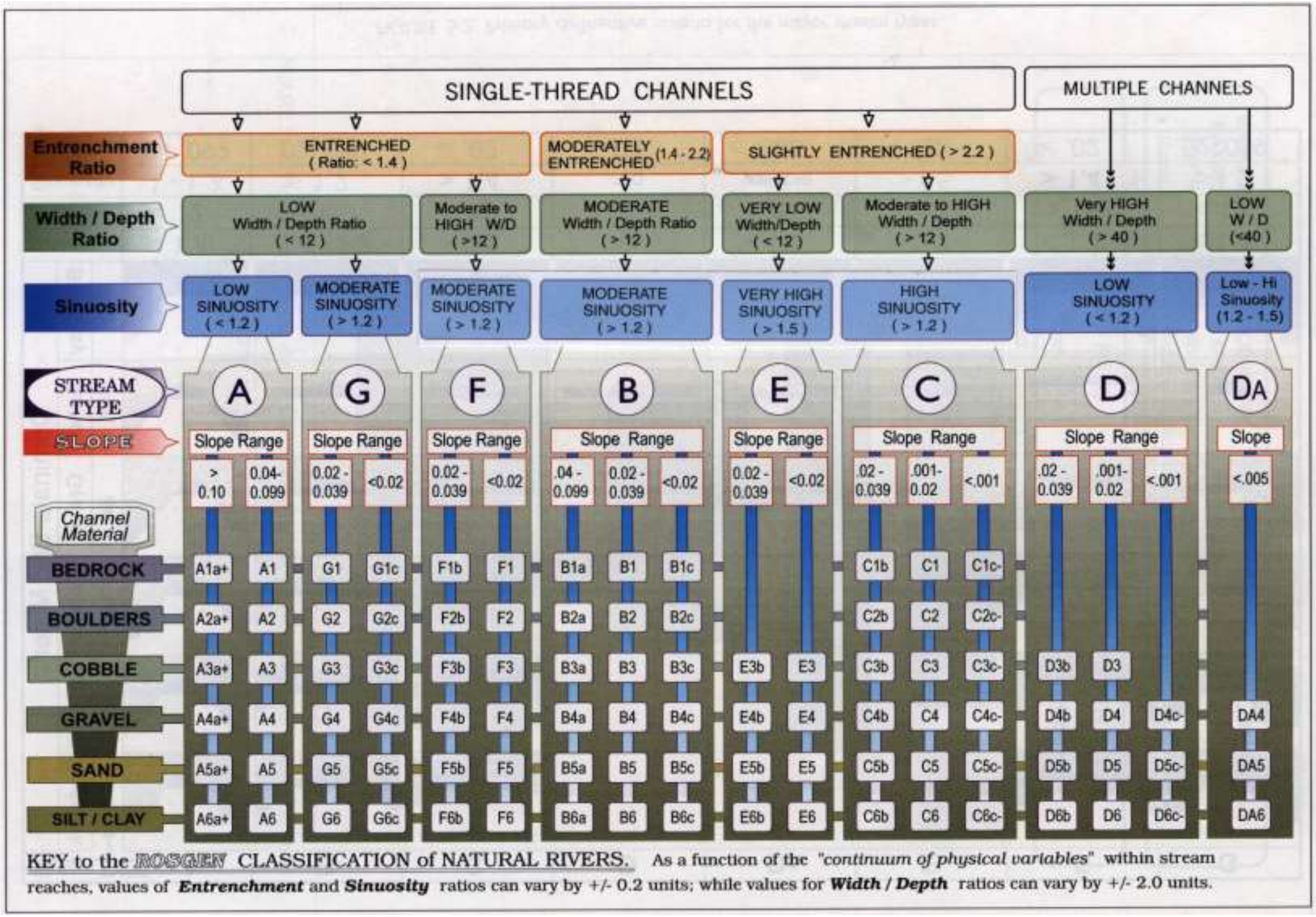


Figure A-2. Rosgen Classification System (from Rosgen 1996)

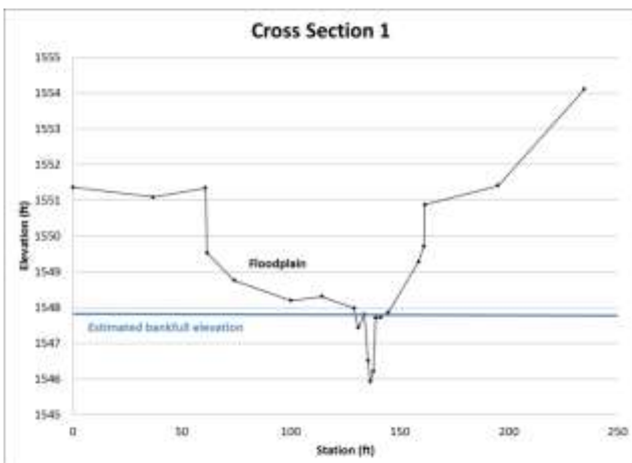
Appendix B

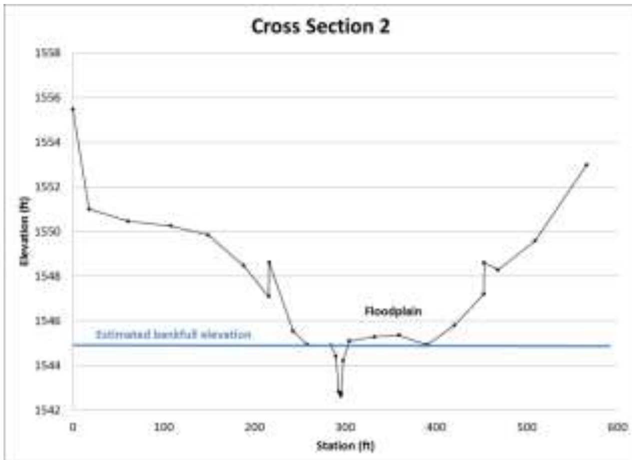
Rosgen Level I Classification Data Sheets

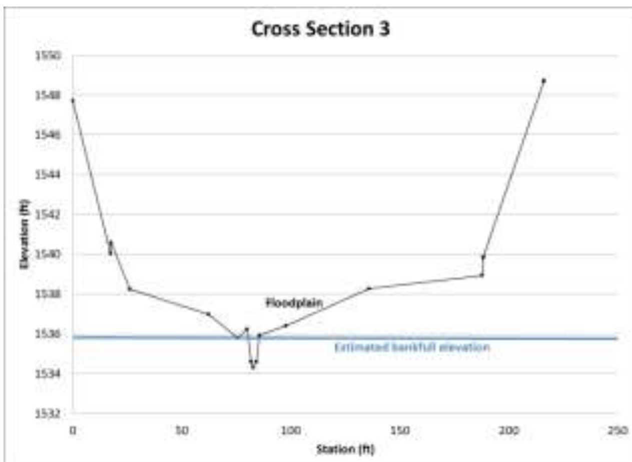
Data Sheet 1. Unnamed Creek

Channel Dimensions:

Parameter	Cross-Section 1	Cross-Section 2	Cross-Section 3
Stream feature	Riffle	Run	Riffle
Bankfull Width (ft)	7.85	53.83	5.16
Bankfull Area (ft^2)	5.8	20.26	4.86
Entrenchment Ratio	12.4	12.16	12.36
Width/Depth Ratio	10.61	21.15	5.49
Floodprone Width (ft)	97.41	221.21	63.83
Dominant Bed Material	Cobble	Silt	Cobble
Avg. Channel Slope (ft/ft)	0.03	0.003	0.03
Sinuosity	1.14	1.76	1.15
Channel Type	C/E	C/E	E




Cross Section 2
Elevation (ft)
1558
1556
1554
1552
1550
1548
1546
1544
1542
0
100
200
300
400
500
600
Station (ft)
Floodplain
Estimated bankfull elevation


Cross Section 3
Elevation (ft)
1550
1548
1546
1544
1542
1540
1538
1536
1534
1532
0
50
100
150
200
250
Station (ft)
Floodplain
Estimated bankfull elevation