Geomorphic Characterization of Restored Streams

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ABSTRACT

Research was performed on two stream restoration projects: a) Austintown Township Park in Austintown, OH; and b) Pine Hollow Run Tributary (Indian Run) in Hermitage, PA. The main goals of the research were to:

1. Determine the physical condition of two restored streams including longitudinal profile, cross-section, sinuosity, and substrate, through field surveys;

2. Perform Level II Stream classification based on Rosgen (1996); and

3. Evaluate the success of the stream restoration projects in meeting the objectives and goals of the client and designer.

Field surveys were done on both projects to determine longitudinal profile, cross-section and channel materials. Rosgen (1996) Level I and Level II assessments were used to classify the streams. The essential morphological parameters that were determined from the field survey were bankfull width, mean bankfull depth, maximum bankfull depth, width of flood prone area, width/depth ratio, entrenchment ratio, channel materials and sinuosity. From those parameters the Rosgen Level II classification was performed. The Rosgen classification showed both the unnamed tributary (UNT) to Meander Creek running through Austintown Township Park and Indian Run to be "B4c" type streams.

Bankfull velocity and discharge of Austintown Township Park UNT were estimated as 1.52 ft/s and 7.29 cfs, respectively. Similarly, bankfull velocity and discharge of Indian Run were estimated as 1.40 ft/s and 9.80 cfs, respectively.

DEDICATION

This research is dedicated to my parents, Mr. Shambhu R. Pant and Mrs. Sabitri Pant who are always a great source of strength to me. I am very thankful to my parents for their love and support.

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CHAPTER 1

INTRODUCTION

1.1 Background

Stream and rivers have been very important to human development from the early days of civilization. Rivers and streams are used for various purposes like drinking, washing, fishing, irrigation, transportation and waste disposal. The United States has more than 3.5 million miles of rivers and streams that comprise great economic, social, cultural and environmental value (American Rivers, 2009). Stream corridors are not only good habitat for various aquatic and terrestrial plants and animals but they also perform a number of ecological function such as modulating stream flow, storing water and removing harmful materials from water. They also serve as conduits for the movement of animals and transportation of sediments. Naturally flowing streams are stable and ecologically sound. However, due to rapid population growth and urbanization in much of the world, many streams are impaired in their stability and function.

Development and urbanization are major problems causing disturbances in stream ecosystems and flow patterns. Increased use of water for various purposes like industrial and domestic water supply, irrigation, transportation, hydropower, mining, recreation and aesthetics are often fulfilled by manipulating the natural stream. Development increases surface water runoff and wastewater discharge, which not only increases the flow in streams but also decreases the quality of water. Streams are sometimes channelized to increase their hydraulic capacity and gain access to adjacent land for development. In addition, vegetation is often removed from the riparian corridor. These changes cause the stream to lose some of its natural functions and can lead to stream bank erosion.

To reverse the negative impacts of development on streams, many streams restoration projects have been implemented in recent years. Restoration is a complex endeavor that begins by recognizing the disturbances that are damaging the structure and functions of the ecosystem or preventing its recovery to a sustainable condition (Pacific Rivers Council, 1996). Potential goals of stream restoration are to improve water quality, in-stream and riparian habitat, and geomorphology such that the biotic integrity and stability of the stream are improved, approaching the original undisturbed condition. Stream restoration approaches vary depending upon the degree of impairment and the objectives of restoration.

Restoration of the stream is done to achieve specific goals which can vary from project to project. Some stream restorations are designed to reduce bank erosion and control flow in the streams while others may be done for the improvement of water quality and aquatic life. So, the goals of restoration vary from project to project. It is very important to conduct post-project evaluation to determine if the goals of the stream restoration project have been met. Without conducting such evaluation and widely disseminating the results, lessons will not be learned from successes and failures, and the field of river restoration cannot advance. (Kondolf *et al.*, 1995)

1.2 Goals/Objectives of the Project

The goals of this project were to:

1. Determine the physical condition of two restored streams including longitudinal profile, cross-section, sinuosity, and substrate, through field surveys;
2. Perform Level II Stream classification based on Rosgen (1996); and

3. Evaluate the success of the stream restoration projects in meeting the objectives and goals of the client and designer.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of Streams

A stream is a natural body of running water with a current, confined within a bed and stream banks. Streams have been very important to human beings from ancient times. Healthy streams are those that have stable dimensions, pattern and profile with a wide and densely vegetated riparian corridor and good aquatic habitat.

2.2 Functions of Healthy Streams

The main goal of stream restoration, in general, is to reestablish the ecosystem and natural functions of a stream. The six main functions of healthy streams are habitat, conduit, filter, barrier, source and sink.

Habitat: Habitat refers to the places where plants and animals live, grow, feed, and reproduce for any portion of their lifecycle. The well-restored stream should be an ideal place for many species to live, find food and water, reproduce, and establish viable populations (FISRWG, 1998).

Conduit: Streams serve as flow pathways for energy, materials and organisms. The stream corridor can function as a conduit both laterally or longitudinally for the movement of organism and materials. Generally, materials such as organic debris and nutrients move from higher to lower floodplains. Animals can move in any direction within the stream corridor. Streams are also conduits for the movement of energy, which occurs in many forms. The gravity driven energy of flowing water can modify the landscape. Another important conduit function is the transport of sediment both as bed load and suspended load (FISRWG, 1998).

Filter and Barrier: Streams can function as barriers that prevent movement or filters that allow selective penetration of energy, materials and organisms. Various attributes such as native plant communities, riparian corridor and sometimes the stream itself, or in-stream bars or islands, can act as barriers. Barriers in a stream corridor reduce water pollution, minimize sediment transport and often provide a natural boundary to land uses, plant communities, and some less mobile wildlife species. Structural attributes of stream corridors also help to filter material, energy and organisms that move into and through them. Attributes such as the structure of native plant communities can physically affect the amount of runoff entering a stream system through uptake, absorption, and interruption. Vegetation in the corridor can filter out much of the overland flow of nutrients, sediments, and water (FISRWG, 1998).

Source and Sink: A source can be defined as a location where the output of water materials, energy, and/or organisms exceeds input. A sink is a location where the input exceeds output. Stream corridors or features within them can act as a source or sink of environmental materials. Some stream corridors act as both, depending on the time of year or location in the corridor. For example, a stream bank can act as both source and sink of sediment. Stream banks most often act as a source, transferring sediment to the stream. However, they can also function as a sink when flow decreases after a storm and sediment deposits at the stream banks (FISRWG, 1998).

2.3 Features of a Stream

Some major features of streams are riffles, runs, pools, glides, meanders, bars, floodplains, and thawleg. These are described below (Rosgen, 1996).

Riffle: A shallow stretch of a river or stream, where the current is above the average stream velocity and where the water forms small rippled waves as a result. Most often they have a rocky bed of gravel or small stones.

Run: A smooth flowing area of decreasing velocity, typically in the transition from riffle to pool.

Pool: A stretch of creek or stream in which water depth is above average and the stream velocity is quite low. Stream pools may be bedded in sediment or armored with gravels; in some cases the pools may have been formed as basins in bedrock materials. Pools are very important to fish habitats, especially in summer when many stream reaches experience high temperatures and low flow characteristics.

Glide: A smooth, flowing area where velocity increases, typically in the transition from pool to riffle.

Meander: A bend in the stream. A meander is formed when the moving water in the stream erodes the outer banks and widens its valley. A stream of any discharge may assume a meandering course, eroding sediments from the outside of a bend and depositing them on the inside. The result is a snaking pattern as the stream traverses back and forth across its valley. Meandering is a natural mechanism to dissipate the energy of flowing water.

Bar: A feature formed by sediment deposition in the stream channel. Point bars form at the inside of a meander (Figure 2-1). Transverse bars run across a stream channel.

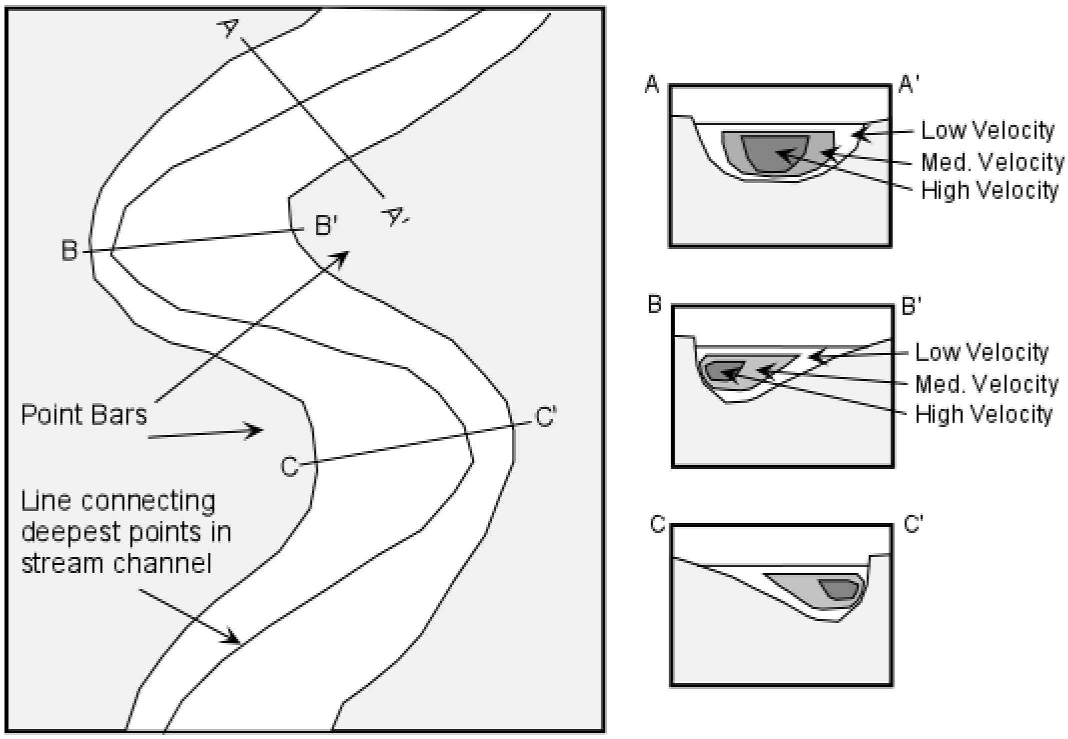


Figure 2-1. Meanders and point bars in a stream (Nelson, 2003).

Floodplain: Flat or nearly flat land adjacent to a stream or river that experiences occasional or periodic flooding.

Thawleg: A line drawn to join the lowest points along the entire length of a streambed or valley in its downward slope, defining its deepest channel. It commonly marks the natural direction of a watercourse. The thalweg is almost always the line of fastest flow in any river.

2.4 Classification of Streams

Stream classification has been performed by various researchers in the past. Currently, the most commonly used stream classification system is the one developed by Rosgen (1996). The Rosgen system was used in this research and is described in detail here.

2.4.1 Objectives of Stream Classification

- Predict a river's behavior from its appearance;
- Develop specific hydraulic and sediment relationships for a given stream type and its state;
- Provide a mechanism to extrapolate site-specific data to stream reaches having similar characteristics; and
- Provide a consistent frame of reference for communicating stream morphology and condition among a variety of disciplines

2.4.2 Level I: Geomorphic Characterization

Rosgen’s Level I classification and delineation process provides a general characterization of valley types and landforms, and identifies the corresponding major stream types, A through G. Table 2-1 and Figure 2-2 summarize the stream types A through G.

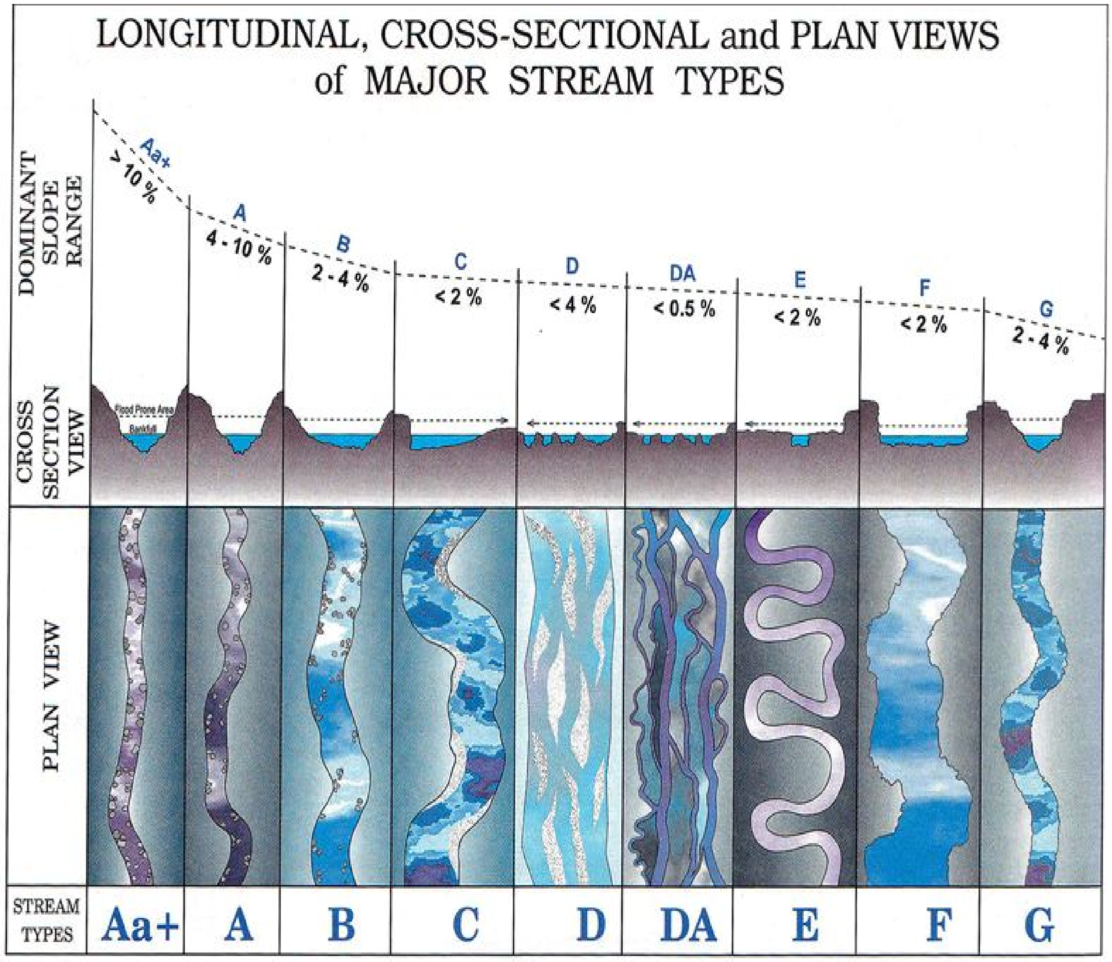


Figure 2-2. Level I stream classification delineation showing longitudinal, cross-sectional and plan views of major stream types (Rosgen, 1994).

Table 2-1. Stream types defined by Rosgen (1996).

Stream Type	General Description	Entrenchment Ratio	W/D Ratio	Sinuosity	Slope	Landform/Soils/Features
Aa+	Very steep, deeply entrenched, debris transport, torrent streams	<1.4	<12	1.0 to 1.1	>.10	Very high relief, Erosional,bedrock or depositional features, debris flow potential. Deeply entrenched streams. Vertical steps with deep scour pools, waterfalls
A	Steep, entrenched, cascading , step/pool streams. High energy/debris transport associated with depositional soil. Very stable if bedrock or boulder dominated channel	<1.4	<12	1.0 to 1.2	.04 to .10	High relief. Erosional or depositional and bedrock forms. Entrenched and confined streams with cascading reaches. Frequently spaced, deep pools in associated step/pool bed morphology.
B	Moderately entrenched, moderate gradient, riffle dominated channel, with infrequently spaced pools. Very stable plan and profile Stable banks.	1.4 to 2.2	>12	>1.2	.02 to .039	Moderate relief, colluvial deposition and /or structural. Moderate entrenchment and W/D ratio. Narrow, gently sloping valleys. Rapids predominate w/scour pools.
C	Low gradient, meandering, point-bar, riffle/pool, alluvial channels with broad, well defined floodplains.	>2.2	>12	>1.2	<.02	Broad valleys w/terraces, in association with floodplains, alluvial soils. Slightly Entrenched with well defined meandering channels. Riffle/pool bed morphology.
D	Braided channel with longitudinal and transverse bars. Very wide channel with eroding banks.	n/a	>40	n/a	<.04	Broad valleys with alluvium, steeper fans. Glacial debris and depositional features. Active lateral adjustment, w/abundance of sediment supply. Convergence/divergence bed features, aggradational processes, high bedload and bank erosion.
DA	Anastomosing (multiple channels) narrow and deep with extensive , well vegetated flood plains and associated wetlands. Very gentle relief with highly variable sinuosities and width/depth ratios. Very stable stream banks.	>2.2	Highly Variable	Highly Variable	<.005	Broad, low-gradient valleys with fine alluvium and/or lacustrine soils. Anastomosed (multiple channel) geologic control creating fine deposition w/well-vegetated bars that are laterally stable with broad wetland flood plains. Very low bedload, high wash load sediment.
E	Low gradient, meandering riffle/pool stream with low width/depth ratio and little deposition. Very efficient and stable. High meander width ratio.	>2.2	<12	>1.5	<.02	Broad valley/meadows. Alluvial materials with flood plains. Highly sinuous with stable, well-vegetated banks. Riffle/pool morphology with very low width/depth ratios.
F	Entrenched meandering riffle/pool channel on low gradients with high width/depth raito	<1.4	>12	>1.2	<0.2	Entrenched in highly weathered material. Gentle gradients, with a high width/depth ratio. Meandering, laterally unstable with high bank erosion rates. Riffle/ pool morphology.
G	Entrenched “gully” step/pool and low width/depth ratio on moderate gradients	<1.4	<12	>1.2	0.02 to .039	Gullies, step/pool morphology w/ moderate slopes and low width/depth ratio. Narrow valleys, or deeply incised in alluvial or colluvial materials, i.e., fans or deltas, Unstable, with grade control problems and high bank erosion rates.

2.4.3 Level II: The Morphological Description

While Level I stream types are distinguished primarily on the basis of the valley landforms and channel dimensions observable on aerial photos and maps, Level II stream types are determined with field measurements from specific channel reaches and fluvial features within the stream's valley. Figure 2-3 illustrates how the representative channel cross-sectional configurations, channel materials, and primary morphologic criteria are combined for the full (detailed) stream classification. In Level II classification, the nine Level I, or major stream types are refined by the additional six categories of channel materials (bed rock through silt and clay), and by quantitative criteria for entrenchment, sinuosity, width/depth ratio, and water surface slope. The classification of streams based on all these factors is shown in Figure 2-4.

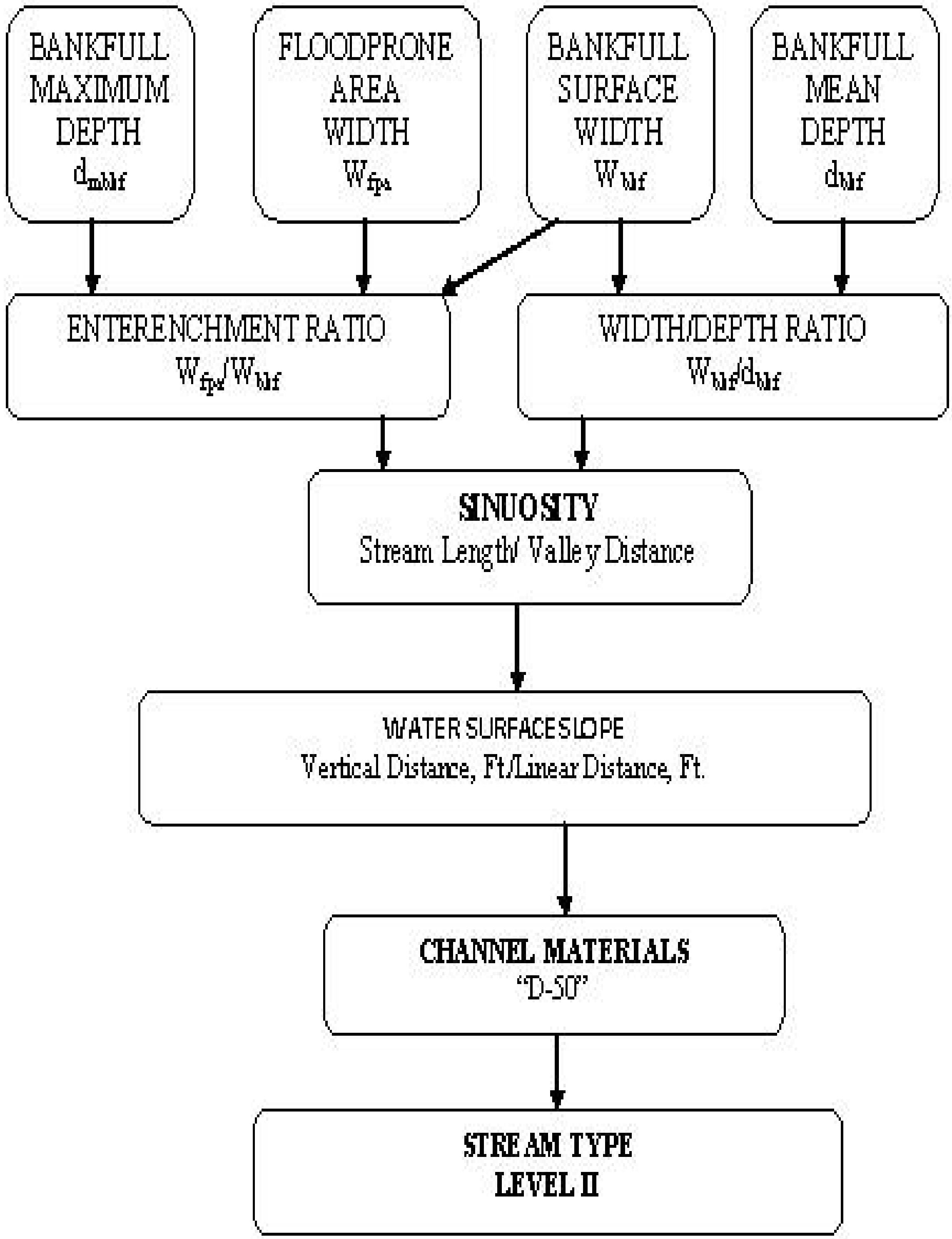


Figure 2-3. Flow chart showing delineative criteria used for the Morphological Description (Level II) (Rosgen, 1996).

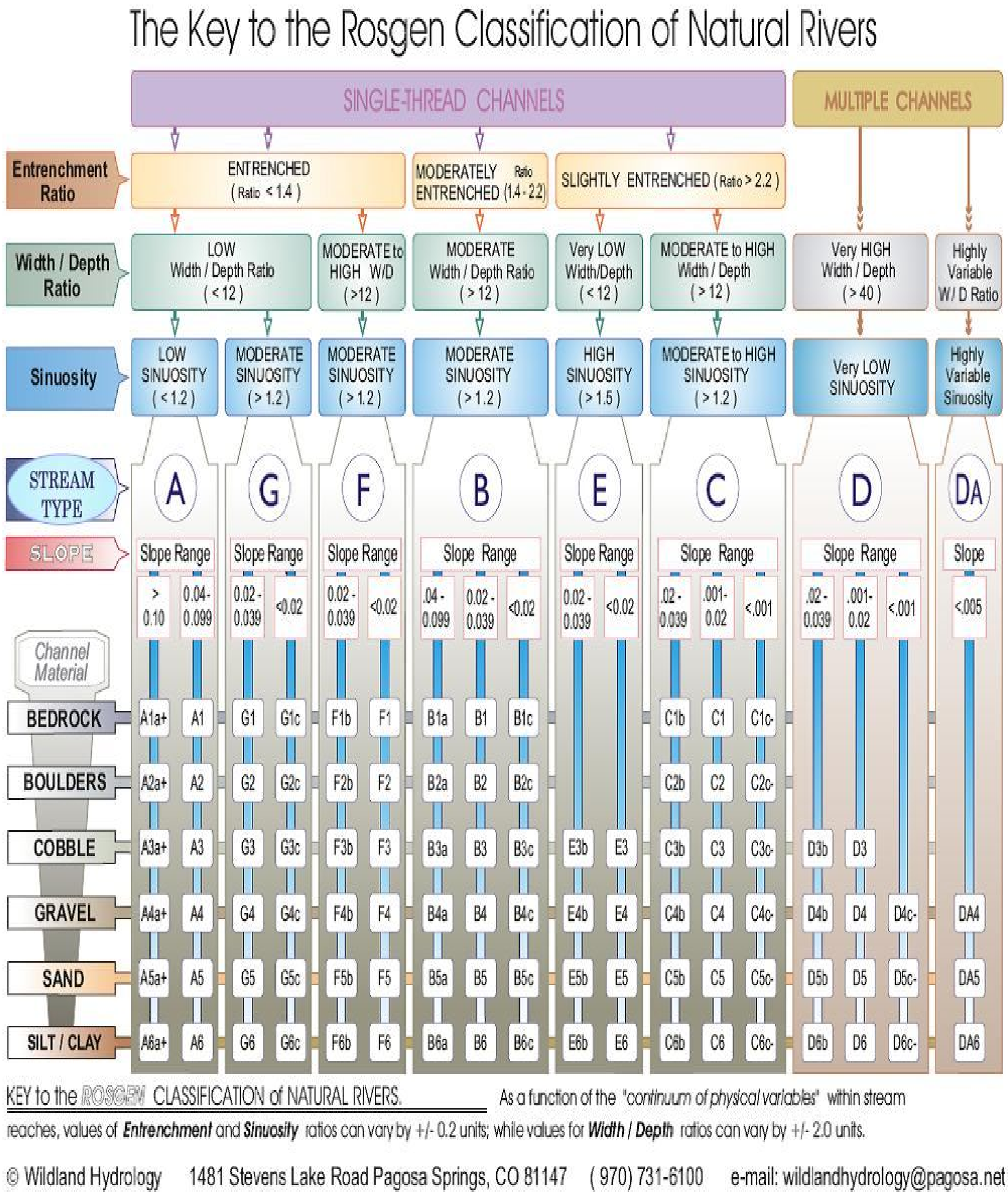


Figure 2-4. Level II Classification key for natural rivers (Rosgen, 1996).

2.4.4 Geomorphic Parameters Used in Rosgen Classification of Streams

Geomorphic parameters that are used during the stream classification by Rosgen are shown in Figure 2-5 and described below. (Rosgen,1996). Determination of these parameters requires a detailed cross-sectional survey of the stream channel.

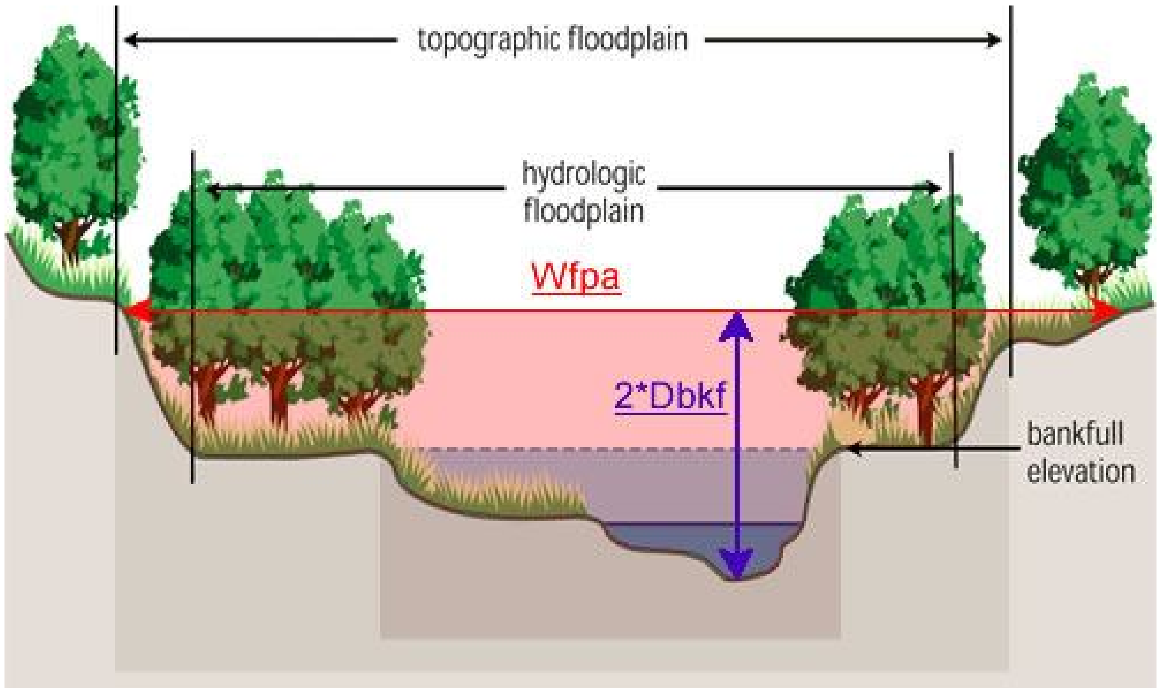


Figure 2-5. Typical stream cross-section, showing bankfull stage, width of flood-prone area, hydrologic floodplain and topographic flood plain (Rosgen, 1996).

Bankfull stage, or bankfull discharge, is one of the most important parameters used in Level II classifications. The bankfull stage represents the incipient point of flooding, where flow moves out of the main channel and onto the flood plain. It is often related to the elevation associated with a shift in hydraulic geometry of the channel and associated with a return period of 1-2 years, with an average of 1.5 years. Bankfull discharge is considered to be the most effective stream flow for moving sediment and shaping the morphology of the channel (Rosgen, 1996). Correctly identifying the elevation of bankfull stage is the most important task when classifying the stream. Since site visits are not often made during the bankfull discharge event, physical indicators like floodplains, depositional features, breaks in slope, and change in vegetation must be relied on to estimate the water surface of the stream at the bankfull discharge. All bankfull indicators are not available for all stream types in all climates, so locating bankfull stage is a skill that is developed over time by field observation of many different stream types in a variety of climates. Bankfull indicators that are used to locate the bankfull stage are described below.

Floodplains: Bankfull elevation is the point at which the stream begins to spread out onto the floodplain. Some of stream types like C, D, DA and E have the well-developed floodplains and this indicator can be applied to those streams (Wildland Hydrology, 2008).

Highest active depositional feature: The bankfull stage is the elevation on top of the highest depositional feature (point bar or central bar) within the active channel. These depositional features are especially good bankfull stage indicators for confined channels.

Slope breaks or change in particle size distribution: Breaks in slope of the banks or change of the particle size distribution from coarse to fine are indicators of bankfull stage.

Stained rocks: Bankfull stage can also be determined if rocks in the stream and/or its banks are stained. The stain mark on the rock is the elevation of bankfull stage.

Certain riparian vegetation: Some common riparian species can be used as indicators of bankfull stage, such as certain species of birch, dogwood, cottonwood and alder, which can colonize from seed and become established at levels close to bankfull stage (Wildland Hydrology, 2008).

The parameters that are based on bankfull stage are described below.

Bankfull Width (W_{bkf}): This refers to the width of a stream channel (in feet) at bankfull stage elevation, in a riffle section.

Mean Bankfull Depth (d_{bkf}): This is the mean depth of a stream channel cross-section, in feet, at bankfull stage elevation, in a riffle section as calculated by Equation 2-1.

$$d_{bkf} = \frac{A}{W_{bkf}} \quad (2\text{-}1)$$

Where A=bankfull cross-sectional area, ft^2

Maximum Bankfull Depth (d_{mbkf}): This is the maximum depth of the bankfull cross-section, or distance between the bankfull stage and thawleg elevations, in a riffle section.

Width of Flood-Prone Area (W_{fpa}): Width of flood-prone area is the width of the stream channel at an elevation of two times the maximum bankfull depth above the thawleg (Figure 2-5).

Width/Depth Ratio: This is the ratio of bankfull channel width to the mean bankfull depth in a riffle section in units of ft/ft. The width/depth ratio is related to the distribution of energy within a channel, and the ability of various discharges occurring within the channel to move sediment. As width/depth ratio increases, the channel grows wider and shallower, the hydraulic stress against banks increases, and bank erosion is accelerated.

Entrenchment Ratio (ER): Entrenchment is defined as the vertical containment of a river and the degree to which it is incised in the valley floor. (Kellerhalls *et al.*, 1972). Entrenchment Ratio (ER) is the ratio of flood-prone area width divided by bankfull channel width (Eq. 2-2) at a riffle section.

$$ER = \frac{W_{fpa}}{W_{bkf}} \tag{2-2}$$

Channel Materials: Channel materials are essential for Level II classification. Channel bed materials and bank materials not only influence the cross-sectional form, plan view and longitudinal profile of rivers, but also determine the extent of sediment transport and provide a means of resistance to hydraulic stress. The Wolman (1954) pebble count method, as modified by Rosgen (1996), is used for sampling the bed materials. At least 100 representative channel bed particles (or “pebbles") are selected from a channel reach of 20-30 bankfull widths. Channel materials are classified according to its size (Table 2-2). To obtain median particle diameter or D_{-50}, the pebble count data are plotted on a semi-log (Figure 2-6) graph as a cumulative percent (y-axis) finer than corresponding particle size (x-axis). Median diameter D_{-50} is used for the classification of channel material.

Table 2-2. Channel material classifications (Rosgen, 1996)

Particle	Millimeters	Type	Particle	Millimeters	Type
Silt/Clay	<.062	Slit/Clay	Small	64-128	Cobble
Very Fine	.062-.125	Sand	Large	128-256	
Fine	.125-.25		Small	256-512	Boulder
Medium	.25-.50		Medium	512-1024	
Coarse	.50-.10		Large-Very large	1024-2048	
Very Coarse	1.0-2		Bedrock		Bedrock
Very Fine	2-4	Gravel			
Fine	4-8				
Medium	8-16				
Coarse	16-32				
Very Coarse	32-64				

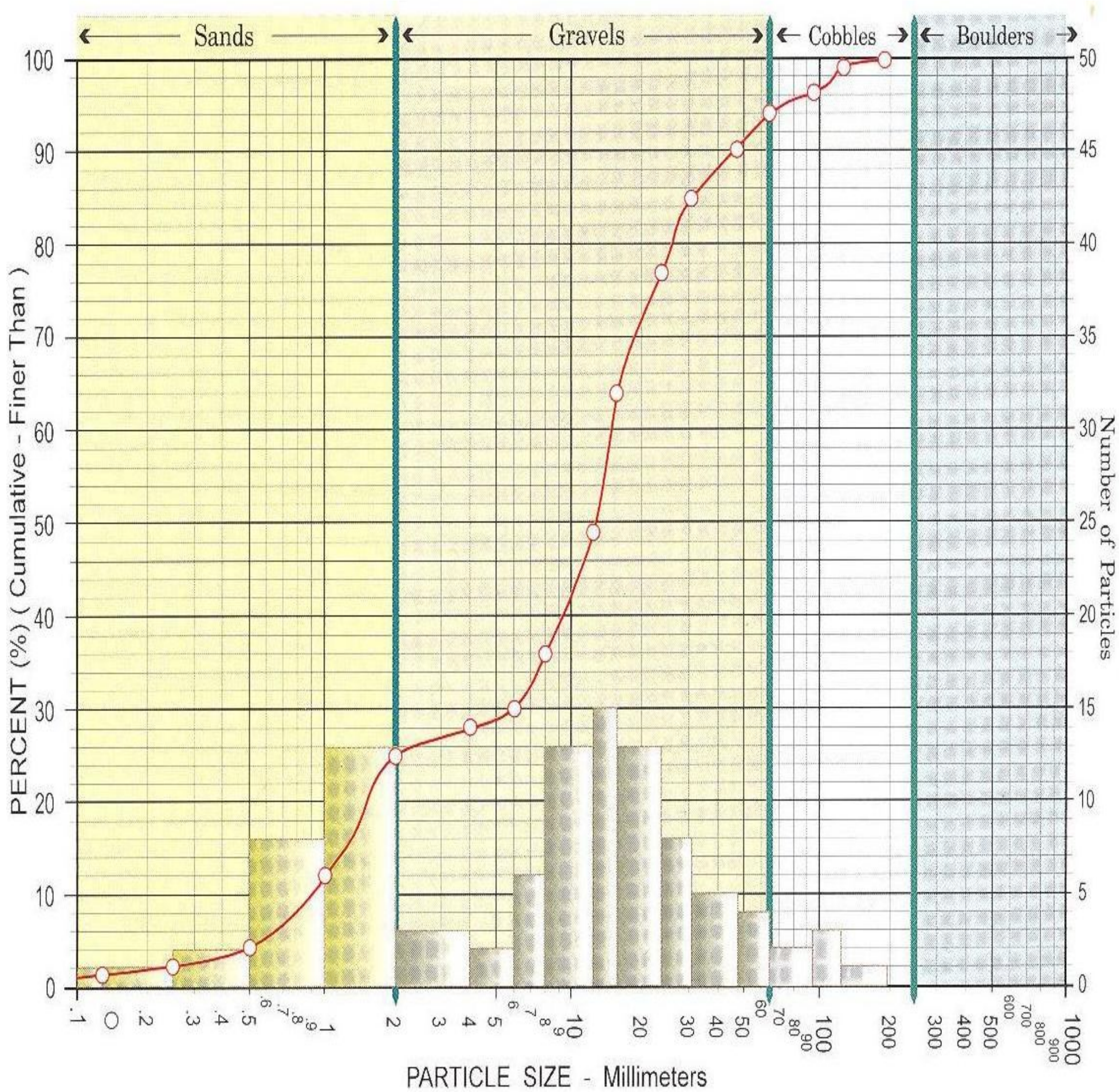


Figure 2-6. Sample plot of pebble-count data (Rosgen, 1996).

Sinuosity (k): This is the ratio of stream length (SL) to valley length (VL), as shown in Equation 2-3. It can also be defined as the ratio of valley slope to channel slope. Sinuosity can be best measured using aerial photography.

$$k = \frac{SL}{VL} \qquad (2\text{-}3)$$

Slope: Channel slope (S) is the elevation drop per unit length, of the bankfull stage for a reach approximately 20-30 bankfull channel widths in length, with the riffle to riffle water surface slope representing the gradient at bankfull stage. Units are ft/ft.

Rosgen (1996) has developed a worksheet to summarize all the parameters required for Level II characterization, and the resulting stream classification. This worksheet is shown in Table 2-3. He has also developed a worksheet (Table 2-4) to estimate bankfull velocity by three methods, and the corresponding bankfull discharge.

Table 2-3. Field form for Level II stream classification (Wildland Hydrology, 2008).

Stream:			
Basin:	Drainage Area:	acres	mi^2
Location:			
Twp.&Rge:	Sec.&Qtr.:		
Cross-Section Monuments (Lat./Long.):		Date:	
Observers:		Valley Type:	

Bankfull WIDTH (W_{bkf}) WIDTH of the stream channel at bankfull stage elevation, in a riffle section.		ft
Bankfull DEPTH (d_{bkf}) Mean DEPTH of the stream channel cross-section, at bankfull stage elevation, in a riffle section ($d_{bkf} = A / W_{bkf}$).		ft
Bankfull X-Section AREA (A_{bkf}) AREA of the stream channel cross-section, at bankfull stage elevation, in a riffle section.		ft^2
Width/Depth Ratio (W_{bkf} / d_{bkf}) Bankfull WIDTH divided by bankfull mean DEPTH, in a riffle section.		ft/ft
Maximum DEPTH (d_{mbkf}) Maximum depth of the bankfull channel cross-section, or distance between the bankfull stage and Thalweg elevations, in a riffle section.		ft
WIDTH of Flood-Prone Area (W_{fpa}) Twice maximum DEPTH, or ($2 \times d_{mbkf}$) = the stage/elevation at which flood-prone area WIDTH is determined in a riffle section.		ft
Entrenchment Ratio (ER) The ratio of flood-prone area WIDTH divided by bankfull channel WIDTH (W_{fpa} / W_{bkf}) (riffle section).		ft/ft
Channel Materials (Particle Size Index) D_{50} The D_{50} particle size index represents the mean diameter of channel materials, as sampled from the channel surface, between the bankfull stage and Thalweg elevations.		mm
Water Surface SLOPE (S) Channel slope = "rise over run" for a reach approximately 20–30 bankfull channel widths in length, with the "riffle-to-riffle" water surface slope representing the gradient at bankfull stage.		ft/ft
Channel SINUOSITY (k) Sinuosity is an index of channel pattern, determined from a ratio of stream length divided by valley length (SL / VL); or estimated from a ratio of valley slope divided by channel slope (VS / S).		

Stream Type →		← **See Classification Key**

Table 2-4. Worksheet for computations of bankfull velocity and discharge using various methods (Wildland Hydrology, 2008).

Bankfull VELOCITY / DISCHARGE Estimates

Site		Location	
Date	Stream Type	Valley Type	
Observers		HUC	__ __ __ __ __ __ __ __ __ __ __ __

INPUT VARIABLES			OUTPUT VARIABLES		
Bankfull Cross-sectional		A_{bkf} (ft^2)	Bankfull Mean DEPTH		D_{bkf} (ft)
Bankfull WIDTH		W_{bkf} (ft)	Wetted PERIMETER ~ $2 * d_{bkf} + W_{bkf}$		W_p (ft)
D_{84} @ Riffle		Dia. (mm)	D_{84} mm / 304.8 =		D_{84} (ft)
Bankfull SLOPE		S_{bkf} (ft / ft)	Hydraulic RADIUS A_{bkf} / W_p		R (ft)
Gravitational Acceleration	32.2	g (ft / sec^2)	Relative Roughness R (ft) / D_{84} (ft)		
Drainage AREA		DA (mi^2)	Shear Velocity $u^* = \sqrt{gRS}$		u^* (ft / sec)

ESTIMATION METHODS	Bankfull VELOCITY		Bankfull DISCHARGE	
1. Friction Factor / Relative Roughness $u = [\, 2.83 + 5.66 \text{Log}\{ R / D_{84} \} \,] u^*$		ft / sec		cfs
2. Roughness Coefficient: a) Manning's 'n' from friction factor / relative roughness (Figs. 2-18, 19) $u = 1.4865 * R^{2/3} * S^{1/2} / n$ n =		ft / sec		cfs
2. Roughness Coefficient: $u = 1.4865 * R^{2/3} * S^{1/2} / n$ b) Manning's 'n' from Jarrett (USGS): $n = 0.39 S^{.38} R^{-.16}$ n = Note: This equation is for applications involving steep, step-pool, high boundary roughness, cobble- and boulder-dominated stream systems; i.e., for stream types A1, A2, A3, B1, B2, B3, C2 and E3.		ft / sec		cfs
2. Roughness Coefficient: $u = 1.4865 * R^{2/3} * S^{1/2} / n$ c) Manning's 'n' from Stream Type n =		ft / sec		cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
4. Continuity Equations: a) Regional Curves u = Q / A Return Period for Bankfull Discharge Q = Yr.		ft / sec		cfs
4. Continuity Equations: b) USGS Gage Data u = Q / A		ft / sec		cfs

Options for using the D_{84} term in the relative roughness relation (R/D_{84}), when using estimation method 1.

Option 1.	For **sand-bed** channels: Measure the **"protrusion height"** (h_{sd}) of sand dunes above channel bed elevations. Substitute an average sand dune protrusion height (h_{sd} in ft) for the D_{84} term in est. method 1.
Option 2.	For **boulder-dominated** channels: Measure several **"protrusion heights"** (h_{bo}) of boulders above channel bed elevations. Substitute an ave. boulder protrusion height (h_{bo} in ft) for the D_{84} term in est. method 1.
Option 3.	For **bedrock-dominated** channels: Measure several **"protrusion heights"** (h_{br}) of rock separations/steps/joints/ uplifted surfaces above channel bed elevations. Substitute an average bedrock protrusion height (h_{br} in feet) for the D_{84} term in estimation method 1.

2.4.5 Level III: Stream "State" or Condition

Level III describes the existing condition or "state" of the stream as it relates to its stability, response potential, and function. At this level, additional filed parameters are evaluated that influence the stream state (e.g. riparian vegetation, sediment supply, flow regime, debris occurrence, depositional features, channel stability, bank erodibility, and direct channel disturbances). Level III analysis are both reach and feature specific and are especially useful as a basis for integrating companion studies (Rosgen, 1996).

2.4.6 Level IV: Validation Level

Level IV is the level at which measurements are taken to verify process relationships inferred from preceding analyses. The objective is to establish empirical relationship for use in prediction. The developed empirical relationships are specific to individual stream type for a given state, and enable extrapolation to other similar reaches for which Level IV data is not available. Using relationships developed at level IV, existing data from gage stations and research sites can be analyzed and extrapolated to similar stream types. (Rosgen, 1996)

2.5 Stream Restoration Methods

Stream restoration methods depend upon the goal of the restoration project. The main goal of the stream restoration on both projects studied in this research was stream bank stabilization. Some of the methods and structures used for stream bank stabilization are described below.

Channel Morphometry and Flood Plain Connectivity: Stream bed stability is necessary in order to achieve bank stability (FISRWG, 1998). The restoration designer must determine the proper width, depth, slope, sinuosity, entrenchment ratio, etc., to carry the required flow and sediment load without aggradation or degradation of the stream bed. Entrenched streams may need to be reconnected to existing flood plains, or new flood plains constructed. Where land use limits the ability to modify the stream channel, grade control structures such as cross-vanes or J-hook vanes can be used.

Cross-Vane: The cross-vane is a grade control structure that decreases near-bank shear stress, velocity and stream power, but increases the energy in the center of the channel. The structure will establish grade control, reduce bank erosion, create a stable width/depth ratio, and maintain channel capacity, while maintaining sediment transport capacity (Rosgen, 2001). A typical cross-section, profile and plan view of cross-vane is shown in Figure 2-7.

J-Hook Vane: The J-hook vane is an upstream-directed, gently sloping structure composed of natural materials. The structure can include a combination of boulders, logs and root wads and is located on the outside of stream bends where strong downwelling and upwelling currents, high boundary stress, and high velocity gradients generate high stress in the near-bank region. The structure is designed to reduce bank erosion by reducing near-bank slope, velocity, velocity gradient, stream power and shear stress. (Rosgen, 2001). A typical cross-section, profile and plan view of J-hook vane is shown in Figure 2-8.

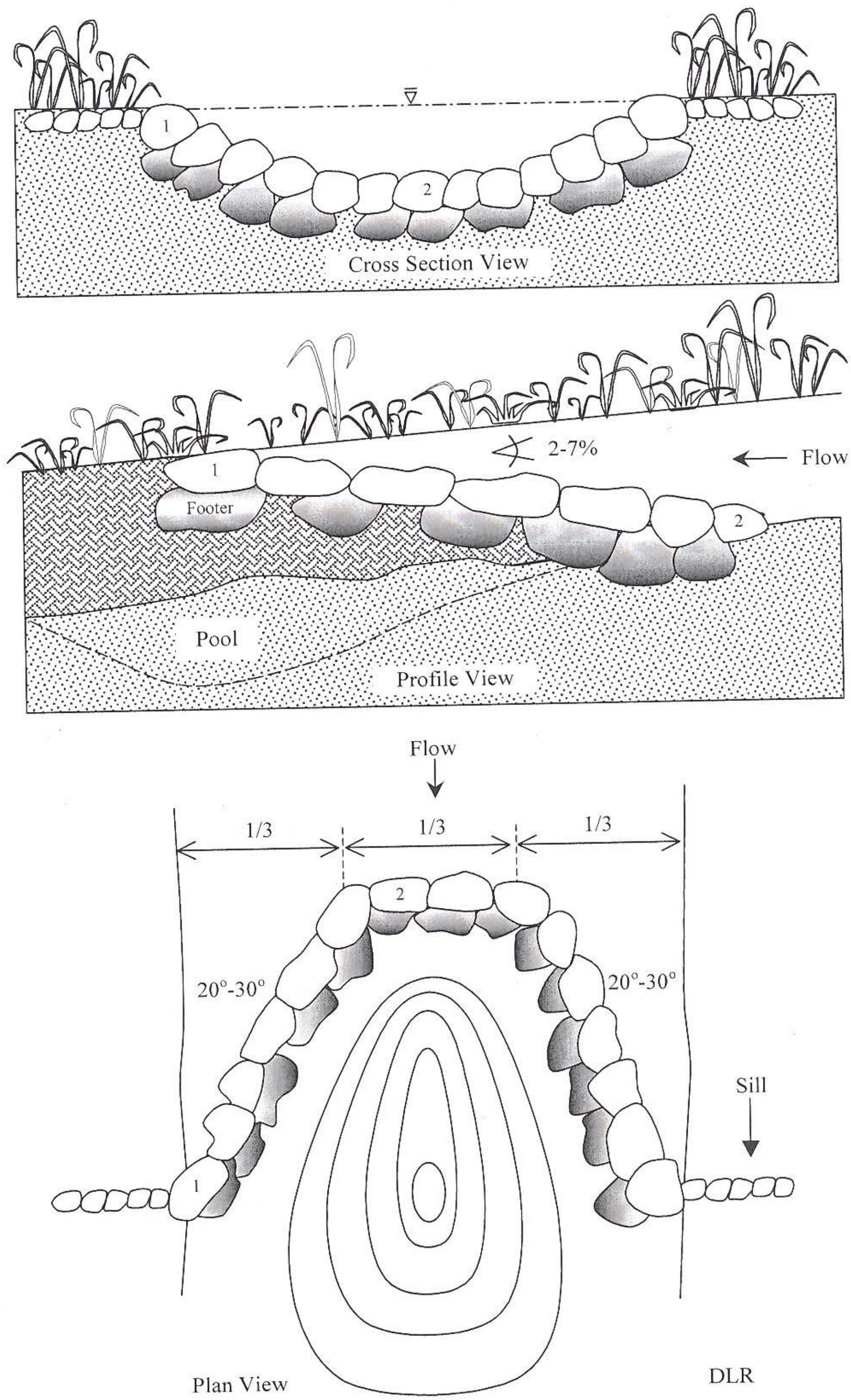


Figure 2-7. Cross section, profile and plan view of a cross-vane (Rosgen, 2001).

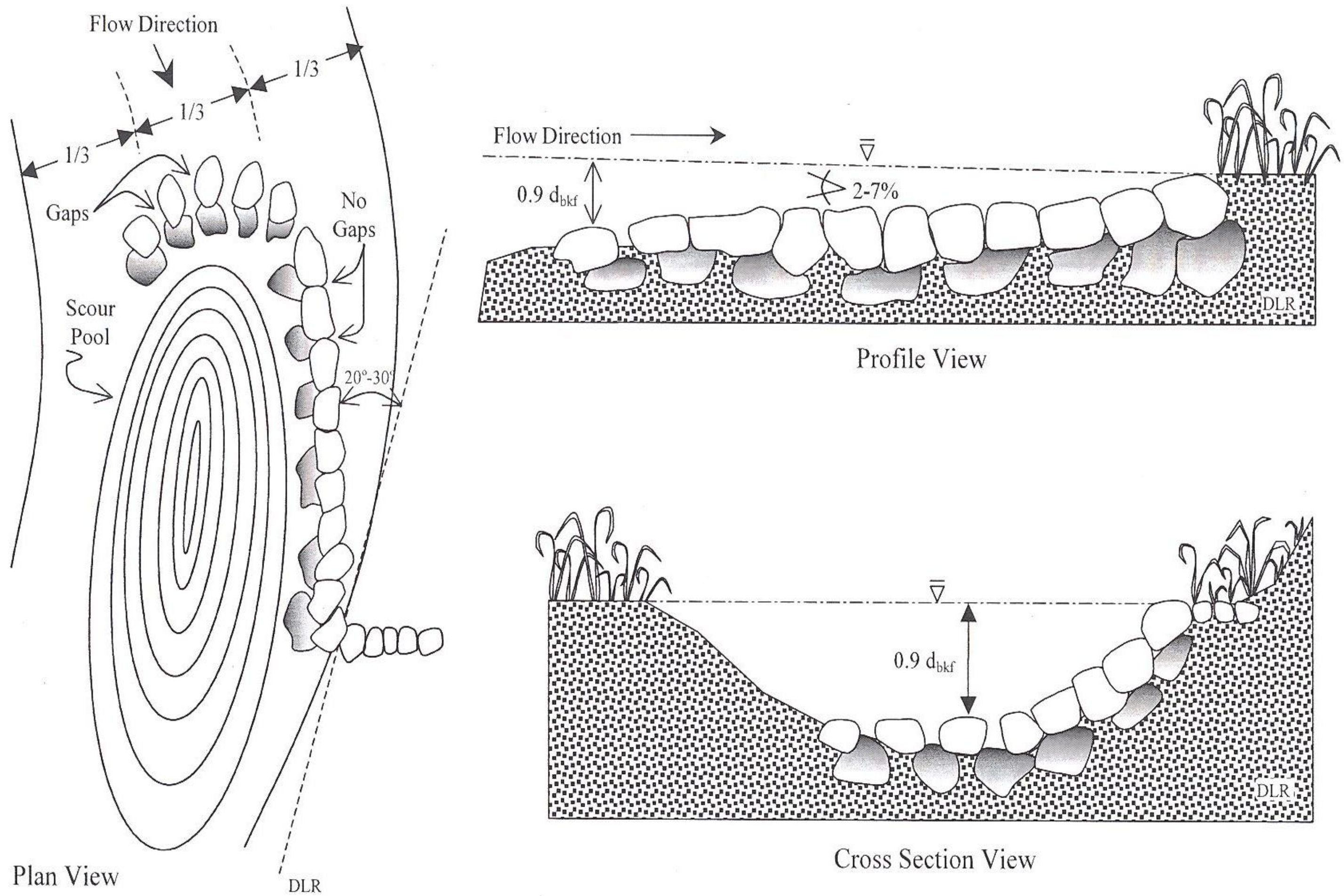


Figure 2-8. Plan profile and section view of the J-hook vane (Rosgen, 2001).

Riparian Vegetation: This is a very cost-effective method for stabilizing the stream bank. The riparian zone is the interface between land and stream. Riparian vegetation is crucial to the health of a stream. It provides bank stability, habitat for diverse communities of plants and animals and a source of organic materials to the stream. Establishment of dense grass and/or shrubs on the stream bank, flood plains, and adjacent land provides excellent protection against bank erosion.

2.6 Weakness of Rosgen Stream Classification

Application of the Rosgen methodology associated with classification of streams can lead to some inconsistencies in classification. One problem that can be encountered with the Rosgen method is confusion in identifying bankufull stage. One of the primary reasons for the confusion in identifying the bankfull stage is that, bankfull discharge and dimension, represented by hydraulic geometry relationship refer to stable channels. This is a critical issue in that "natural channel design" often aims to restore highly modified or disturbed channels. The term "natural" does not mean "stable" because it implies a balance between transport capacity and load. The bankfull level in unstable streams can be exceedingly difficult to identify particularly in erosional channels because of lack of depositional features and because channel dimensions, including water surface elevations are changing with time (Simon *et al.*, 2007).

Many in the scientific community feel that classification systems such as Rosgen's are not needed for restoration design, and may give misleading information about geomorphic processes (Simon *et al.*, 2007).

2.7 Background on Poject Sites

2.7.1 Austintown Township Park

The project area is located along Kirk Road at the entrance of Austintown Township Park, in Mahoning County, OH (Figure 2-9). The stream, an unnamed tributary (UNT) to Meander Creek, flows from east-to-west across the project site, running roughly parallel to Kirk Road. The site upon which the Austintown Park stream was restored slopes gradually downward to the west at a valley slope of approximately 0.0182, estimated from the USGS topographic map. The stream turns to the southwest and crosses under Kirk Road through twin 48 in diameter corrugated metal pipe culverts anchored by a concrete headwall. The entrance road to the park crosses over the UNT to Meander Creek via a precast concrete bridge structure. The bridge was the upstream limit of the project area and the culvert headwall was the downstream limit of the project area. The length of restored stream between these structures was 230 ft.

According to park officials (Gottron, personal communication, 2008), before the stream restoration the condition of the banks of the streams was unstable. There was significant scouring on the east end of the culvert headwall. This also caused significant erosion of the southern stream bank immediately adjacent to the headwall. As there was significant bank erosion, the sediment load carried by the stream increased beyond the stream’s capacity. Small sand bars and point bars were formed in the areas of slower moving water.

Restoration of the UNT to Meander Creek was performed on September, 2007 and consisted of reducing the slope of the stream banks, increasing sinuosity, increasing the width of vegetation in the riparian corridor, and installing five stone cross-vane structures were installed during the restoration. Cross-vanes were designed to focus the flow of water back toward the center of the channel, and prevent scouring, undercutting and erosion of the stream banks.

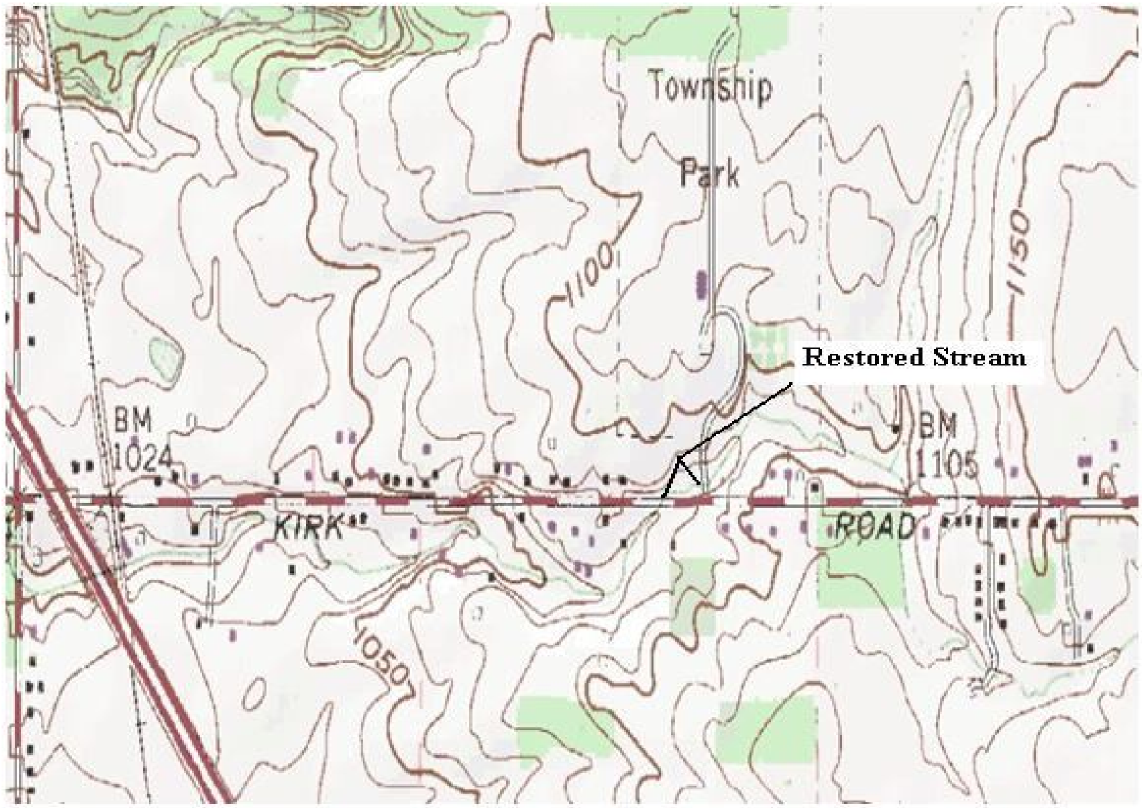


Figure 2-9. Topographic map of Austintown Township Park (MyTopo, 2009).

2.7.2 Pine Hollow Run Tributary Stream Restoration Project

The Pine Hollow Run Tributary Stream Restoration Project area is approximately 1900 linear feet section of unnamed tributary to Pine Hollow Run. The project area is located within the city of Hermitage, PA, just southwest of the intersection of State Route 18 and Highland Road and directly behind (west of) the Artman Elementary School (Figure 2-10). The project area includes an open field, a stream running along the length of the field, and wooded area along the west side of the stream and in the north west corner of the site. The restored stream is known locally as Indian Run, and will be referred to by this name throughout this thesis.

Before restoration, the stream was trying to regain its meander pattern; the banks (mostly the right bank looking downstream) were severely eroded (Figure 2-11). The stream banks were approximately4-7 ft in height and vertically eroded with little vegetation at the top of banks. The erosion rate was approximately 0.5-1.0 ft per year, based on observations by school personnel. It was estimated that about 6000 ft^3 per year of sediment entered the stream from the right (east) bank only. Erosion of the left (west) bank was less severe (reference Wallace and Pancher report).

The main purpose of the stream restoration was to stop the erosion of stream banks and the loss of property within the project stream reach. The goal of the project was to eliminate approximately 6000 ft^3 pr year of sediment loading and a significant non-point source of pollution to Pine Hollow Run and Shenango River.

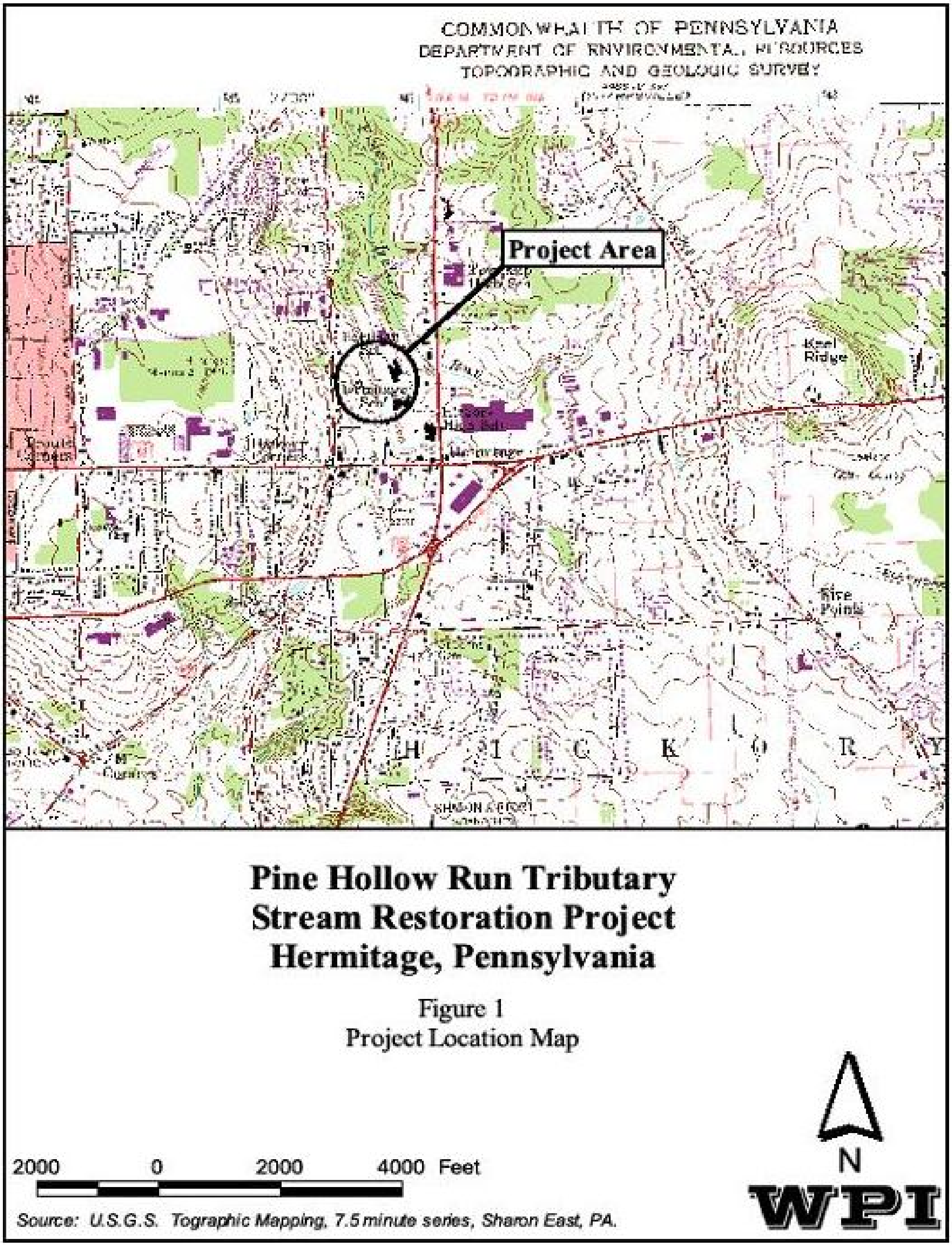


Figure 2-10. Project location map (WPI, 2010).

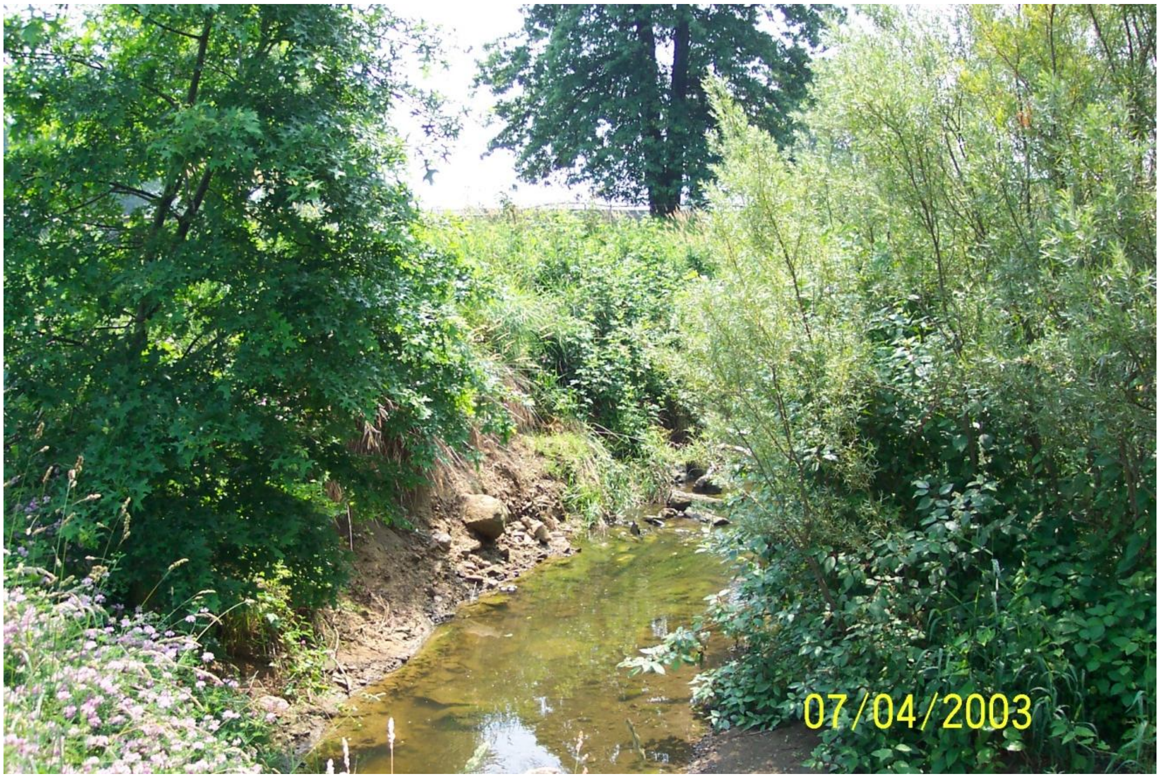


Figure 2-11. Right bank erosion in Indian Run (WPI, 2010).

CHAPTER 3

METHODS AND PROCEDURES

3.1 Longitudinal Profile Survey

3.1.1 Overview

The longitudinal profile characterizes average stream slopes and depths of riffles, pools, runs, glides, rapids and step/pools. Longitudinal profile surveys help to determine bankfull stage, and water slopes of individual bed features which are important parameters for the classification of streams.

3.1.2 Field Procedures

Field measurements of the parameters used in stream classification were performed as described by Rosgen (1996).

Benchmark selection: A benchmark was selected in each stream channel. The benchmarks were permanent or stable features. The upstream invert of a corrugated metal culvert under Kirk Road was used for the Austintown Township Park site, and assigned an elevation of 1106.90 ft. The top of a large rock was selected for the Indian Run site and assigned an arbitrary elevation of 1100.00 ft.

Level setup: The level (Carl Zeiss Ni2) was set up on a tripod and leveled, with a clear line of sight to the selected benchmark. The approximate number and location of setups needed is based on line of sight limitations. The instrument was placed at an elevation higher than the highest feature required for the survey.

Laying tape: A 300 ft tape was laid along the centerline of the channel, with the zero mark at the upstream end of the restored section. This was possible since flow was low at the time of the field surveys.

Surveying procedures: A backsight (BS) was taken to the benchmark (BM) of known or (assumed) elevation. Height of instrument was determined using Equation 3-1.

$$\text{Height of instrument (HI)} = \text{BM elevation} + \text{BS rod reading} \tag{3-1}$$

Starting from the upstream end of the reach, foresight (FS) readings were taken on the fiberglass leveling rod at many locations along the reach. At each location, water surface, bankfull, thawleg and lowest bank height (if greater than bankfull stage) measurements were recorded. The measurements were taken wherever the stream changed its features. The longitudinal profile surveys covered totals of 230 ft and 1150 ft in Austintown dsTownship Park and Indian Run, respectively. Elevations were calculated by Equation 3-2.

$$\text{Elevation} = \text{HI-FS} \tag{3-2}$$

3.1.3 Data Analysis

All the data obtained from surveying were entered into a Microsoft Excel 2007 spreadsheet, and the longitudinal profile was plotted as elevation (ft) versus distance along the stream (ft). In the longitudinal profile graph, elevations of channel bed (thalweg), water surface, and bankfull level were all plotted. Water surface slope was calculated from the longitudinal profile graph. It was calculated by “rise over run” for the entire stream reach surveyed, using Equation 3-3.

$$Slope\ (S)\ =\ \frac{Elevation\ Drop\ (ft)}{Length\ of\ Stream\ Reach\ (ft)} \quad (3\text{-}3)$$

3.2 Cross-Sectional Survey

3.2.1 Overview

The cross-section data provides the majority of the morphological parameters required for stream classifications. Bankfull cross-sectional area, bankfull width, mean bankfull depth, maximum bankfull depth, width/depth ratio and entrenchment ratio are all determined from cross-sectional surveys.

3.2.2 Field Procedures

The locations of cross-sections were selected to represent the range of channel and bank characteristics within each stream reach. For Indian Run, where riparian vegetation was very dense, accessibility was also a consideration. Four cross-sectional surveys were performed at each of the two sites. The level was set up in a location where the entire cross-section could be viewed, if possible. However, surveying to the width of the flood-prone area required multiple setups due to dense foliage at some of the Indian Run locations. Wooden stakes were driven into the ground to establish the location of each cross-section. The 300 ft tape was stretched across the channel (zero on left bank) making sure that the tape was perpendicular to the direction of flow. A backsight (BS) reading was taken on the benchmark. After that, foresight (FS) rod reading were taken at major breaks in bed elevation and key features such as left bankfull (LBF), left edge of water (LEW), thawleg (THL), right edge of water (REW) and right bankfull (RBF). This process is shown graphically in Figure 3-1. The distance on tape, corresponding FS reading, and feature notes were recorded on cross-section data forms. The width of flood prone area was also measured and recorded.

3.2.3 Data Analysis

Field data were entered into a Microsoft Excel 2007 spreadsheet, and elevations were calculated on each cross-section using Equations 3-1 and 3-2. The graph of horizontal distance versus elevation was plotted. To determine the cross-sectional area at bankfull stage, the cross-section was approximated as a series of trapezoids and the area of each trapezoid was computed by Equation 3-4.

$$Area = \frac{1}{2}(Depth_1 + Depth_2)(Width) \quad (3\text{-}4)$$

Total cross-sectional area was determined by adding the areas of all the individual trapezoids. Bankfull width (W_{bkf}) was measured at the bankfull stage elevation. Width of flood-prone area (W_{fpa}) and the entrenchment ratio were determined as described in Figure 3-1.

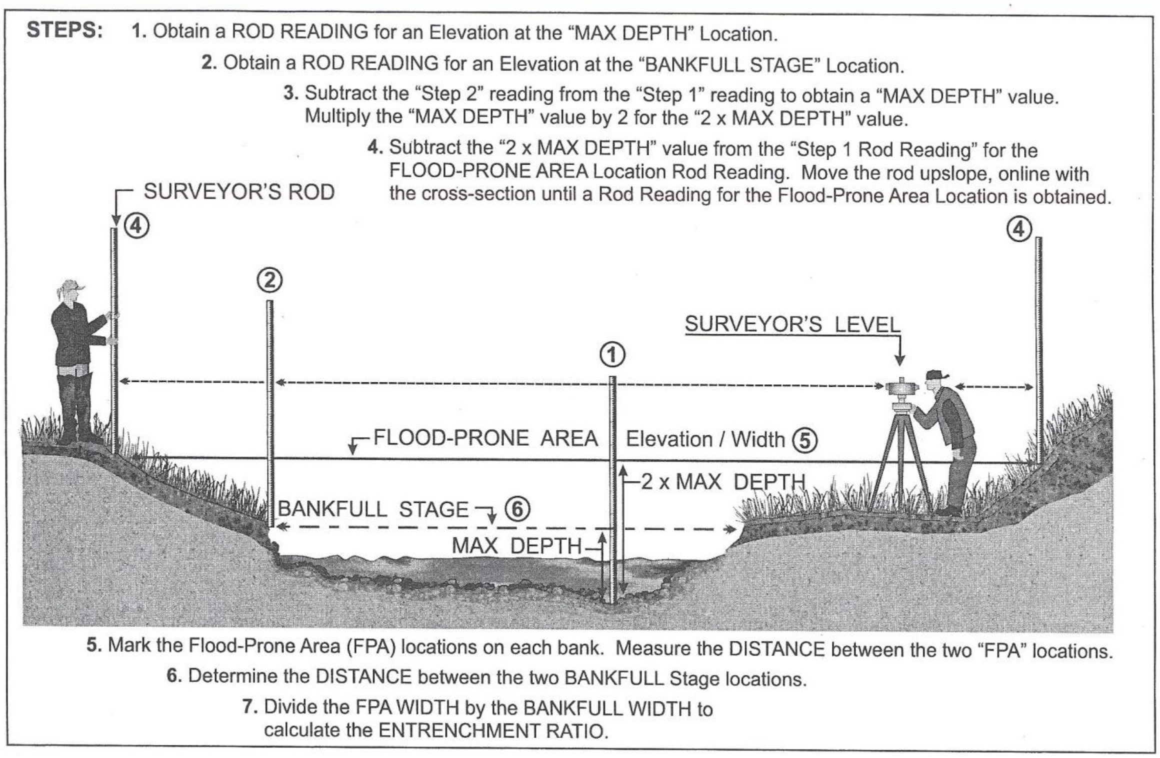


Figure 3-1. Determining the entrenchment ratio (Wildland Hydrology, 2008).

3.3 Pebble Count Method

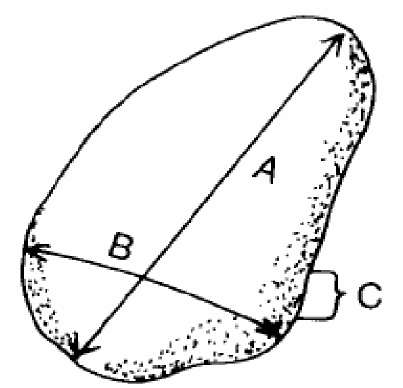
3.3.1 Overview

The pebble count characterizes the channel bed material present through a given study reach. A representative pebble count is used to determine the stream type. The main goal of the pebble count is to determine median particle size (D_{50}) of channel materials, as sampled from the channel surface, between the bankfull stage and thawleg elevations.

3.3.2 Field Procedures

A modification of Wolman's (1954) "Pebble Count" method described in Rosgen (1996) was used for the field determination of the particle size distribution of channel materials. A systematic sampling method was performed based on frequency of riffle/pools occurring within a channel reach approximately 20-30 bankfull channel widths in length (or two meander wavelengths). The total sample size of 100 was taken from both streams (Indian Run and Austintown Township Park). The samples were taken from both riffles and pools depending upon the frequency of these features. For example, if 70 percent of channel reach length is composed of riffles and 30 percent composed of pools, then 70 “pebbles”, or bottom particles, are taken from riffles and 30 from pools.

Sample particles were selected randomly using the “first blind touch” method. Without looking at the stream, an index finger was placed on the stream bottom, and the particle touched was removed. The intermediate axis of the particle (Figure 3-2) was measured and recorded in mm.



A=Longest axis (length)
B=Intermediate axis (width)
C=Short axis (thickness)

Figure 3-2. Intermediate axis of the particle (West Virginia Department of Environmental Protection, 2009).

3.3.3 Data Analysis

Depending upon their intermediate axis dimension, stream bed materials fall into five different major size categories, including bedrock, boulders, cobbles, gravel, sand, and silt/clay. To facilitate stream classification, the field data were transferred to the form shown in Table 3-1. The graph of particle size (x axis) versus cumulative % finer than(y axis) was also plotted (see Figure 2-6). From the table and plotted graph, D_{50} and D_{84} were determined; these parameters are very helpful for classification of the stream and estimation of bankfull discharge, respectively.

Table 3-1. Field form for documentation and analysis of pebble count data (Rosgen, 1996).

				PEBBLE COUNT					PEBBLE COUNT			PEBBLE COUNT		
Site:					Date:				DATE:			DATE:		
Party:					Reach:				REACH:			REACH:		
INCHES	PARTICLE	MILLIMETER		Particle Count		TOT #	ITEM %	% CUM	TOT #	ITEM %	% CUM	TOT #	ITEM %	% CUM
	Silt/Clay	< .062	S/C											
	Very Fine	.062 - .125	S											
	Fine	.125 - .25	A											
	Medium	.25 - .50	N											
	Coarse	.50 - 1.0	D											
.04 - .08	Very Coarse	1.0 - 2	S											
.08 - .16	Very Fine	2 - 4												
.16 - .24	Fine	4 - 6	G											
.24 - .31	Fine	6 - 8	R											
.31 - .47	Medium	8 - 12	A											
.47 - .63	Medium	12 - 16	V											
.63 - .94	Coarse	16 - 24	E											
.94 - 1.26	Coarse	24 - 32	L											
1.26 - 1.9	Very Coarse	32 - 48	S											
1.9 - 2.5	Very Coarse	48 - 64												
2.5 - 3.8	Small	64 - 96	C											
3.8 - 5.0	Small	96 - 128	O											
5.0 - 7.6	Large	128 - 192	B											
7.6 - 10	Large	192 - 256	L											
10 - 15	Small	256 - 384	B											
15 - 20	Small	384 - 512	L											
20 - 40	Medium	512 - 1024	D											
40 - 160	Lrg-Very Lrg	1024 - 4096	R											
	BEDROCK		BDRK											
					TOTALS									

3.4 Stream Classificaton

The various parameters like entrenchment ratio, width/depth ratio, sinuosity and channel materials were used in combination with Figure 2-4 (from Rosgen, 1996) to classify the stream. Depending upon those parameters Figure 2-4 was used to classify the stream. First, the channel type, entrenchment ratio and width: depth ratio were used to determine the major stream type. Then this was combined with the channel material and slope to obtain the full stream classification.

3.5 Estimation of Bankfull Discharge

Table 2-4 was used for the computation of bankfull discharge. To compute the bankfull discharge, the bankfull cross-sectional area, bankfull width, D_{84} at riffles, bankfull slope and gravitational acceleration are used as input variables. Two different methods are used for the calculation of bankfull discharge.

3.5.1 Method 1 - Friction Factor/Relative Roughness

First, mean stream velocity is calculated by:

$$u = 2.88 + 5.66\, Log\left(\frac{R}{D_{84}}\right) u^{*} \qquad (3\text{-}5)$$

Where, Shear velocity (ft/s) $u^{*} = \sqrt{gRS}$, R = Hydraulic Radius (ft) = $\frac{A_{bkf}}{W_p}$; A_{bkf} = Bankfull cross sectional area (ft^2), W_p = wetted perimeter (ft) , S= Bankfull slope (ft/ft).

$$\text{Bankfull discharge } (Q_{bkf}) = u \times A_{bkf} \qquad (3\text{-}6)$$

3.5.2 Method 2- Use of Manning's Equation

Manning's equation for U.S. Customary unit is :

$$u = 1.4865 \times R^{\frac{2}{3}} S^{\frac{1}{2}}$$

Where n = Manning's roughness coefficient (3-7)

Two applicable approaches are given in Table 2-4 for finding Manning's n, resulting in two different estimates of bankfull velocity and discharge by Manning's equation.

a. **Calculating 'n' from friction factor and relative roughness**

   Manning's n can be calculated from friction factor and relative roughness. With the help of relative roughness (R/D_{84}) and Figure 3-3, the corresponding resistance factor (u/u^*) is found. Then, using Figure 3-4 and u/u^*, Manning's roughness coefficient n is found.

b. **Manning's n from stream type**

   Manning's n can also be estimated depending upon the type of stream classified by the Rosgen method using Figure 3-5.

   In all, completion of Table 2-4 yields three estimates of bankfull velocity and discharge for a given stream.

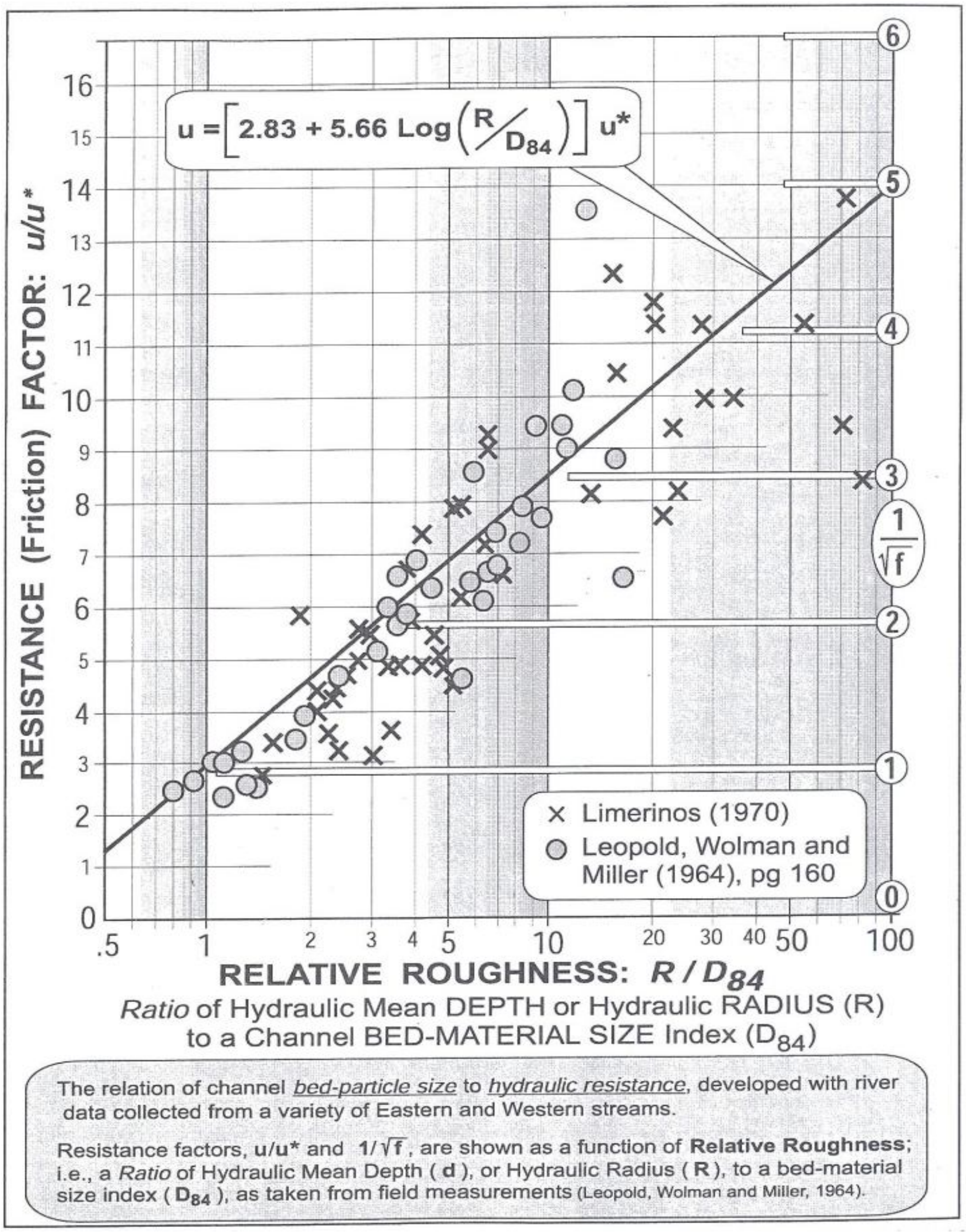


Figure 3-3. Relative roughness (R/D_{84}) vs. friction factor (u/u^*). (Rosgen and Silvey, 2007)

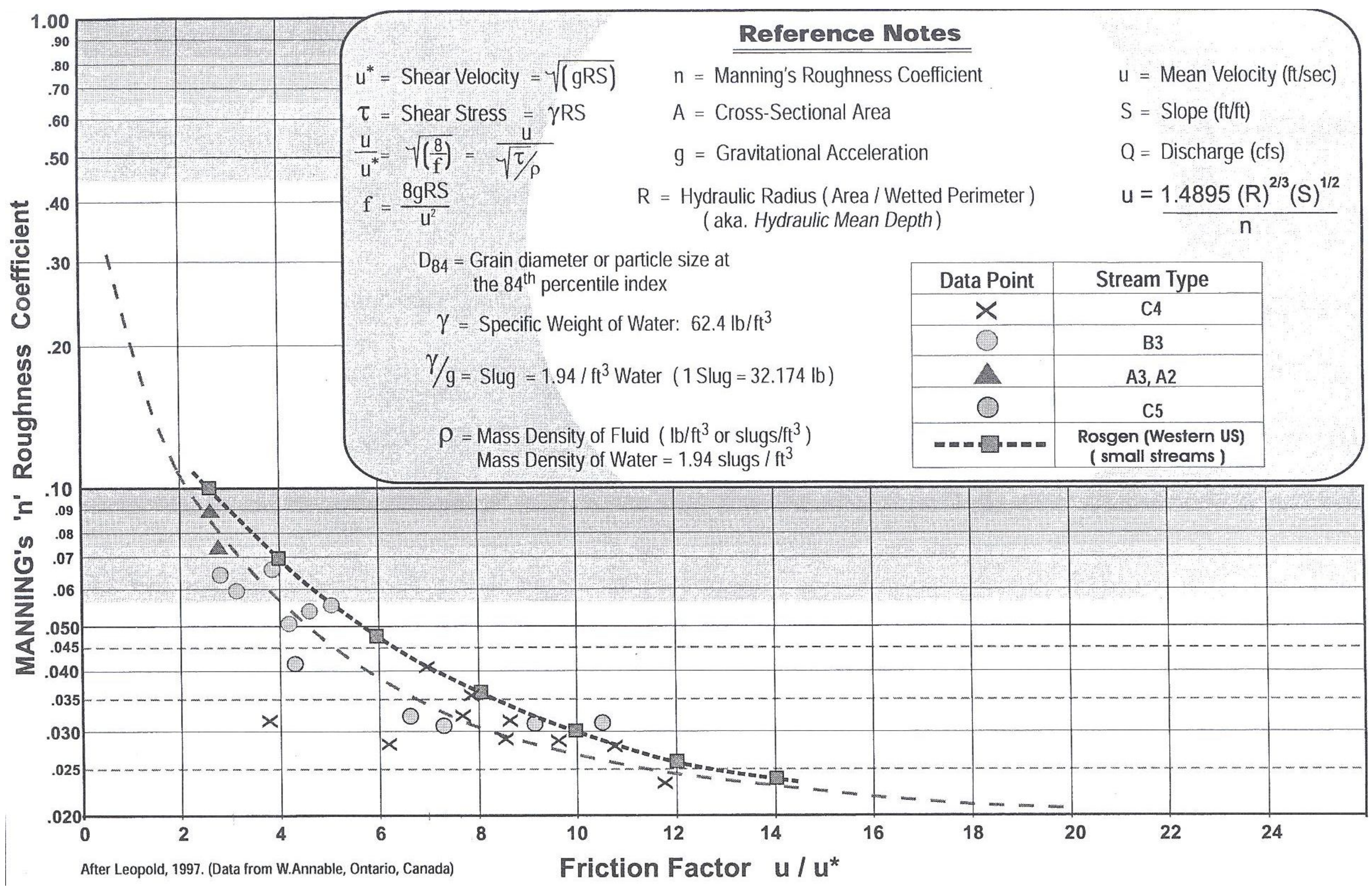


Figure 3-4. Friction factor (u/u*) vs. Manning's roughness coefficient 'n' (Rosgen and Silvey, 2007).

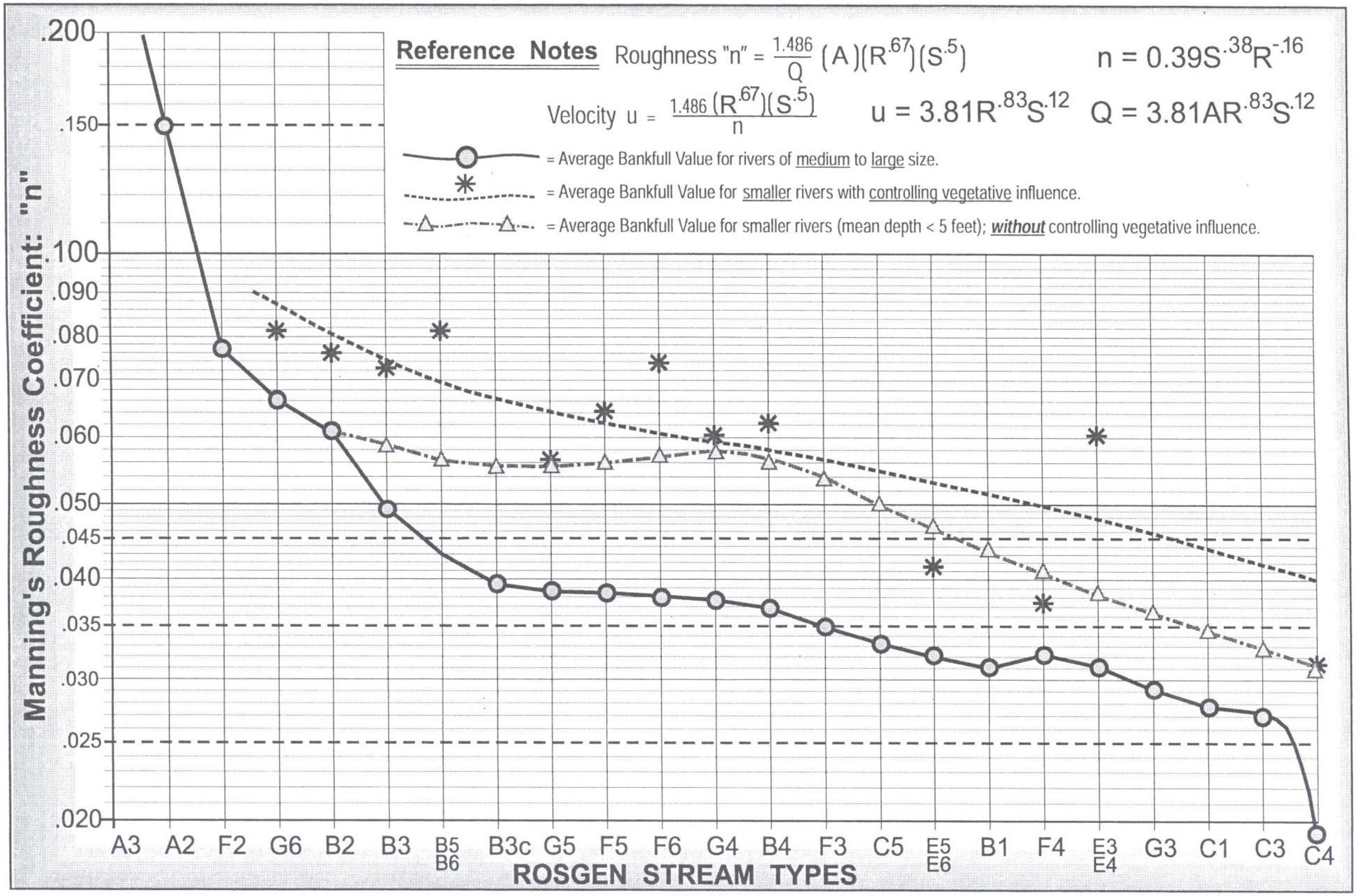


Figure 3-5. Manning's 'n' by stream type (Rosgen and Silvey, 2007).

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Longitudinal Profile

4.1.1 Austintown Township Park UNT

The surveying data for the longitudinal profile of Austintown Township Park UNT are summarized in Appendix A, Table A-1. A plot of longitudinal profile for the unnamed tributary to Meander Creek is shown in Figure 4-1. The slope calculation for the study reach of stream is shown below.

$$\text{Slope} = \frac{1109.88 - 1106.75}{230} = 0.014$$

This slope is typical of C type streams, which normally fall in the slope range of 0.001 to 0.02 (Table 2-4).

4.1.2 Indian Run Stream Restoration Project

The surveying data for the longitudinal profile of Indian Run Stream Restoration Project are summarized in Appendix A, Table A-2. A plot of longitudinal profile for the restored section of Indian Run is shown in Figure 4-2. The calculated slope of the section is

$$\text{Slope} = \frac{1098.54 - 1089.43}{1150} = 0.0079$$

This slope is also typical of C type streams, which normally fall in the slope range of 0.001 to 0.02 (Table 2-4).

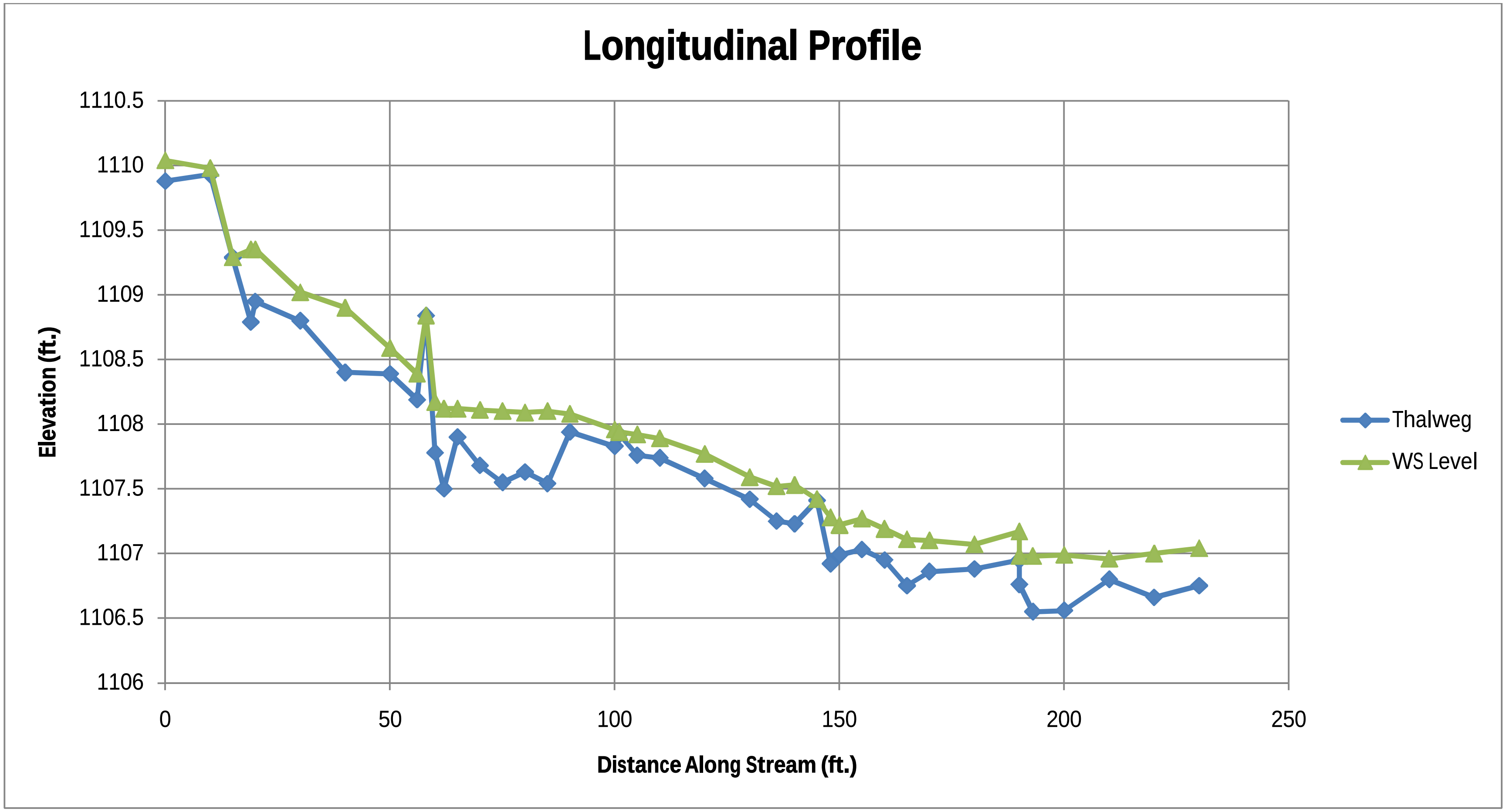


Figure 4-1. Longitudinal profile of Austintown Township Park project UNT.

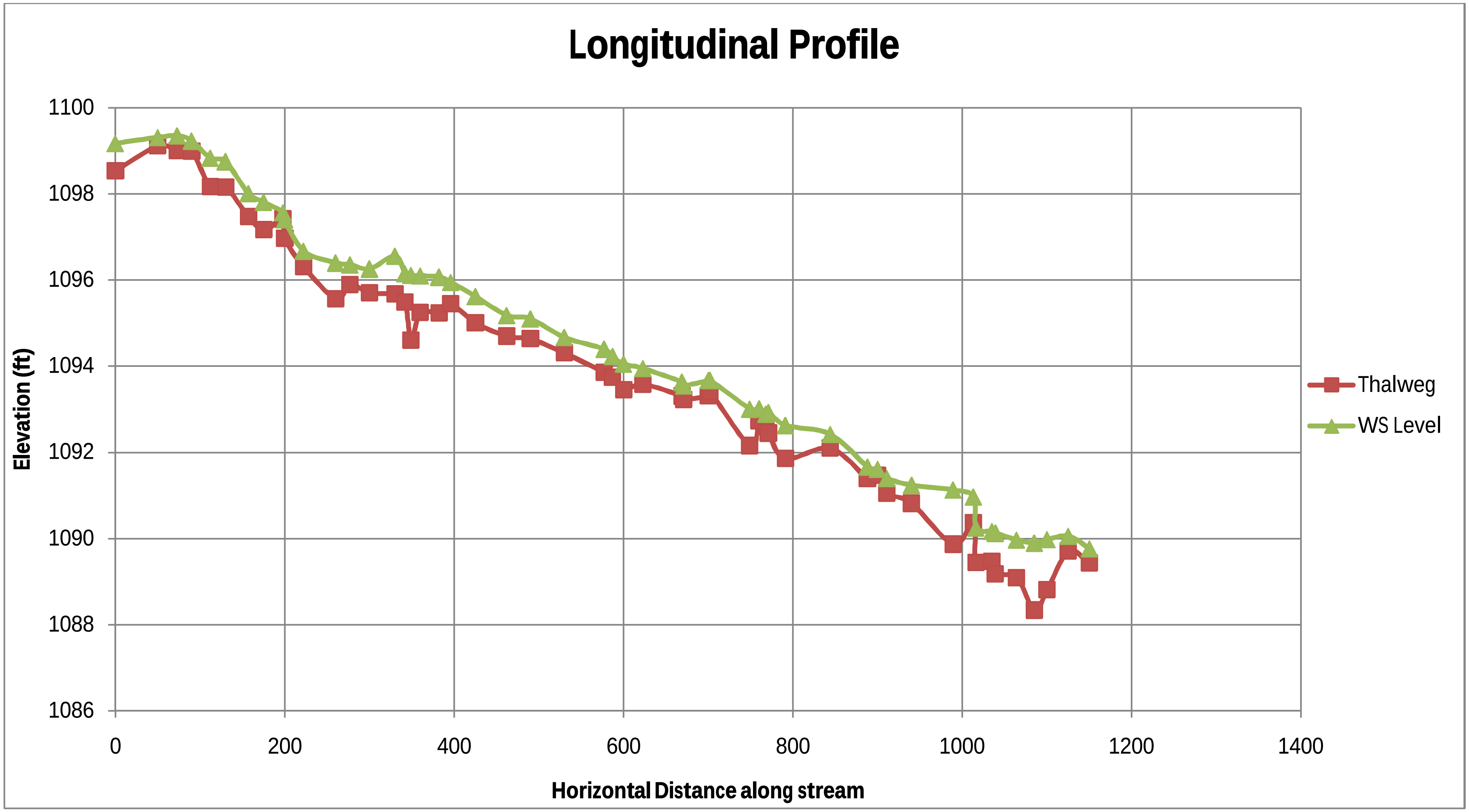


Figure 4-2. Longitudinal profile of restored section of Indian Run.

4.2 Cross-Sections

4.2.1 Austintown Township Park

At the Austintown UNT site, a total of four cross-sections were surveyed. The cross-sections were taken at stations 0+50, 1+00, 1+50 and 2+00. The cross-sectional profiles are shown in Figures 4-3, 4-4, 4-5, and 4-6 respectively. The surveying data are shown in Appendix B, Table B-1.

4.2.2 Indian Run Stream Restoration Project

At the Indian Run restoration project site, a total of four cross-sections were surveyed. The cross-sections were taken at stations 0+15, 6+25, 6+80 and 7+75. The cross-sectional profiles are shown in Figure 4-7, 4-8, 4-9 and 4-10 respectively. The surveying data for the cross-sections are shown in Appendix B, Table B-2.

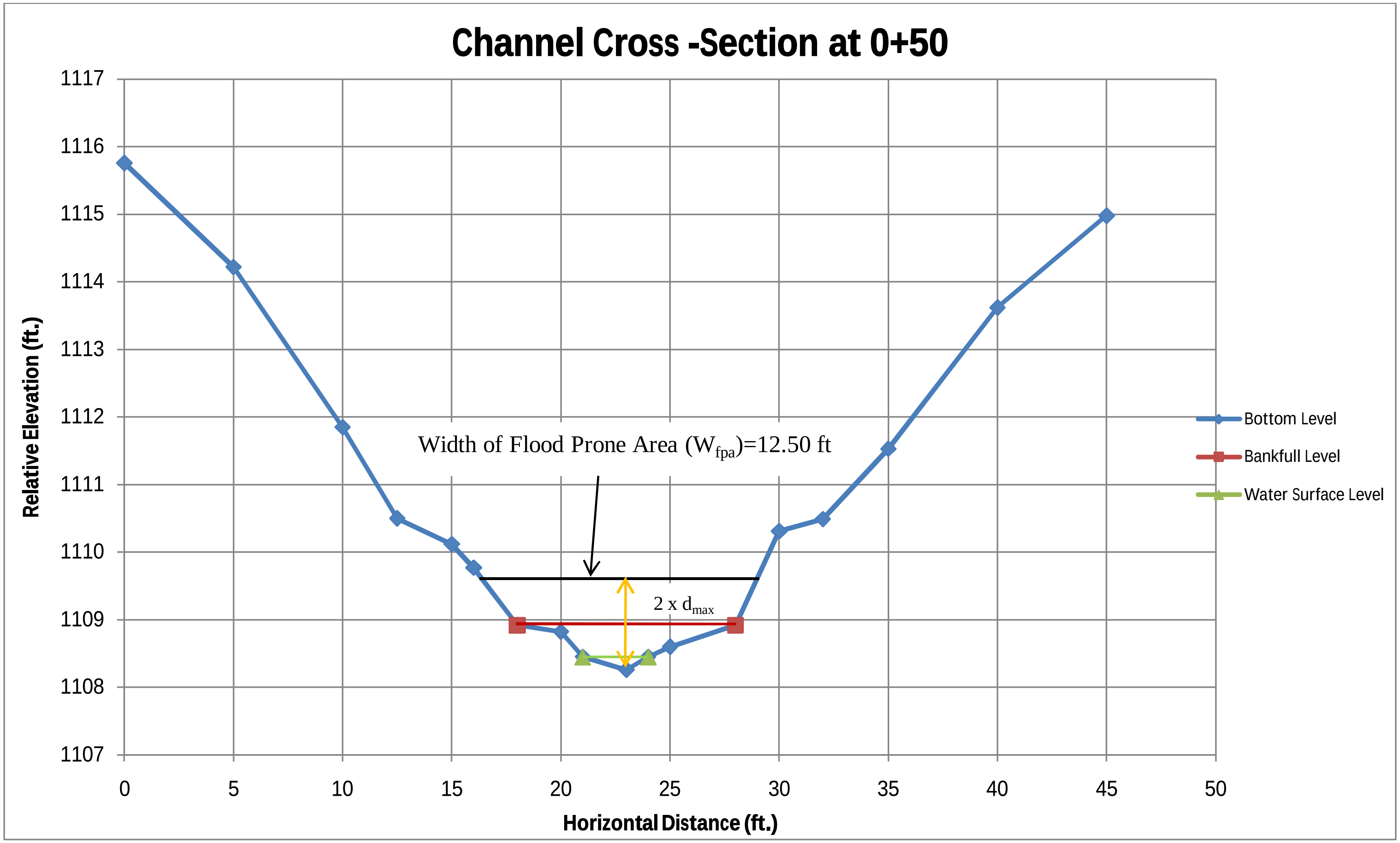


Figure 4-3. Channel cross-section at station 0+50 on unnamed stream in Austintown Township Park.

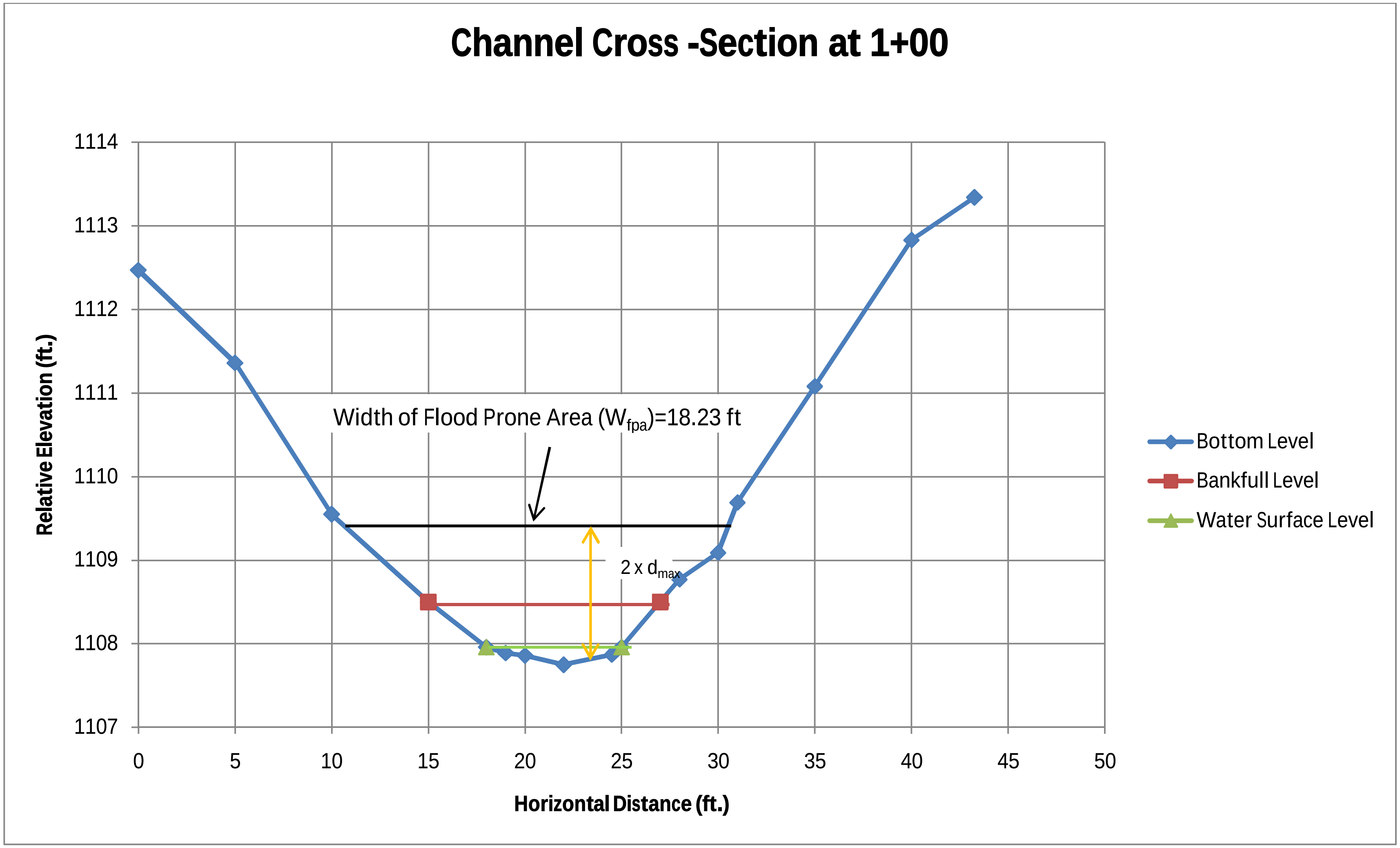


Figure 4-4. Channel cross-section at station 1+00 on unnamed stream in Austintown Township Park.

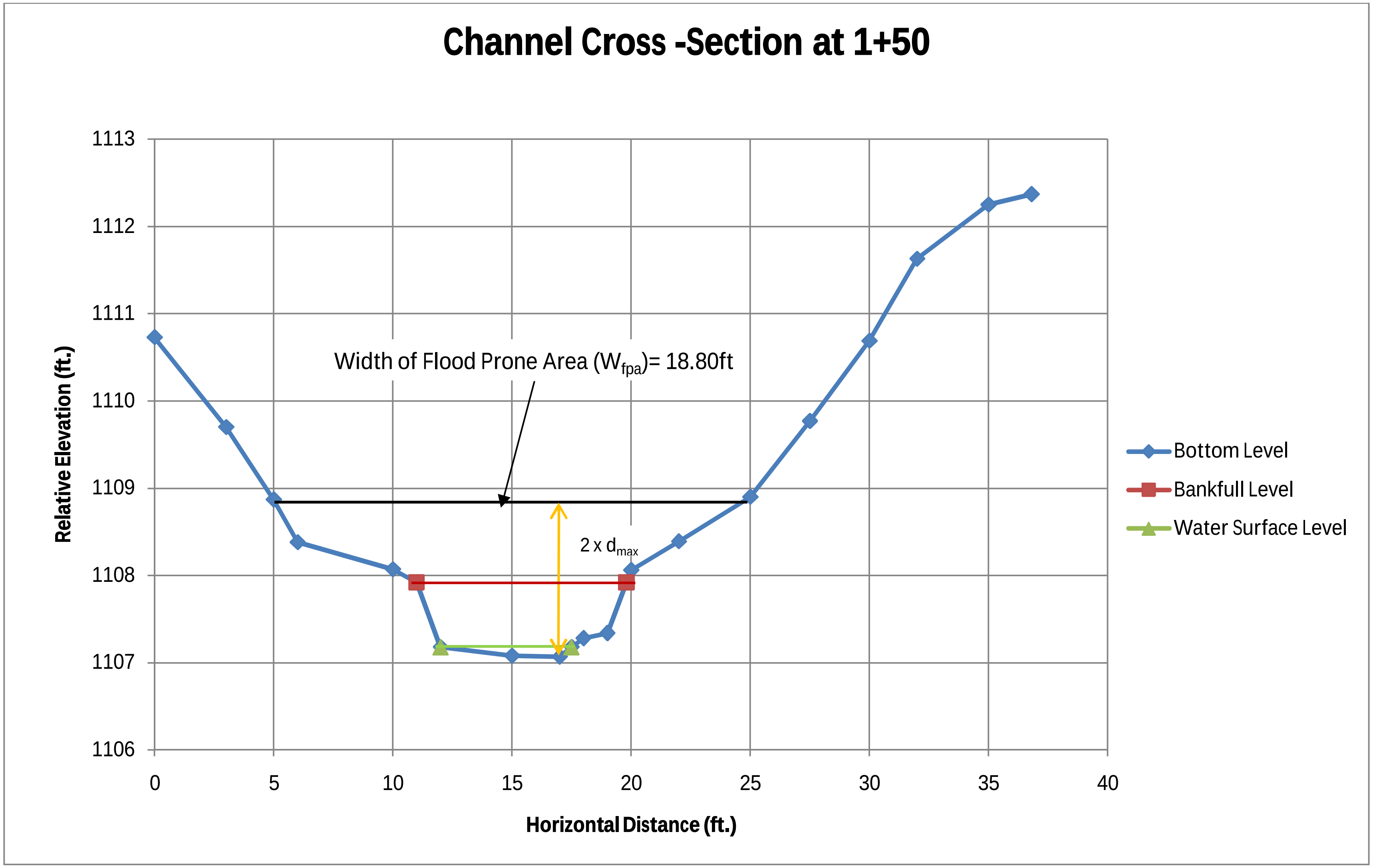


Figure 4-5. Channel cross-section at station 1+50 on unnamed stream in Austintown Township Park.

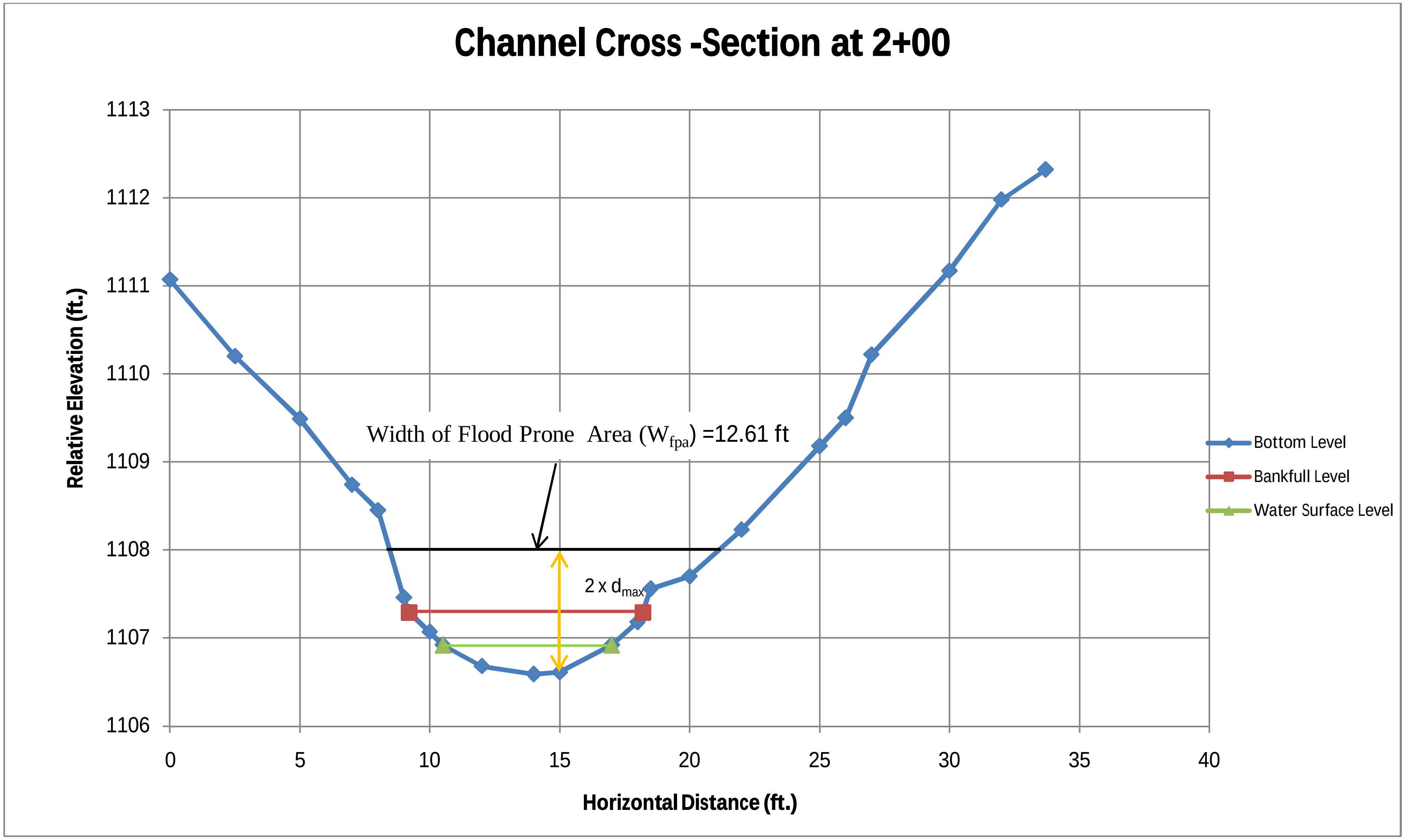


Figure 4-6. Channel cross-section at station 2+00 on unnamed stream in Austintown Township Park.

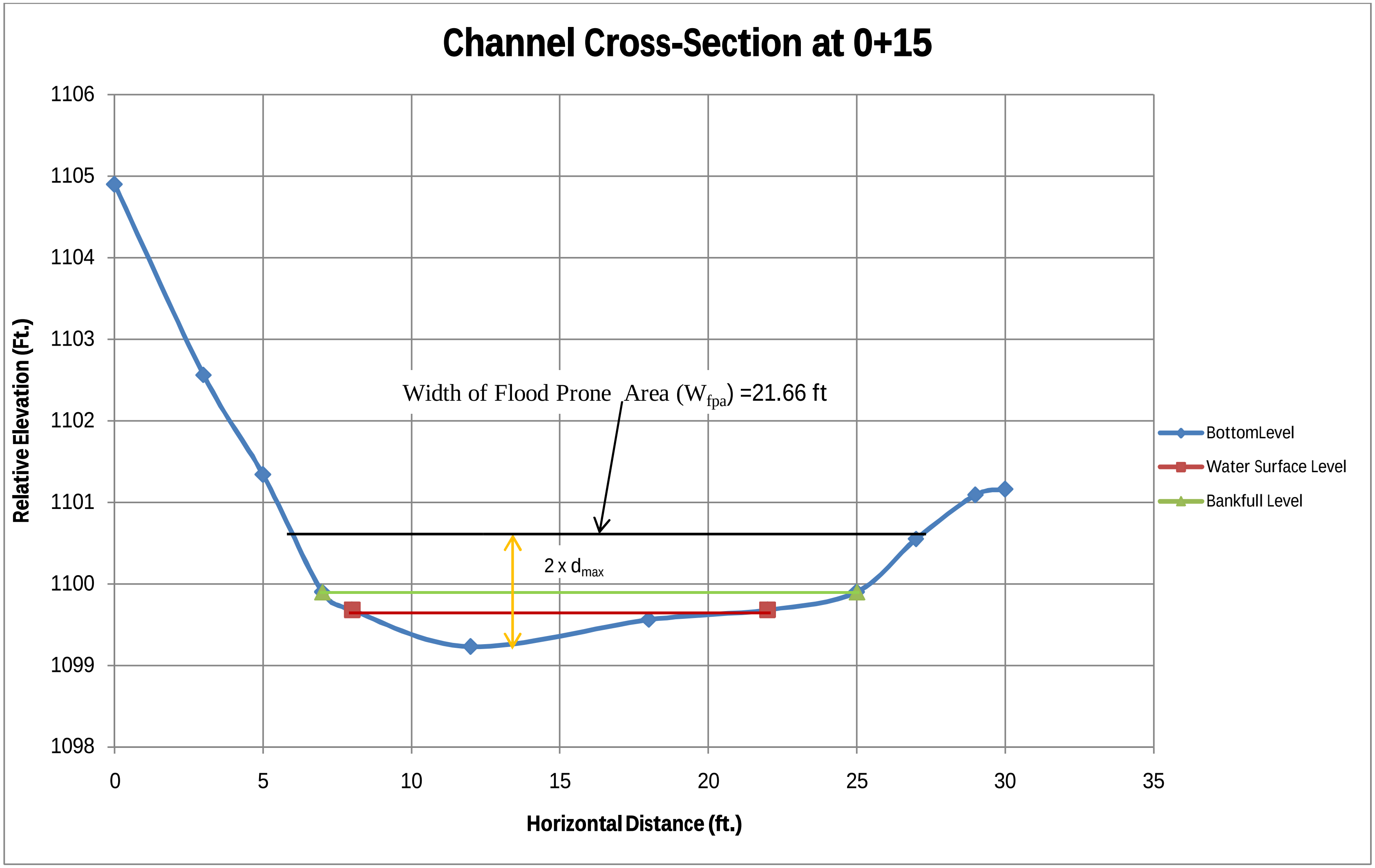


Figure 4-7. Channel cross-section at station 0+15 on Indian Run.

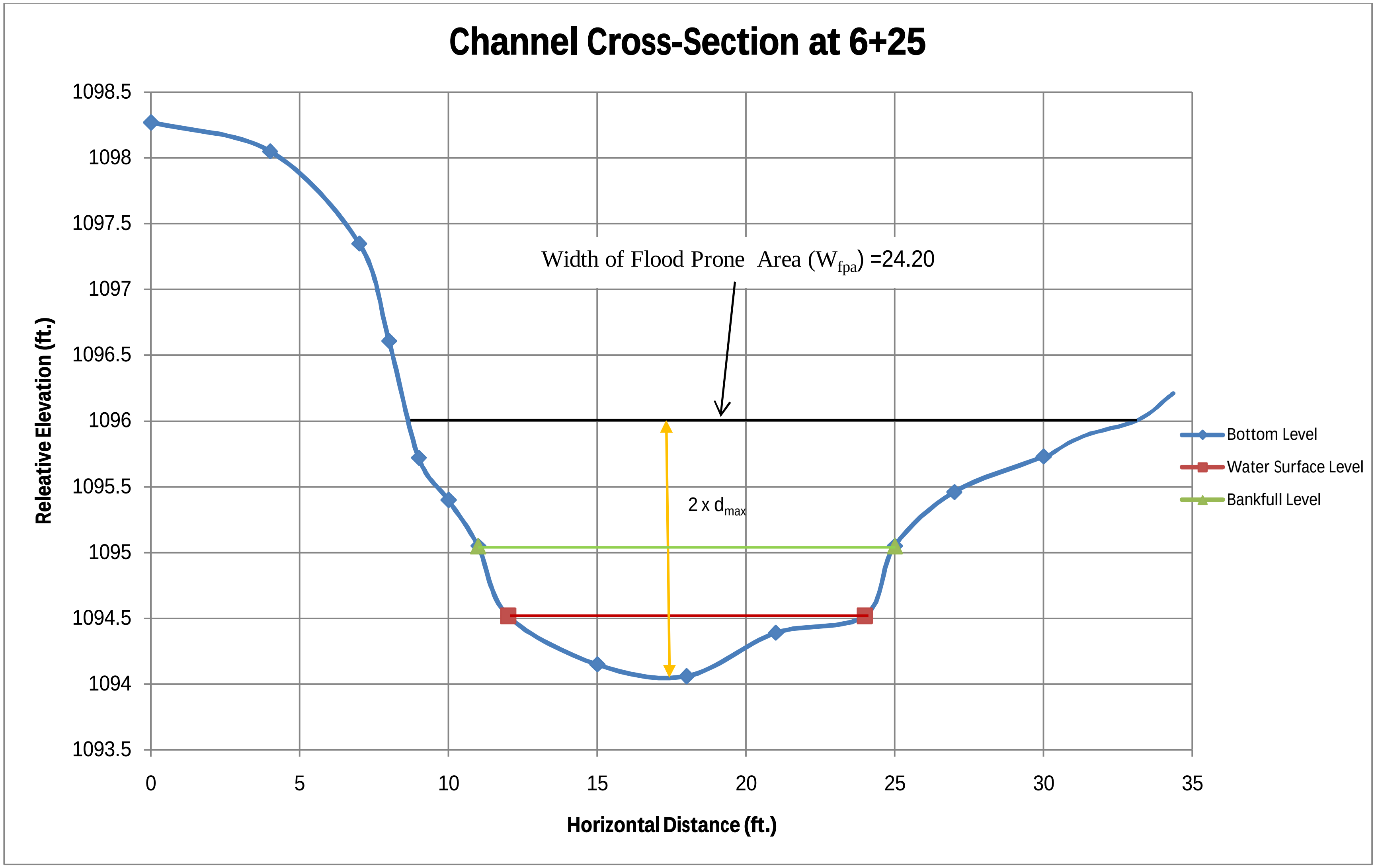


Figure 4-8. Channel cross-section at station 6+25 on Indian Run.

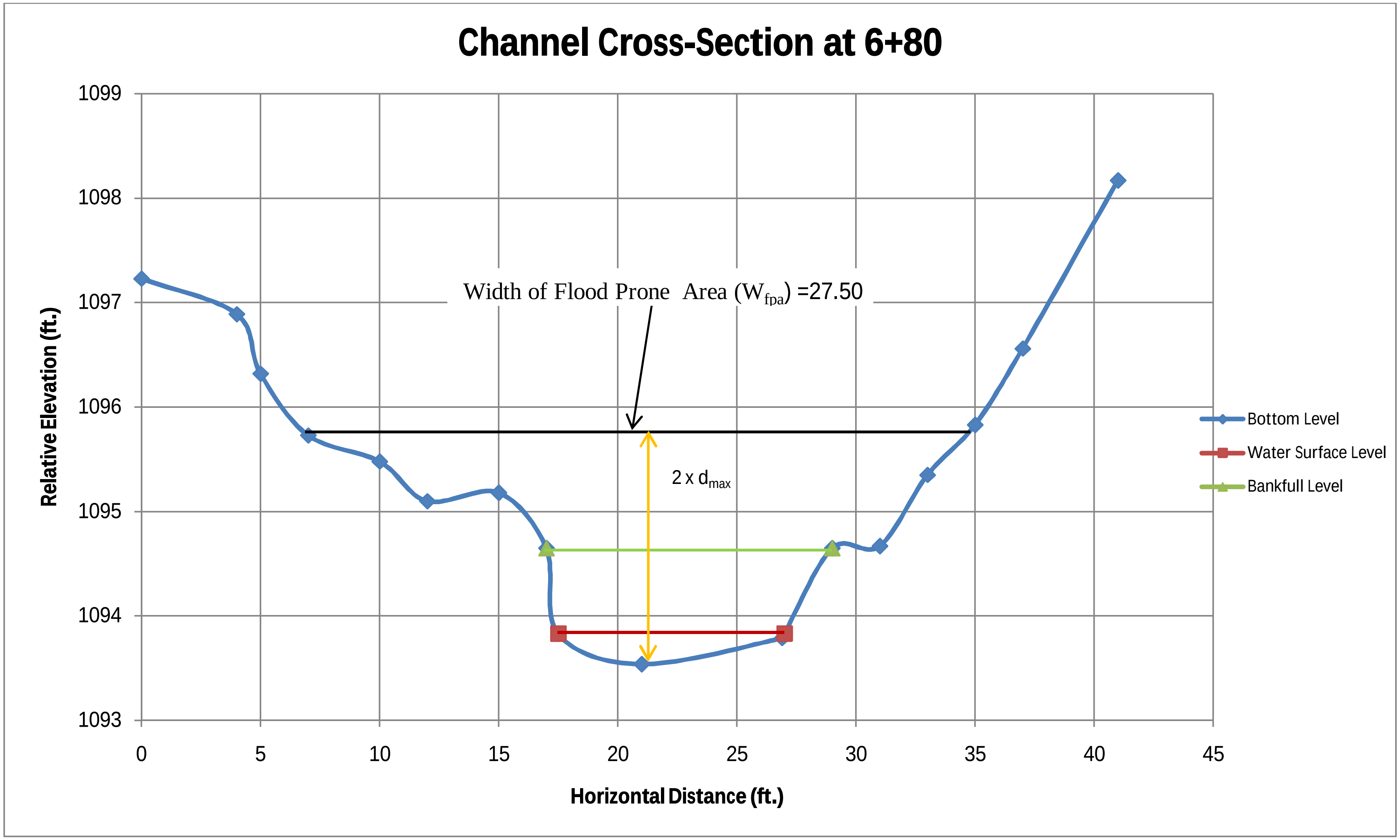


Figure 4-9. Channel cross-section at station 6+80 on Indian Run.

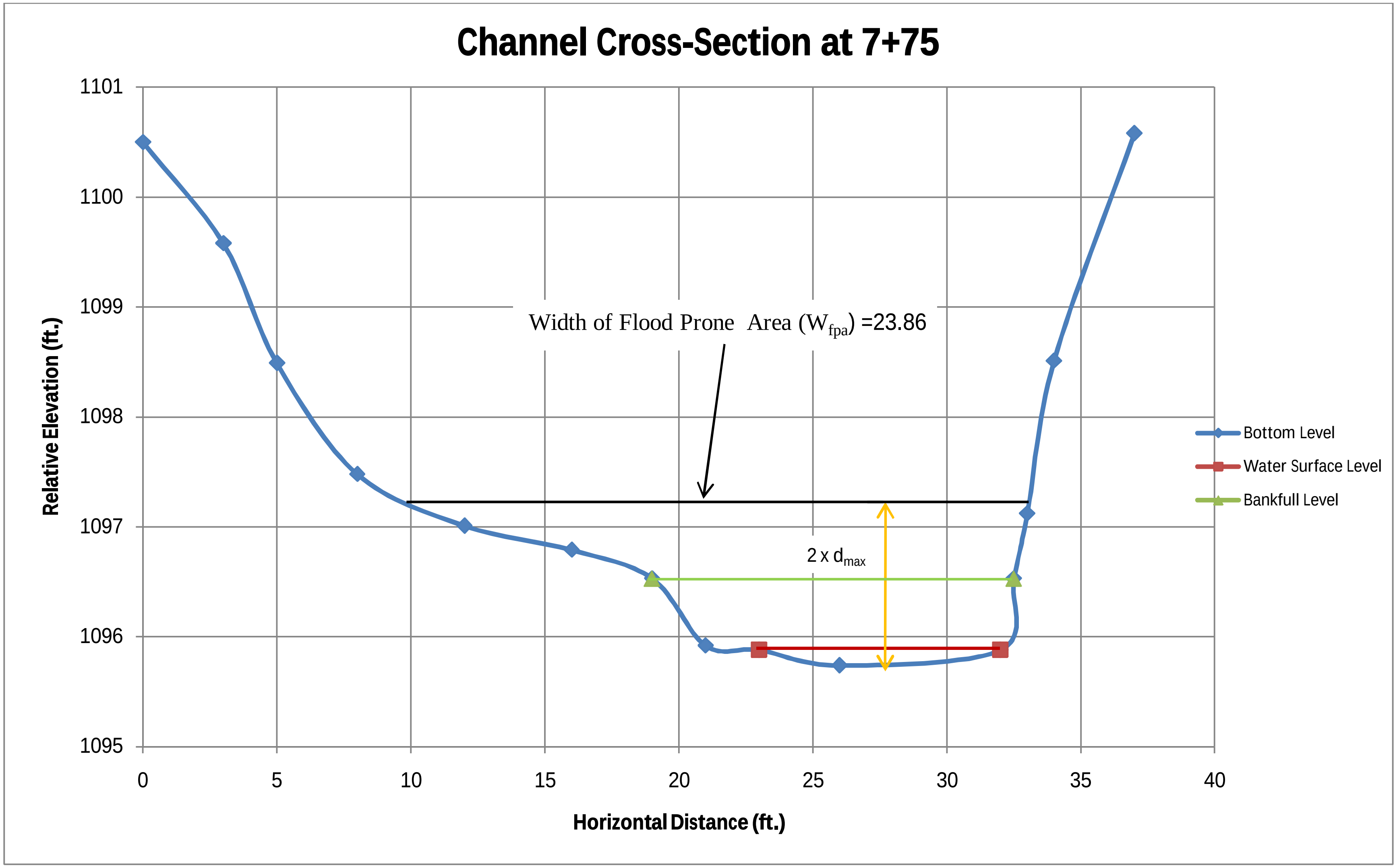


Figure 4-10. Channel cross-section at station 7+75 on Indian Run.

4.3 Pebble Count

One hundred representative samples of bed material ("pebbles") were taken from the stream bottom along each study reach (Austintown Township Park UNT and Indian Run). Channel materials were classified according to the size of intermediate axis and plotted to determine D_{50} and D_{84}. D_{50} values for the Austintown Township Park and Indian Run were 38 mm and 22 mm, respectively, which shows that channel materials on both sites are classified as gravel. D_{84} values for the Austintown UNT and Indian Run were 100 mm and 77 mm, respectively, which are used for bankfull discharge calculations. Tables 4-1 and 4-2 show the channel material distribution and classification for Austintown Township Park UNT and Indian Run, respectively. Figures 4-11 and 4-12 show graphs of the size distributions for Austintown Township Park UNT and Indian Run, respectively.

Table 4-1. Pebble count for Austintown Township Park UNT.

Inches	Particle Type	Milimeters		Composite	Item %	% Cum
	Silt / Clay	< 0.062	S/C			
	Very Fine	0.062 - 0.125	SAND			
	Fine	0.125 - 0.25				
	Medium	0.25 - 0.50				
	Coarse	0.50 - 1.0				
0.04 - 0.08	Very Coarse	1.0 - 2.0		1	1	1
0.08 - 0.16	Very FIne	2.0 - 4.0	GRAVEL	0	0	1
0.16 - 0.22	Fine	4.0 - 5.7		3	3	4
0.22 - 0.31	Fine	5.7 - 8.0		3	3	7
0.31 - 0.44	Medium	8.0 - 11.3		4	4	11
0.44 - 0.63	Medium	11.3 - 16.0		5	5	16
0.63 - 0.89	Coarse	16.0 - 22.6		16	16	32
0.89 - 1.3	Coarse	22.6 - 32.0		9	9	41
1.3 - 1.8	Very Coarse	32.0 - 45.0		15	15	56
1.8 - 2.5	Very Coarse	45.0 - 64.0		15	15	71
2.5 - 3.5	Small	64.0 - 90.0	COBBLE	8	8	79
3.5 - 5.0	Small	90.0 - 128.0		16	16	95
5.0 - 7.1	Large	128.0 - 180.0		5	5	100
7.1 - 10.1	Large	180.0 - 256.0				
10.1 - 14.3	Small	256.0 - 362.0	BOULDER			
14.3 - 20.0	Small	362.0 - 512.0				
20.0 - 40.0	Medium	512.0 - 1024.0				
40.0 - 80.0	Large - Very Large	1024.0 - 2048.0				
	Bedrock					

Table 4-2. Pebble count for Indian Run.

Inches	Particle Type	Milimeters		Composite	Item %	% Cum
	Silt / Clay	< 0.062	S/C			
	Very Fine	0.062 - 0.125	SAND			
	Fine	0.125 - 0.25				
	Medium	0.25 - 0.50				
	Coarse	0.50 - 1.0		10	10	10
0.04 - 0.08	Very Coarse	1.0 - 2.0				
0.08 - 0.16	Very FIne	2.0 - 4.0	GRAVEL	3	3	13
0.16 - 0.22	Fine	4.0 - 5.7		5	5	18
0.22 - 0.31	Fine	5.7 - 8.0		4	4	22
0.31 - 0.44	Medium	8.0 - 11.3		9	9	31
0.44 - 0.63	Medium	11.3 - 16.0		6	6	37
0.63 - 0.89	Coarse	16.0 - 22.6		7	8	45
0.89 - 1.3	Coarse	22.6 - 32.0		5	5	50
1.3 - 1.8	Very Coarse	32.0 - 45.0		11	11	61
1.8 - 2.5	Very Coarse	45.0 - 64.0		10	10	71
2.5 - 3.5	Small	64.0 - 90.0	COBBLE	10	10	81
3.5 - 5.0	Small	90.0 - 128.0		12	12	93
5.0 - 7.1	Large	128.0 - 180.0		4	4	97
7.1 - 10.1	Large	180.0 - 256.0				
10.1 - 14.3	Small	256.0 - 362.0	BOULDER	3	3	100
14.3 - 20.0	Small	362.0 - 512.0				
20.0 - 40.0	Medium	512.0 - 1024.0				
40.0 - 80.0	Large - Very Large	1024.0 - 2048.0				
	Bedrock					

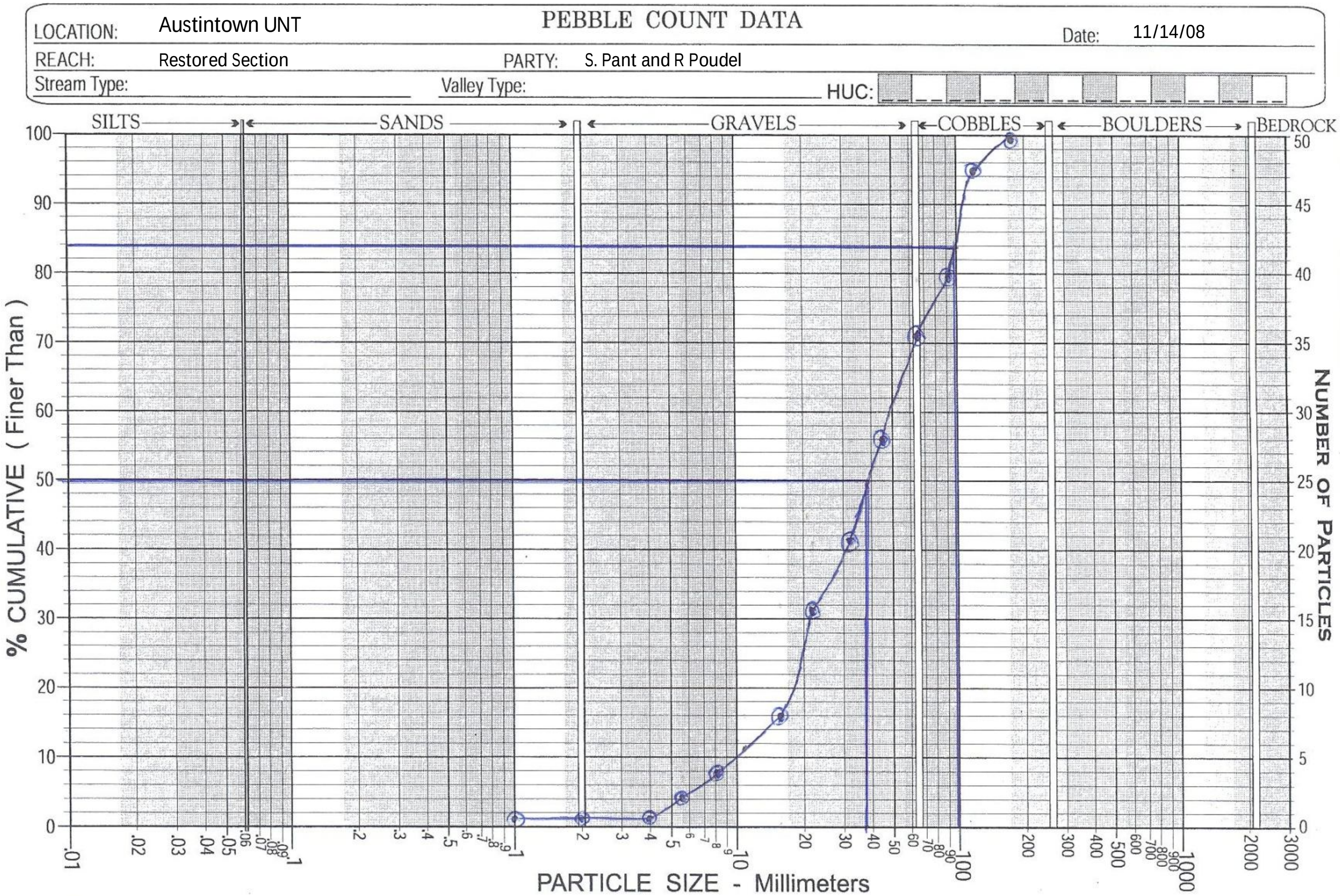


Figure 4-11. Pebble count plot for Austintown Township Park UNT.

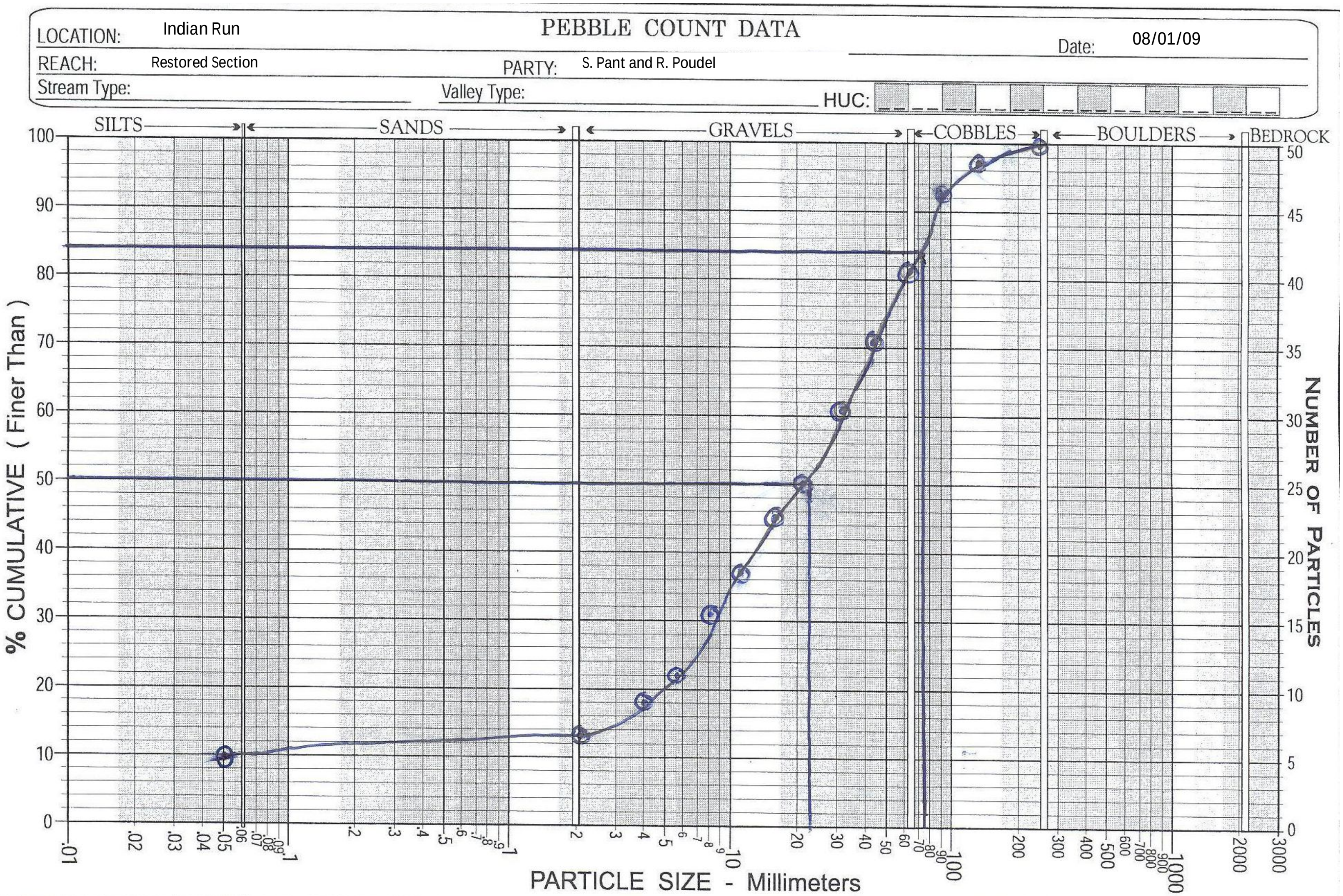


Figure 4-12. Pebble count plot for restored section of Indian Run.

4.4 Classification of Streams

4.4.1 Austintown Township Park UNT

Sample Calculations: Table 4-3 shows the bankfull area calculation, bankfull width, width-depth ratio, width of flood prone area and entrenchment ratio for the cross-section at 0+50. Tables for the remaining cross-sections are shown in Appendix C.

Table 4-3. Cross sectional area calculation at 0+50 on Austintown Township Park UNT

Station (ft)	Bottom Thalweg Elev (ft)	BKF (ft)	Depth (ft)	Horizontal Distance (ft)	Area (ft^2)	Total Area (ft^2)
0	1115.76					
5	1114.22					
10	1111.85					
12.5	1110.5					
15	1110.12					
16	1109.77					
18	1108.92	1108.92	0	0	0	2.96
20	1108.82		0.1	2	0.1	
21	1108.45		0.47	1	0.29	
23	1108.26		0.66	2	1.13	
24	1108.45		0.47	1	0.57	
25	1108.6		0.32	1	0.40	
28	1108.92	1108.92	0	3	0.48	
30	1110.31					
32	1110.49					
35	1111.53					
40	1113.62					
45	1114.98					

Calculation of morphological parameters

Bank-full Area (ft^2)	Bank-full Width (ft)	Mean BKF Depth (ft)	Width: Depth Ratio	Width of Flood Prone Area (ft)	Entrench ment Ratio	Max. Depth (ft)
2.96	10	0.30	33.84	12.5	1.25	0.66

Interpretation of data

Area sample calculation = $\frac{0.1+0.47}{2}$ ft x 1 ft = 0.29 ft^2 (between stations 20 and 21 ft)

Bankfull cross-sectional area = 0 + 0.1 + 0.29 + 1.13 + 0.57 + 0.40 + 0.48 = 2.96 ft^2

Mean bankfull depth = $\frac{2.96\ ft}{10\ ft}$ = 0.296 = 0.3ft

Width/depth ratio = $\frac{10\ ft}{0.296\ ft}$ = 33.84

Entrenchment ratio = $\frac{W_{fpa}}{W_{bkf}} = \frac{12.5\ ft}{10\ ft}$ = 1.25

All the parameters for all cross-sections were calculated and averages of those data were taken to classify the stream (Table 4-4).

Table 4-4. Average morphological parameters for the classification of Austintown Township Park UNT.

Parameter	Cross-Section Location				Average
	0+50	1+00	1+50	2+00	
Entrenchment Ratio (ER)	1.25	1.52	2.14	1.40	1.58
Width/Depth Ratio	33.84	24.17	12.88	18.96	22.46
Sinuosity					1.02
Slope					0.014
Channel Material D_{50}					38 mm

The standard form shown in Table 4-5 and classification key shown in Figure 2-4 were used for Level II classification of the stream. The Austintown Township Park UNT is classified as a B4c type stream. The entrenchment and width/depth ratios are typical of B type streams, but the slope is more typical of C type streams. Sinuosity is very low due to man-made constraints, including bridges at both ends of the study reach.

Table 4-5. Level II classification of Austintown Township Park UNT.

Stream:	**Unnamed Tributary to Meander Creek**		
Basin:		Drainage Area:	acres / mi²
Location:	**Austintown Township Park**		
Twp.&Rge:		Sec.&Qtr.:	
Cross-Section Monuments (Lat./Long.):		Date:	
Observers:	**Santosh R Pant & Rajesh K Poudel**	Valley Type:	

Parameter	Value	Unit
Bankfull WIDTH (W_{bkf}) WIDTH of the stream channel at bankfull stage elevation, in a riffle section.	9.95	ft
Bankfull DEPTH (d_{bkf}) Mean DEPTH of the stream channel cross-section, at bankfull stage elevation, in a riffle section ($d_{bkf} = A / W_{bkf}$).	0.49	ft
Bankfull X-Section AREA (A_{bkf}) AREA of the stream channel cross-section, at bankfull stage elevation, in a riffle section.	4.79	ft^2
Width/Depth Ratio (W_{bkf} / d_{bkf}) Bankfull WIDTH divided by bankfull mean DEPTH, in a riffle section.	22.46	ft/ft
Maximum DEPTH (d_{mbkf}) Maximum depth of the bankfull channel cross-section, or distance between the bankfull stage and Thalweg elevations, in a riffle section.	0.74	ft
WIDTH of Flood-Prone Area (W_{fpa}) Twice maximum DEPTH, or ($2 \times d_{mbkf}$) = the stage/elevation at which flood-prone area WIDTH is determined in a riffle section.	15.53	ft
Entrenchment Ratio (ER) The ratio of flood-prone area WIDTH divided by bankfull channel WIDTH (W_{fpa} / W_{bkf}) (riffle section).	1.58	ft/ft
Channel Materials (Particle Size Index) D_{50} The D_{50} particle size index represents the mean diameter of channel materials, as sampled from the channel surface, between the bankfull stage and Thalweg elevations.	38	mm
Water Surface SLOPE (S) Channel slope = "rise over run" for a reach approximately 20–30 bankfull channel widths in length, with the "riffle-to-riffle" water surface slope representing the gradient at bankfull stage.	0.014	ft/ft
Channel SINUOSITY (k) Sinuosity is an index of channel pattern, determined from a ratio of stream length divided by valley length (SL / VL); or estimated from a ratio of valley slope divided by channel slope (VS / S).	1.02	

Stream Type	**B4c**	**See Classification Key (Figure 2-21)**

4.4.2 Indian Run Stream Restoration Project

The major parameters determined from field surveys and used during the classification of Indian Run are shown in Table 4-6. The stream classification worksheet is shown in Table 4-7. Tables showing cross-sectional area calculations and other parameters for Indian Run are presented in Appendix D.

Table 4-6. Major morphological parameters for the classification of Indian Run.

Parameter	Cross-Section Location				Average
	0+15	6+25	6+80	7+75	
Entrenchment Ratio (ER)	1.2	2.02	2.29	1.77	1.82
Width/Depth Ratio	50.86	50	13.98	21.41	34.06
Sinuosity					1.06
Slope					0.0079
Channel Material D_{50}					22 mm

Indian Run is classified as a B4c type stream. The entrenchment and width/depth ratios are typical of B type streams, but the slope is more typical of C type streams. Sinuosity is lower than expected due to the steep bank on the east side of the stream. It appears that the slope of the bank was increased by placement of fill during construction of the nearby school building.

Table 4-7. Level II classification of Indian Run.

Stream:	**Unnamed Tributary to Pine Hollow Run**		
Basin:	Drainage Area:	acres	mi^2
Location:	**Indian Run stream restoraton Project**		
Twp.&Rge:	Sec.&Qtr.:		
Cross-Section Monuments (Lat./Long.):	Date:		
Observers:	**Santosh R Pant & Rajesh K Poudel**	Valley Type:	

Bankfull WIDTH (W_{bkf}) WIDTH of the stream channel at bankfull stage elevation, in a riffle section.	13.88	ft
Bankfull DEPTH (d_{bkf}) Mean DEPTH of the stream channel cross-section, at bankfull stage elevation, in a riffle section ($d_{bkf} = A / W_{bkf}$).	0.52	ft
Bankfull X-Section AREA (A_{bkf}) AREA of the stream channel cross-section, at bankfull stage elevation, in a riffle section.	7.02	ft^2
Width/Depth Ratio (W_{bkf} / d_{bkf}) Bankfull WIDTH divided by bankfull mean DEPTH, in a riffle section.	34.06	ft/ft
Maximum DEPTH (d_{mbkf}) Maximum depth of the bankfull channel cross-section, or distance between the bankfull stage and Thalweg elevations, in a riffle section.	0.76	ft
WIDTH of Flood-Prone Area (W_{fpa}) Twice maximum DEPTH, or ($2 \times d_{mbkf}$) = the stage/elevation at which flood-prone area WIDTH is determined in a riffle section.	24.3	ft
Entrenchment Ratio (ER) The ratio of flood-prone area WIDTH divided by bankfull channel WIDTH (W_{fpa} / W_{bkf}) (riffle section).	1.82	ft/ft
Channel Materials (Particle Size Index) D_{50} The D_{50} particle size index represents the mean diameter of channel materials, as sampled from the channel surface, between the bankfull stage and Thalweg elevations.	22	mm
Water Surface SLOPE (S) Channel slope = "rise over run" for a reach approximately 20–30 bankfull channel widths in length, with the "riffle-to-riffle" water surface slope representing the gradient at bankfull stage.	0.0079	ft/ft
Channel SINUOSITY (k) Sinuosity is an index of channel pattern, determined from a ratio of stream length divided by valley length (SL / VL); or estimated from a ratio of valley slope divided by channel slope (VS / S).	1.06	

Stream Type	**B4c**	**See Classification Key**

4.5 Bankfull Velocity/Discharge Estimation

Different calculation methods were used to estimate bankfull velocity and discharge. Table 4-8 and Table 4-9 show the bankfull velocity and discharge estimates for the Austintown Township Park UNT and Indian Run, respectively, at the stream restoration project site. From the various estimation methods, the bankfull velocity and bankfull discharge of Austintown Township Park UNT averaged were 1.52 ft/sec and 7.29 cfs, respectively. Similarly, average bankfull velocity and bankfull discharge estimates for Indian Run were 1.40 ft/sec and 9.80 cfs, respectively.

Table 4-8. Computation of velocity and discharge of unnamed stream in Austintown Township Park using various methods.

Bankfull VELOCITY / DISCHARGE Estimates

Site	Austintown Township Park		Location	Austintown	
Date	04/5/2010	Stream Type	B4c	Valley Type	
Observers	Santosh R Pant, Rajesh Poudel		HUC		

INPUT VARIABLES			OUTPUT VARIABLES		
Bankfull Cross-sectional	4.79	A_{bkf} (ft²)	Bankfull Mean DEPTH	0.49	D_{bkf} (ft)
Bankfull WIDTH	9.95	W_{bkf} (ft)	Wetted PERIMETER ~ $2 * d_{bkf} + W_{bkf}$	10.93	W_p (ft)
D_{84} @ Riffle	100.0	Dia. (mm)	D_{84} mm / 304.8 =	0.328	D_{84} (ft)
Bankfull SLOPE	0.013	S_{bkf} (ft / ft)	Hydraulic RADIUS A_{bkf} / W_p	0.44	R (ft)
Gravitational Acceleration	32.2	g (ft / sec²)	Relative Roughness R (ft) / D_{84} (ft)	1.34	
Drainage AREA	1.1	DA (mi²)	Shear Velocity $u^* = \sqrt{gRS}$	0.43	u* (ft / sec)

ESTIMATION METHODS	Bankfull VELOCITY		Bankfull DISCHARGE	
1. Friction Factor / Relative Roughness $u = [\,2.83 + 5.66 \text{Log}\{\,R / D_{84}\,\}\,] u^*$	1.52	ft / sec	7.27	cfs
2. Roughness Coefficient: a) Manning's 'n' from friction factor / relative roughness (Figs. 2-18, 19) $u = 1.4865 * R^{2/3} * S^{1/2} / n$ n = 0.075	1.30	ft / sec	6.24	cfs
2. Roughness Coefficient: $u = 1.4865 * R^{2/3} * S^{1/2} / n$ b) Manning's 'n' from Jarrett (USGS): $n = 0.39 S^{.38} R^{-.16}$ n = Note: This equation is for applications involving steep, step-pool, high boundary roughness, cobble- and boulder-dominated stream systems; i.e., for stream types A1, A2, A3, B1, B2, B3, C2 and E3.		ft / sec		cfs
2. Roughness Coefficient: c) Manning's 'n' from Stream Type $u = 1.4865 * R^{2/3} * S^{1/2} / n$ n = 0.056	1.75	ft / sec	8.36	cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
4. Continuity Equations: a) Regional Curves $u = Q / A$ Return Period for Bankfull Discharge Q = Yr.		ft / sec		cfs
4. Continuity Equations: b) USGS Gage Data $u = Q / A$		ft / sec		cfs

Options for using the D_{84} term in the relative roughness relation (R/D_{84}), when using estimation method 1.

Option 1. For **sand-bed** channels: Measure the **"protrusion height"** (h_{sd}) of sand dunes above channel bed elevations. Substitute an average sand dune protrusion height (h_{sd} in ft) for the D_{84} term in est. method 1.

Option 2. For **boulder-dominated** channels: Measure several **"protrusion heights"** (h_{bo}) of boulders above channel bed elevations. Substitute an ave. boulder protrusion height (h_{bo} in ft) for the D_{84} term in est. method 1.

Option 3. For **bedrock-dominated** channels: Measure several **"protrusion heights"** (h_{br}) of rock separations/steps/joints/uplifted surfaces above channel bed elevations. Substitute an average bedrock protrusion height (h_{br} in feet) for the D_{84} term in estimation method 1.

Table 4-9.Computation of velocity and discharge of Indian Run using various methods.

Bankfull VELOCITY / DISCHARGE Estimates

Site	Indian Run			Location	Hermitage, PA
Date	04/5/2010	Stream Type	B4c	Valley Type	
Observers	Santosh R Pant, Rajesh Poudel			HUC	

INPUT VARIABLES			OUTPUT VARIABLES		
Bankfull Cross-sectional	7.02	A_{bkf} (ft²)	Bankfull Mean DEPTH	0.52	D_{bkf} (ft)
Bankfull WIDTH	13.88	W_{bkf} (ft)	Wetted PERIMETER ~ $2 * d_{bkf} + W_{bkf}$	14.92	W_p (ft)
D_{84} @ Riffle	77.0	Dia. (mm)	D_{84} mm / 304.8 =	0.25	D_{84} (ft)
Bankfull SLOPE	0.0079	S_{bkf} (ft / ft)	Hydraulic RADIUS A_{bkf} / W_p	0.47	R (ft)
Gravitational Acceleration	32.2	g (ft / sec²)	Relative Roughness R (ft) / D_{84} (ft)	1.88	
Drainage AREA	1.6	DA (mi²)	Shear Velocity $u^* = \sqrt{gRS}$	0.35	u^* (ft / sec)

ESTIMATION METHODS	Bankfull VELOCITY		Bankfull DISCHARGE	
1. Friction Factor / Relative Roughness $u = [2.83 + 5.66 Log\{R / D_{84}\}] u^*$	1.53	ft / sec	10.74	cfs
2. Roughness Coefficient: a) Manning's 'n' from friction factor / relative roughness (Figs. 2-18, 19) $u = 1.4865 * R^{2/3} * S^{1/2} / n$ n = 0.064	1.23	ft / sec	8.63	cfs
2. Roughness Coefficient: $u = 1.4865 * R^{2/3} * S^{1/2} / n$ b) Manning's 'n' from Jarrett (USGS): $n = 0.39 S^{.38} R^{-.16}$ n = Note: This equation is for applications involving steep, step-pool, high boundary roughness, cobble- and boulder-dominated stream systems; i.e., for stream types A1, A2, A3, B1, B2, B3, C2 and E3.		ft / sec		cfs
2. Roughness Coefficient: $u = 1.4865 * R^{2/3} * S^{1/2} / n$ c) Manning's 'n' from Stream Type n = 0.056	1.43	ft / sec	10.02	cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)		ft / sec		cfs
4. Continuity Equations: a) Regional Curves u = Q / A Return Period for Bankfull Discharge Q = Yr.		ft / sec		cfs
4. Continuity Equations: b) USGS Gage Data u = Q / A		ft / sec		cfs

Options for using the D_{84} term in the relative roughness relation (R/D_{84}), when using estimation method 1.

Option 1. For **sand-bed** channels: Measure the **"protrusion height"** (h_{sd}) of sand dunes above channel bed elevations. Substitute an average sand dune protrusion height (h_{sd} in ft) for the D_{84} term in est. method 1.

Option 2. For **boulder-dominated** channels: Measure several **"protrusion heights"** (h_{bo}) of boulders above channel bed elevations. Substitute an ave. boulder protrusion height (h_{bo} in ft) for the D_{84} term in est. method 1.

Option 3. For **bedrock-dominated** channels: Measure several **"protrusion heights"** (h_{br}) of rock separations/steps/joints/uplifted surfaces above channel bed elevations. Substitute an average bedrock protrusion height (h_{br} in feet) for the D_{84} term in estimation method 1.

4.6 Departure from Natural Conditions

Regional curves (Rosgen and Silvey, 2007) were used to determine expected values of width, cross-sectional area and mean depth for each stream based on watershed area. The regional curves for eastern United States were used. Figure 4-13 shows the regional curves for the various regions.

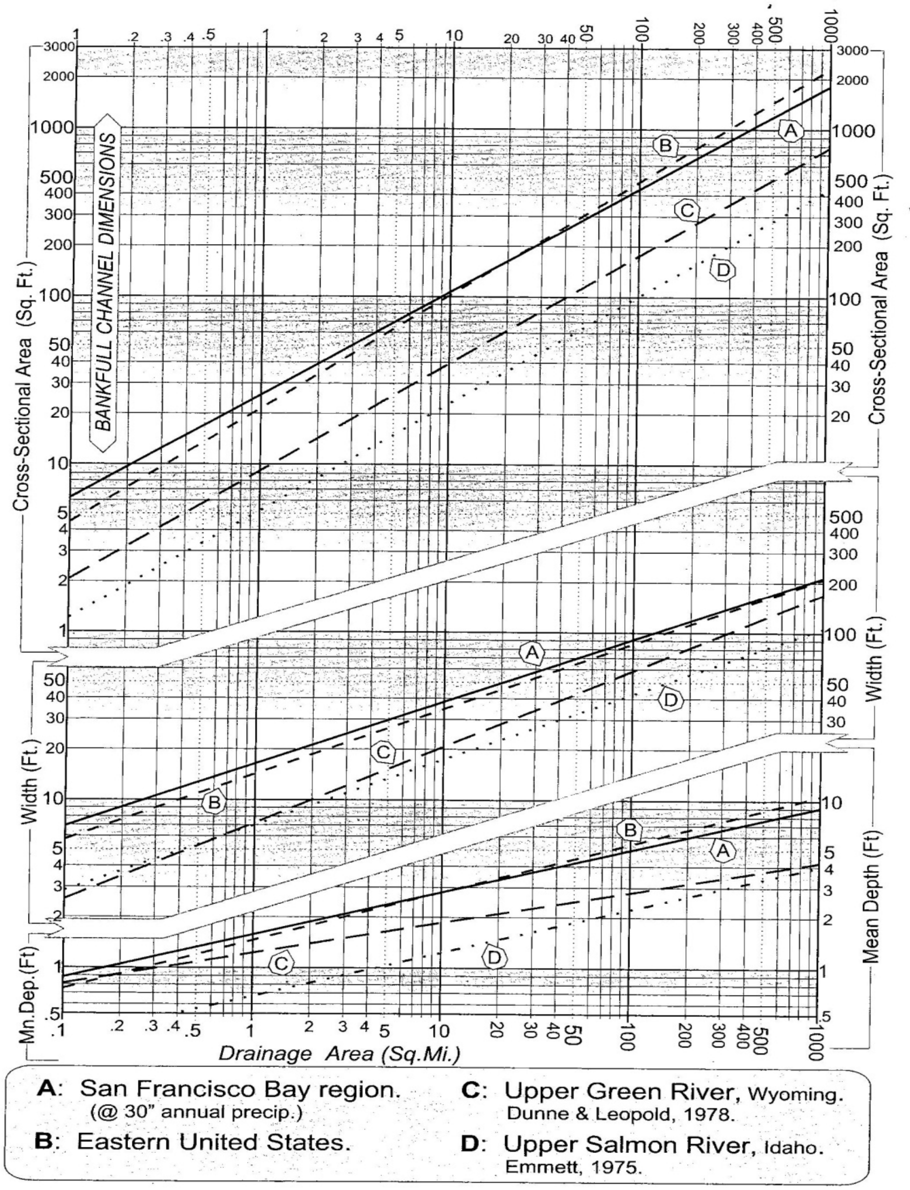


Figure 4-13. Regional curves showing bankfull dimension vs. drainage areas for various hydro-physiographic provinces (Rosgen and Slivey, 2007).

4.6.1 Comparison of Mean Depth, Width and Cross-sectional Area of Streams from Regional Curves and Actual Field Data,

Table 4-10 shows the values obtained from the regional curves and field data for both Austintown Township Park UNT and Indian Run.

Table 4-10. Comparison of the stream morphometry values obtained from regional curve and actual field data.

Sites	Regional curves			Field data		
	Mean Depth	width	x-sectional area	Mean depth	Width	x-sectional area
Austintown Township Park	1.5 ft	17 ft	22 sq ft	0.49 ft	9.95 ft	4.79 sq ft
Indian Run	1.8 ft	16 ft	28 sq ft	0.52 ft	13.88 ft	7.02 sq ft

The above comparison shows that there is significant difference between the values obtained from regional curves and field data. The streams we are considering are relatively small, and the predicted width and depth is much larger than the measured values. This may be due to various reasons. The most important reason is that we don't have regional curves for the local area where the streams are located. We are using the regional curves for eastern United States which will give the average values for all the streams that are in the region. Those curves were derived from data on streams with minimal human impact, while the streams studied in this project have considerable human impact.

Both streams were classified as B4c type streams. Based on slope, we would expect these streams to be C type streams in the absence of human impacts. Sinuosity for both streams was less than expected. Sinuosity less than 1.2 is usually only found in A type streams. However, entrenchment was more typical of B type stream. This observation was probably due to the stream channel being constrained by man-made features. All of these discrepancies suggest that the streams are not at their optimal natural condition.

Although there is still small amount of bank erosion on both Austintown UNT and Indian Run, the objectives of client and designer to reduce the bank erosion of both streams were mostly achieved. However, the full natural geomorphic and biological functions of the streams have most likely not been restored. Natural streams typically exist in a condition of dynamic equilibrium, where sediment is continuously eroded and deposited, and the channel changes location.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Based on the analysis of data collected in this study, the following conclusions were drawn:

1. The restored sections of both streams - Austintown Township Park UNT and Indian Run - were classified as "B4c" type streams.
2. Bankfull velocity and discharge of Austintown Township Park UNT were estimated as 1.52 ft/sec and 7.29 cfs, respectively. Similarly, bankfull velocity and discharge of Indian Run were estimated as 1.40 ft/sec and 9.80 cfs, respectively.
3. There were significant differences in the mean depth, width and cross-sectional area obtained from regional curves and those measured in the field.
4. Based upon field visits, survey data and stream classification, the restored sections of both streams are not at their optimum natural condition.
5. While the slopes of both streams are typical of C type streams, the entrenchment ratios are typical of B type streams, most likely due to the effects of man-made features.
6. The objectives of client and designer to reduce the bank erosion of both streams were mostly achieved. However, full natural geomorphic biological functions are not restored.

5.2 Recommendations

Based on the results obtained for the two restored stream sections, the following recommendations should be considered:

1. The entrenchment ratio and sinuosity of both streams should be increased to ranges typical of “C” type streams in order to achieve more natural stream conditions.
2. Development of regional curves for Ohio or the upper Midwest region would be helpful as a guide to identify the natural morphometry of streams in this area.
3. Rosgen Level III and Level IV assessments should be performed for both the Austintown Park UNT and Indian Run.

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APPENDIX A

Table A-1. Longitudinal data for Austintown UNT.

STATION	BS (ft.) [+]	HI (ft.)	FS (ft.) [-]	BED LEVEL ELEV. (ft.)	WATER SURFACE ELEV. (ft.)	REMARKS
	6.19	1113.09		1106.99		BM Culvert invert
2+30			6.34	1106.75	1107.04	
2+20			6.43	1106.66	1107	
2+10			6.29	1106.8	1106.96	Small Riffle
2+00			6.53	1106.56	1106.99	Shallow Pool
1+93			6.54	1106.55	1106.98	Pool Below CV
1+90			6.33	1106.76	1106.98	Below CV
1+90			6.14	1106.95	1106.95	Top of CV
1+80			6.21	1106.88	1107.07	Riffle
1+70			6.23	1106.86	1107.1	Riffle
1+65			6.34	1106.75	1107.11	Pool
1+60			6.14	1106.95	1107.19	Riffle
1+55			6.06	1107.03	1107.27	Riffle
1+50			6.1	1106.99	1107.22	Riffle
1+48			6.17	1106.92	1107.28	Pool Below CV
1+45			5.68	1107.41	1107.42	Top of CV
1+40			5.86	1107.23	1107.53	
1+36			5.84	1107.25	1107.52	
1+30			5.67	1107.42	1107.59	Riffle
1+20			5.51	1107.58	1107.77	
1+10			5.35	1107.74	1107.89	
1+05			5.33	1107.76	1107.92	Below CV
1+01			5.17	1107.92	1107.94	Top of CV
1+00			5.26	1107.83	1107.96	Riffle
0+90			5.15	1107.94	1108.08	
0+85			5.55	1107.54	1108.1	Pool
0+80			5.46	1107.63	1108.09	Pool
0+75			5.54	1107.55	1108.1	Pool
0+70			5.41	1107.68	1108.11	Pool
0+65			5.19	1107.9	1108.12	Riffle
0+62			5.59	1107.5	1108.12	Pool Below CV
0+60			4.5.31	1107.78	1108.17	
0+58			4.25	1108.84	1108.84	Top of CV
0+50			4.7	1108.39	1108.59	

STATION	BS (ft.) [+]	HI (ft.)	FS (ft.) [-]	BED LEVEL ELEV. (ft.)	WATER SURFACE ELEV. (ft.)	REMARKS
0+30			4.29	1108.8	1109.02	Riffle
0+20			4.14	1108.95	1109.35	
0+19			4.3	1108.79	1109.35	Pool Below CV
0+15			3.8	1109.29	1109.29	Top of CV
0+10			3.16	1109.93	1109.98	
0+00			3.21	1109.88	1110.04	Beginning Point

Table A-2. Longitudinal data for Indian Run.

STATION	BS (ft.) [+]	HI (ft.)	FS (ft.) [-] (Thalweg)	Edge of water	BED LEVEL ELEV. (ft.)	WATER SURFACE ELEV. (ft.)	REMARKS
BM1	3.97	1103.97			1100		Top of downstream rock
0+00			5.43	4.8	1098.54	1099.17	
0+50			4.85	4.66	1099.12	1099.31	
0+73			4.96	4.62	1099.01	1099.35	Log structure
0+90			4.98	4.74	1098.99	1099.23	
1+12			5.8	5.14	1098.17	1098.83	
1+30			5.81	5.22	1098.16	1098.75	
1+57			6.49	5.96	1097.48	1098.01	
1+75			6.8	6.16	1097.17	1097.81	
1+98			6.55	6.4	1097.42	1097.57	Above the log structure
2+00			7	6.57	1096.97	1097.4	Below the log structure
2+22			7.65	7.3	1096.32	1096.67	
BM2	4.12	1101.54			1097.42		
2+60			5.97	5.14	1095.57	1096.4	
2+77			5.64	5.18	1095.9	1096.36	
3+00			5.83	5.28	1095.71	1096.26	
BM 3	3.4	1099.98	4.96		1096.58		

STATION	BS (ft.) [+]	HI (ft.)	FS (ft.) [-] (Thalweg)	Edge of water	BED LEVEL ELEV. (ft.)	WATER SURFACE ELEV. (ft.)	REMARKS
3+30			4.3	3.42	1095.68	1096.56	
3+42			4.49	3.83	1095.49	1096.15	
3+49			5.37	3.87	1094.61	1096.11	
3+60			4.73	3.88	1095.25	1096.1	
3+82			4.74	3.91	1095.24	1096.07	
3+96			4.53	4.03	1095.45	1095.95	
4+25			4.97	4.36	1095.01	1095.62	
4+62			5.28	4.8	1094.7	1095.18	
BM4	4.33	1099.53	4.78		1095.2		
4+90			4.89	4.43	1094.64	1095.1	
5+30			5.22	4.86	1094.31	1094.67	
5+77			5.67	5.13	1093.86	1094.4	
5+87			5.78	5.3	1093.75	1094.23	
6+00			6.07	5.48	1093.46	1094.05	
BM5	3.32	1097.88	4.97		1094.56		
6+23			4.3	3.93	1093.58	1093.95	
6+69			4.57	4.25	1093.31	1093.63	Above the log structure
6+71			4.65	4.33	1093.23	1093.55	Below the log structure
7+00			4.56	4.21	1093.32	1093.67	Above the log structure
7+02			4.47	4.2	1093.41	1093.68	Below the log structure
7+49			5.72	4.87	1092.16	1093.01	
7+60			5.14	4.86	1092.74	1093.02	

STATION	BS (ft.) [+]	HI (ft.)	FS (ft.) [-] (Thalweg)	Edge of water	BED LEVEL ELEV. (ft.)	WATER SURFACE ELEV. (ft.)	REMARKS
7+68			5.27	4.99	1092.61	1092.89	Above the log structure
7+71			5.43	4.95	1092.45	1092.93	Below the log structure
7+91			6.02	5.25	1091.86	1092.63	
8+44			5.78	5.46	1092.1	1092.42	
8+88			6.48	6.22	1091.4	1091.66	
BM6	3.99	1095.67	6.2		1091.68		
9+00			4.2	4.06	1091.47	1091.61	
9+11			4.62	4.27	1091.05	1091.4	
9+40			4.85	4.43	1090.82	1091.24	
9+89			5.8	4.54	1089.87	1091.13	
10+13			5.3	4.7	1090.37	1090.97	Above log structure
10+16			6.22	5.42	1089.45	1090.25	Below the log structure(Pool)
10+35			6.2	5.5	1089.47	1090.17	Above the log structure
10+39			6.49	5.54	1089.18	1090.13	Below the log structure
10+64			6.58	5.7	1089.09	1089.97	
BM7	3.62	1093.75	5.54		1090.13		
10+85			5.41	3.85	1088.34	1089.9	
11+00			4.94	3.77	1088.81	1089.98	Above log structure
11+25			4.04	3.69	1089.71	1090.06	
11+50			4.32	3.98	1089.43	1089.77	

APPENDIX B

Table B-1. Cross-sectional data for Austintown UNT.

Cross-section at	STATION	BS [+]	HI	FS [-]	ELEV. [FEET]	REMARKS
0+50	BM	10.52	1117.42		1106.9	Bench Mark Culvert Invert
	0+00			1.66	1115.76	
	0+05			3.2	1114.22	
	0+10			5.57	1111.85	
	0+12.5			6.92	1110.5	
	0+15			7.3	1110.12	
	0+16			7.65	1109.77	Top of Left Channel
	0+18			8.65	1108.77	
	0+20			8.6	1108.82	
	0+21			9.1	1108.32	
	0+23			9.16	1108.26	
	0+25			8.82	1108.6	
	0+28			8.57	1108.85	
	0+30			7.11	1110.31	Top of Right Channel
	0+32			6.93	1110.49	
	0+35			5.89	1111.53	
	0+40			3.8	1113.62	
	0+45			2.44	1114.98	
1+00	0+00			4.95	1112.47	
	0+05			6.06	1111.36	
	0+10			7.87	1109.55	
	0+15			8.84	1108.58	
	0+18			9.39	1108.03	
	0+19			9.53	1107.89	Edge of Water
	0+20			9.56	1107.86	
	0+22			9.67	1107.75	
	0+24.5			9.55	1107.87	Edge of Water
	0+25			9.43	1107.99	
	0+28			8.65	1108.77	
	0+30			8.33	1109.09	
	0+31			7.73	1109.69	
	0+35			6.34	1111.08	
	0+40			4.59	1112.83	
	0+43.25			4.08	1113.34	

Cross-section at	STATION	BS [+]	HI	FS [-]	ELEV. [FEET]	REMARKS
	0+00			5.78	1110.73	
	0+03			6.81	1109.7	
	0+05			7.64	1108.87	
	0+06			8.13	1108.38	
	0+10			8.44	1108.07	
	0+11			8.55	1107.96	Top of the Bank
	0+12			9.32	1107.19	LEW
	0+15			9.43	1107.08	
	0+17			9.44	1107.07	
	0+18			9.23	1107.28	REW
	0+19			9.17	1107.34	
	0+20			8.45	1108.06	Top of the Bank
	0+22			8.12	1108.39	
	0+25			7.61	1108.9	
	0+27.5			6.74	1109.77	
	0+30			5.82	1110.69	
	0+32			4.88	1111.63	
	0+35			4.26	1112.25	
	0+36.8			4.14	1112.37	
2+00	0+00			5.44	1111.07	
	0+2.5			6.31	1110.2	
	0+05			7.02	1109.49	
	0+07			7.77	1108.74	
	0+08			8.06	1108.45	
	0+09			9.05	1107.46	
	0+10			9.44	1107.07	
	0+10.5			9.59	1106.92	LEW
	0+12			9.83	1106.68	
	0+14			9.92	1106.59	C/L
	0+15			9.9	1106.61	
	0+17			9.58	1106.93	REW
	0+18			9.33	1107.18	
	0+18.5			8.95	1107.56	
	0+20			8.81	1107.7	
	0+22			8.28	1108.23	
	0+25			7.33	1109.18	

Cross-section at	STATION	BS [+]	HI	FS [-]	ELEV. [FEET]	REMARKS
2+00	0+26			7.01	1109.5	
	0+27			6.29	1110.22	
	0+30			5.34	1111.17	
	0+32			4.53	1111.98	
	0+33.7			4.19	1112.32	

Table B-2. Cross-sectional data for Indian Run.

Cross-section at	STATION	BS [+]	HI	FS [-]	ELEV. [FEET]	REMARKS
0+15	BM1	9.19	1109.19		1100	BM1
	0+00			4.29	1104.9	Starting from Rt
	0+03			6.63	1102.56	
	0+05			7.85	1101.34	
	0+07			9.29	1099.9	BKF
	0+08			9.51	1099.68	Edge of water Rt
	0+12			9.96	1099.23	
	0+18			9.63	1099.56	
	0+22			9.51	1099.68	Edge of water Lt
	0+25			9.29	1099.9	BKF
	0+27			8.64	1100.55	
	0+29			8.1	1101.09	
	0+30			8.03	1101.16	
600+25	BM4	7.66	1102.86		1095.2	BM4
	0+00			4.59	1098.27	
	0+04			4.81	1098.05	
	0+07			5.51	1097.35	
	0+08			6.25	1096.61	
	0+09			7.14	1095.72	
	0+10			7.46	1095.4	
	0+11			7.81	1095.05	BKF
	0+12			8.34	1094.52	Edge of water Rt
	0+15			8.71	1094.15	
	0+18			8.8	1094.06	
	0+21			8.47	1094.39	
	0+24			8.34	1094.52	Edge of water Lt
	0+25			7.81	1095.05	BKF
	0+27			7.4	1095.46	
	0+30			7.13	1095.73	`
6+80	BM 4	6.69	1101.89		1095.2	BM4
	0+00			4.66	1097.23	
	0+04			5	1096.89	
	0+05			5.57	1096.32	
	0+07			6.16	1095.73	
	0+10			6.41	1095.48	

Cross-section at	STATION	BS [+]	HI	FS [-]	ELEV. [FEET]	REMARKS
6+80						
	0+15			6.71	1095.18	
	0+17			7.24	1094.65	BKF
	0+17.5			8.06	1093.83	Edge of water Rt
	0+21			8.35	1093.54	
	0+26.9			8.1	1093.79	Top of wooden log str
	0+27			8.06	1093.83	Edge of water Lt
	0+29			7.24	1094.65	BKF
	0+31			7.22	1094.67	
	0+33			6.54	1095.35	
	0+35			6.06	1095.83	
	0+37			5.33	1096.56	
	0+41			3.72	1098.17	
7+75	New stn	5.94	1101.89		1095.95	New stn
	0+00			1.39	1100.5	
	0+03			2.31	1099.58	
	0+05			3.4	1098.49	
	0+08			4.41	1097.48	
	0+12			4.88	1097.01	
	0+16			5.1	1096.79	
	0+19			5.36	1096.53	BKF
	0+21			5.97	1095.92	
	0+23			6.01	1095.88	Edge of water Rt
	0+26			6.15	1095.74	Above log structure
	0+32			6.01	1095.88	Edge of water
	0+32.5			5.36	1096.53	BKF
	0+33			4.77	1097.12	
	0+34			3.38	1098.51	
	0+37			1.31	1100.58	

APPENDIX C

Table C-1. Cross-sectional area calculation at 1+00 (Austintown UNT).

Station (ft)	Bottom LevelElev (ft)	BKF (ft)	Depth (ft)	H Distance (ft)	Area (ft)	Total Area (ft^2)
0	1112.47					
5	1111.36					
10	1109.55					
15	1108.5	1108.5	0	0	0	5.9575
18	1107.96		0.54	3	0.81	
19	1107.89		0.61	1	0.575	
20	1107.86		0.64	1	0.625	
22	1107.75		0.75	2	1.39	
24.5	1107.87		0.63	2.5	1.725	
25	1107.96		0.54	0.5	0.2925	
27	1108.5	1108.5	0	2	0.54	
28	1108.77					
30	1109.09					
31	1109.69					
35	1111.08					
40	1112.83					
43.25	1113.34					

Calculation of key morphological parameters

Bank full area (ft^2)	Bank full width (ft)	Mean bKF depth (ft)	Width Depth ratio	Width of flood prone area (ft)	Entrenchment Ratio	Maximum depth (ft)
5.96	12	0.49	24.17	18.23	1.52	0.75

Table C-2. Cross-sectional area calculation at 1+50 (Austintown UNT).

Station (ft)	Bottom Level Elev (ft)	BKF (ft)	Depth (ft)	H Distance (ft)	Area (ft)	Total Area (ft^2)
0	1110.73					
3	1109.7					
5	1108.87					
6	1108.38					
10	1108.07					
11	1107.92	1107.92	0	0	0	6.0145
12	1107.18		0.74	1	0.37	
15	1107.08		0.84	3	2.37	
17	1107.07		0.85	2	1.69	
17.5	1107.18		0.74	0.5	0.3975	
18	1107.28		0.64	0.5	0.345	
19	1107.34		0.58	1	0.61	
19.8	1107.92	1107.92	0	0.8	0.232	
20	1108.06					
22	1108.39					
25	1108.9					
27.5	1109.77					
30	1110.69					
32	1111.63					
35	1112.25					
36.8	1112.37					

Calculation of key morphological parameters

Bank full area (ft^2)	Bank full width (ft)	Mean bKF depth (ft)	Width Depth ratio	Width of flood prone area (ft)	Entrenchment Ratio	Maximum depth (ft)
6.01	8.8	0.68	12.87	18.8	2.14	0.85

Table C-3. Cross-sectional area calculation at 2+00 (Austintown UNT).

Station (ft)	Bottom Level Elev (ft)	BKF (ft)	Depth (ft)	H Distance (ft)	Area (ft)	Total Area (ft^2)
0	1111.07					
2.5	1110.2					
5	1109.49					
7	1108.74					
8	1108.45					
9	1107.46					
9.2	1107.29	1107.29	0	0	0	4.2715
10	1107.07		0.22	0.8	0.088	
10.5	1106.92		0.37	0.5	0.1475	
12	1106.68		0.61	1.5	0.735	
14	1106.59		0.7	2	1.31	
15	1106.61		0.68	1	0.69	
17	1106.92		0.37	2	1.05	
18	1107.18		0.11	1	0.24	
18.2	1107.29	1107.29	0	0.2	0.011	
18.5	1107.56					
20	1107.7					
22	1108.23					
25	1109.18					
26	1109.5					
27	1110.22					
30	1111.17					
32	1111.98					
33.7	1112.32					

Calculation of key morphological parameters

Bank full area (ft^2)	Bank full width (ft)	Mean bKF depth (ft)	Width Depth ratio	Width of flood prone area (ft)	Entrench ment Ratio	Maximum depth (ft)
4.27	9	0.47	18.96	12.61	1.40	0.7

APPENDIX D

Table D-1. Cross-sectional area calculation at 0+15 (Indian Run).

Station (ft)	Bottom LevelElev (ft)	BKF (ft)	Depth (ft)	H Distance (ft)	Area (ft)	Total Area (ft^2)
0	1104.9					
3	1102.56					
5	1101.34					
7	1099.9	1099.9	0	0	0	6.37
8	1099.68		0.22	1	0.11	
12	1099.23		0.67	4	1.78	
18	1099.56		0.34	6	3.03	
22	1099.68		0.22	4	1.12	
25	1099.9	1099.9	0	3	0.33	
27	1100.55					
29	1101.09					
30	1101.16					

Calculation of key morphological parameters

Bank full area (ft^2)	Bank full width (ft)	Mean bKF depth (ft)	Width Depth ratio	Width of flood prone area (ft)	Entrenc hment Ratio	Maximum depth (ft)
6.37	18	0.35	50.86	21.66	1.20	0.67

Table D-2. Cross-sectional area calculation at 6+25 (Indian Run).

Station (ft)	Bottom Level Elev (ft)	BKF (ft)	Depth (ft)	H Distance (ft)	Area (ft)	Total Area (ft^2)
0	1098.27					
4	1098.05					
7	1097.35					
8	1096.61					
9	1095.72					
10	1095.4					
11	1095.05					
12	1094.52	1094.52	0	0	0	2.88
15	1094.15		0.37	3	0.555	
18	1094.06		0.46	3	1.245	
21	1094.39		0.13	3	0.885	
24	1094.52	1094.52	0	3	0.195	
25	1095.05					
27	1095.46					
30	1095.73					

Calculation of key morphological parameters

Bank full area (ft^2)	Bank full width (ft)	Mean bKF depth (ft)	Width Depth ratio	Width of flood prone area (ft)	Entrenchment Ratio	Maximum depth (ft)
2.88	12	0.24	50	24.2	2.02	0.46

Table D-3. Cross-sectional area calculation at 6+80 (Indian Run).

Station (ft)	Bottom LevelElev (ft)	BKF (ft)	Depth (ft)	H Distance (ft)	Area (ft)	Total Area (ft^2)
0	1097.23					
4	1096.89					
5	1096.32					
7	1095.73					
10	1095.48					
12	1095.1					
15	1095.18					
17	1094.65	1094.65	0	0	0	10.298
17.5	1093.83		0.82	0.5	0.205	
21	1093.54		1.11	3.5	3.3775	
26.9	1093.79		0.86	5.9	5.8115	
27	1093.83		0.82	0.1	0.084	
29	1094.65	1094.65	0	2	0.82	
31	1094.67					
33	1095.35					
35	1095.83					
37	1096.56					
41	1098.17					

Calculation of key morphological parameters

Bank full area (ft^2)	Bank full width (ft)	Mean bKF depth (ft)	Width Depth ratio	Width of flood prone area (ft)	Entrench ment Ratio	Maximum depth (ft)
10.298	12	0.858167	13.983298	27.5	2.291667	1.11

Table D-4. Cross-sectional area calculation at 7+75 (Indian Run).

Station (ft)	Bottom LevelElev (ft)	BKF (ft)	Depth (ft)	H Distance (ft)	Area (ft)	Total Area (ft^2)
0	1100.5					
3	1099.58					
5	1098.49					
8	1097.48					
12	1097.01					
16	1096.79					
19	1096.53	1096.53	0	0	0	8.5125
21	1095.92		0.61	2	0.61	
23	1095.88		0.65	2	1.26	
26	1095.74		0.79	3	2.16	
32	1095.88		0.65	6	4.32	
32.5	1096.53	1096.53	0	0.5	0.1625	
33	1097.12					
34	1098.51					
37	1100.58					

Calculation of key morphological parameters

Bank full area (ft^2)	Bank full width (ft)	Mean bKF depth (ft)	Width Depth ratio	Width of flood prone area (ft)	Entrenc hment Ratio	Maximum depth (ft)
8.51	13.5	0.63	21.41	23.86	1.77	0.79