A ROSGEN LEVEL III ANALYSIS OF TWO STREAM RESTORATION PROJECTS NEAR YOUNGSTOWN, OHIO

by

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ABSTRACT

In this study, the effectiveness of stream restoration projects in reducing stream bank erosion and improving stability was evaluated. Two previously restored streams were studied - an unnamed tributary (UNT) to Meander Creek within Austintown Township Park, Mahoning County, Ohio; and an unnamed tributary (known locally as Indian Run) to Pine Hollow Run (a tributary to the Shenango River), in Hermitage, Pennsylvania. The Rosgen Stream Classification method was applied for the assessment purpose. Field surveys were done during summer 2008 and 2009. Level II analyses and calculations for several morphological parameters were performed by Mr. Santosh Pant as part of a related project. The Rosgen classification showed both of the restored reaches to be "B4c" type streams (Pant 2010).

Assessment of the stream condition and departure from its potential following restoration was performed by quantifying the existing physical character of the stream channel using Rosgen's Level III assessment. By visual observations at both sites, most of the categories in the channel stability (Pfankuch) evaluation table were found to be in good condition. The Pfankuch stability rating procedure gave total scores of 75 for the Austintown Park site and 82 for the Indian Run site. Evaluating these scores with stream type in the conversion table, the channel stability condition for both sites is classified as Fair. Comparing past photographs to present field conditions, restoration definitely reduced bank slope, minimized bank cutting, reduced deposition of bars and stabilized channel bed material at both sites. However, constraints resulting from manmade features (such as bridges, roads, and culverts) prevent the streams from reaching their full potential.

DEDICATION

I dedicate this thesis to my parents, Sobha Poudel and Rajendra Kumar Poudyal. Without their patience, understanding, support and most of all love, the completion of this work would not have been possible.

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I would like to express the deepest appreciation to my advisor and the committee chair Dr. Scott C. Martin. I wish to thank him for his immense time and effort, patience, and good humor. His encouragement, guidance and support from the initial to the final level enabled me to develop an understanding of the subject. Without his guidance and persistent help this dissertation would not have been possible.

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CHAPTER 1

INTRODUCTION

A river is a natural watercourse flowing toward another water body. A river is part of the hydrologic cycle. Water within a river is generally collected from precipitation through surface runoff, groundwater recharge, springs, and also from melting of ice and snowpack. A river is given different names including stream, creek, brook, rivulet, and rill.

In general the longitudinal, lateral and vertical movements of water, materials, energy, and organism influence the character of the stream corridor. These types of movements help in forming the physical structure of the stream corridor. Beside these three dimensions, Ward (1998) has introduced the fourth dimension – time – that also has a significant influence on the stream corridor character (Figure 1.1). Since stream corridors change constantly and are not stable within a time frame, the time dimension is also a very important factor for stream corridors (FISRWG 1998).

The two main natural functions of a river are to transport water and sediment load. Natural rivers are self-constructed and self-maintained. Although these river channels change constantly, they are stable and transport water and sediment in a consistent manner (Rosgen 1996). This is called dynamic equilibrium.

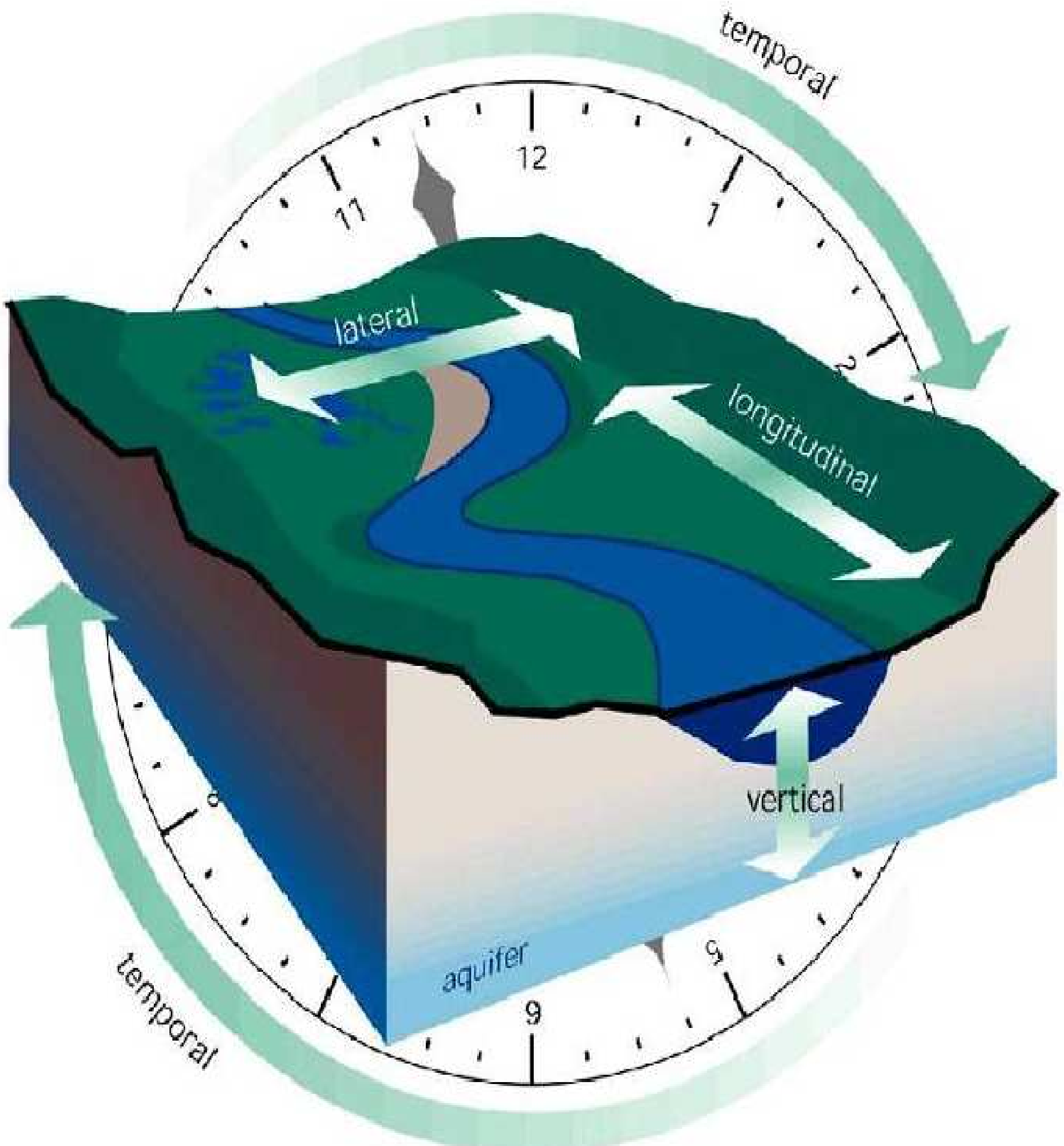

Figure 1.1 Four-dimensional framework for stream corridors (FISRWG 1998).

Vegetation plays an important role in the smooth functioning of a stream corridor. A densely vegetated riparian zone adjacent to the stream not only provides shade that reduces water temperature, but also helps in filtering of sediments and other contaminants. It helps in stabilizing stream banks and also provides wildlife habitat.

Recreational opportunities, visually attractive green belts, and maintenance of aquatic food webs are other important functions of riparian buffer strips. Vegetation in the watershed also contributes to a healthy and stable stream by promoting infiltration of rainfall, minimizing surface runoff, and preventing soil erosion (FISRWG 1998).

Rivers play an important role in the development of human civilization as they have a great influence on social, economic and political development. Rivers have been used as a source of water for several purposes, such as obtaining food, transportation, tourism, aesthetics, recreation, irrigation, as a defensive measure, as a source of hydropower to drive machinery, bathing, and as a means of disposing of waste. Although natural rivers constantly seek their own stability with time and conditions, when human action is contrary to the natural tendencies of the river, the river cannot stay stable. It is, therefore, very important to understand the geomorphic and hydro-morphological characteristic of a river (Rosgen 1996).

Disturbances that affect stream corridors can be natural or human-induced. Severe disturbances can alter the structure and functions of a stream corridor, which may finally disturb the dynamic equilibrium of the stream. Changes in land use in a watershed due to urban development may cause flooding downstream. Removing vegetation and soil, grading the land surface, and constructing drainage networks increase runoff to streams from rainfall and snowmelt. As a result, the peak discharge, volume, and frequency of floods increase in nearby streams (Konrad 2005). According to Rosgen (1996), “a stable stream should be able to transport its sediment load, both in size and type, associated with local deposition and scour”. If the scouring process leads to degradation or excessive sediment deposition (i.e., aggradation), it results in channel instability.

The construction of dams and reservoirs is also an important stressor of rivers. It not only affects the natural flow, but also reduces sediment transport, and reduces the migration of the natural fish stock, leading to fragmented fish distribution. Channelization to facilitate construction, agriculture, or timber movement is another example of anthropogenic impact. Channelization can eliminate a river's connection to its flood plain, reducing sediment deposition and the retention of nutrients, and increasing flooding downstream (Sondergaard and Jeppesen 2007).

Healthy river systems provide vital services to humans and other organisms. In today's world, there is growing consensus about the importance of river restoration to reverse human impacts. According to Palmer and Bernhardt (2005), "River and stream restoration has become a worldwide phenomenon as well as a booming enterprise. Billions of dollars are being spent on stream and river restoration in the USA alone." There are increasingly numerous river and stream restoration projects. But a general problem is that they are rarely subjected to systematic postproject evaluation. Such evaluation is very important to learn lessons from successes and failures of stream restoration projects, and to advance the field of stream restoration. Evaluation techniques should be chosen based upon the project goals. In general, post project monitoring should be continued for at least a decade (Kondolf and Micheli 1995).

This research focused on the assessment of stream condition and departure from its potential following restoration by quantifying the existing physical character of the stream channel. In this research, the Rosgen Stream Classification method was applied.

The objectives of this research were to:

- delineate stream type for two restored streams by calculating geomorphologic characteristics like bankfull stage, entrenchment, width/depth ratio, sinuosity, channel materials, and slope;
- evaluate stability of the restored streams using the Level III analysis proposed by Rosgen (1996); and
- evaluate the success of the stream restoration projects in meeting the goals of the designer.

CHAPTER 2

LITERATURE REVIEW

2.1 Rosgen Stream Analysis System

The Rosgen stream classification system "is based on extensive field observations and quantitative investigations of hundreds of stream systems. The system has been consistently revised to enhance its ability to discriminate between stream types and to improve its predictive capabilities" (Rosgen 1996). The Rosgen system is designed to:

- Organize and integrate information at several levels for convenient analysis.
- Assist in the assessment of cumulative watershed impacts on stream condition.
- Provide a framework to interpret data on sediment and bank erosion, and make stability predictions.
- Provide a mechanism to integrate companion inventories such as fish habitat and riparian vegetation.

Rosgen's classification involves a four level hierarchy. The first level begins with a geomorphic characterization. This is followed by a morphological description which is its second level. The third level, described in detail later in this chapter, involves an assessment of the stream's condition and departure from its potential or best channel condition. The fourth level involves evaluation of the stream's condition, potential and stability through field data. Each level rests on the information derived from the previous level. The first two levels rely heavily on the conditions during bankfull discharge (Rosgen 1996).

As shown in Figure 2.1, the hierarchy in Rosgen's stream classification system is comprised of four assessment levels that vary from a broad geomorphic characterization down to very detailed description and assessment (Rosgen 1996).

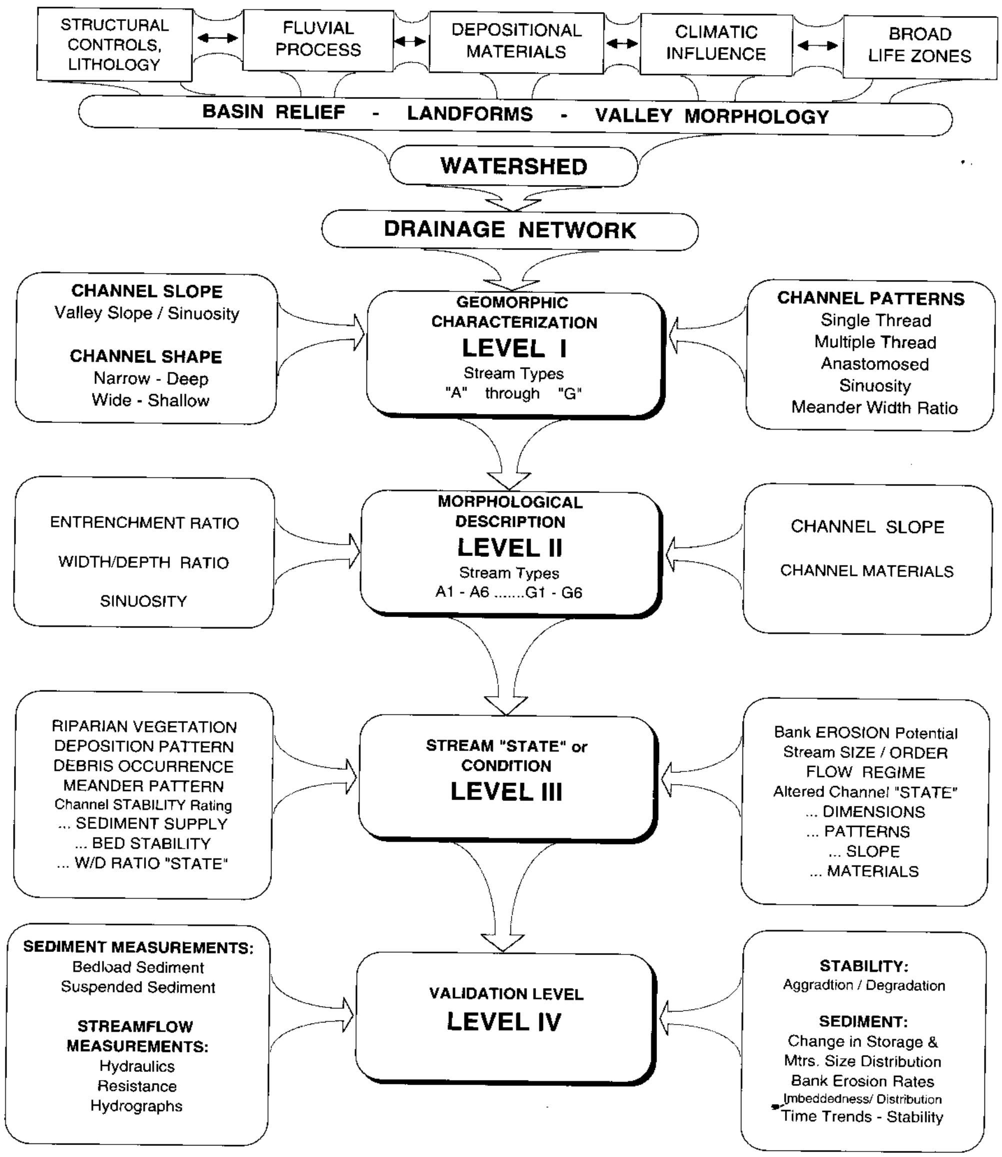

Figure 2.1 The hierarchy of river inventory and assessment (Rosgen 1996).

2.1.1 Stream Classification

The Rosgen stream classification system is one of the most commonly used comprehensive stream classification systems. It is based on common patterns of channel morphological characteristics. Seven parameters are required to classify streams in the first two levels of the Rosgen stream classification analysis. First is the type of stream channel – single or multiple (braided) channels. Next are the stream's entrenchment ratio, width/depth ratio, sinuosity, and slope. Last is the dominant material that lines the stream channel. The field measurements used to calculate the second through fifth parameters are taken at the stream's bankfull stage.

Rosgen uses the bankfull discharge to represent the channel-forming flow. Water in a river can flow in the main channel or the flood plain. Under normal conditions, water flows within its channel and is called channelized flow. The volume of flow when the channel is filled to its maximum determines much of the channel's geometry (i.e., channel depth and width, meander amplitude and wavelength, channel sinuosity and slope). This maximum channelized flow, expressed as volume per unit time, is called bankfull discharge. The maximum elevation of the channelized water surface, just before water flows onto the flood plain, is called the bankfull stage (Rosgen 1996). Once the bankfull elevation has been estimated, all of the required parameters can be determined by straightforward measurements.

Bankfull discharge is a key to stream classification. It is the stream flow at which channel maintenance is most effective – the flow generally doing the work that result in the average morphological characteristics of channels. Bankfull discharge has also been defined as the discharge that fills a stable alluvial channel to the elevation of the active floodplain. The field determination of bankfull stage is basically detective work (Harrelson 1994). From bankfull, stream channel cross-sections, profile, and plan geometry can be characterized, and this information can then be used to determine stream type (Keystone Stream Team 2003). Bankfull stage is the basis for measuring the cross-sectional area, width/depth ratio and entrenchment ratio. Therefore, it is important to correctly identify bankfull stage when classifying streams and designing stream restoration measures (NSCD 2007).

2.1.2 Parameters Used in Stream Type Classifications

Some of the important parameters used in Rosgen's stream type classifications are shown in Figure 2.2 and defined below:

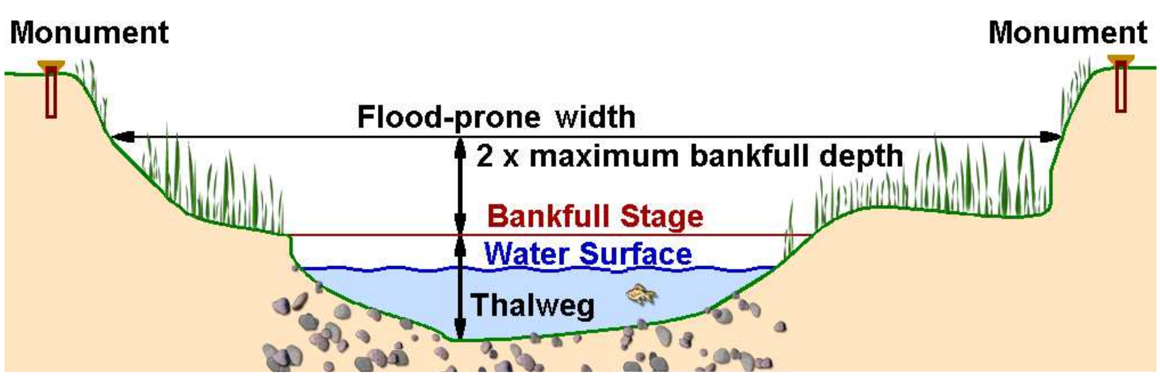

Figure 2.2 General stream cross-section (Michigan's Stream Team 2009).

1) Channel Cross–Section: A river controls its energy through adjustment of its channel cross-section. Along the entire length of a river, the shape and size of the cross-sections are in constant variation, adapting to the discharge and sediment load that is delivered to it. A distinctive channel pattern is produced by this dynamic equilibrium within the overall river system. (Mount 1995)

2) **Thalweg:** In hydrologic terms, the line of maximum depth in a stream. The thalweg is usually the part that has the maximum velocity and causes cutbanks and channel migration.

3) **Cross-Sectional Area, Bankfull Width and Depth:** Bankfull Width (W_{bkf}) is the width of the water surface at bankfull stage. Bankfull cross–sectional area (A_{bkf}) is determined from a cross-sectional survey of the stream. Average bankfull depth is calculated from

$$d_{bkf} = A_{bkf} / W_{bkf} \tag{2.1}$$

Maximum bankfull depth (d_{mbkf}) is the water depth under bankfull conditions at the deepest point along the stream cross-section (i.e., the thalweg).

These calculations require identification of the elevation where the channel, under bankfull conditions, ends and the floodplain begins. In general, the indicators used to assess this elevation are: the top of the point bar (the elevation where channel deposits end), a change in vegetation (especially the lower limit of perennial species), slope change in channel cross-section, top of the undercut slope (the elevation where channel erosion ends), change in particle size (where soils end and sediments begin), drift lines and water marks (Rosgen 1996).

4) **Width/Depth Ratio:** The ratio of surface width to average depth for the bankfull channel.

$$\text{Width/Depth Ratio} = W_{bkf}/d_{bkf} \tag{2.2}$$

5) Sinuosity: Sinuosity (k) is a term indicating the amount of curvature in the channel (see Figure 2.3). It is the ratio of stream centerline length (LS) to valley centerline length (LV) or, alternatively, valley slope (VS) to stream slope (S). If the channel length/valley length ratio is more than about 1.3, the stream can be considered meandering in form (FISRWG 1998).

$$k = LS/LV = VS/S \tag{2.3}$$

6) Bed material particle size: This is the median bed surface particle size, determined in the field by a pebble-count procedure (Wolman 1954). This assesses the size of material over which the water flows. The bed material is classified as bedrock, boulders, cobbles, gravel, sand, or mud (i.e., silt & clay).

7) Stream slope: This refers to the steepness of the stream surface along its flow path. Slope (S) is calculated by dividing the vertical change in water surface elevation by the length of the stream as it passes through at least two meanders or along a distance equal to 20-30 bankfull channel widths (Rosgen 1996). The stream slope is determined from a longitudinal profile survey of the stream. The water surface slopes of individual bed features and average bankfull slope can also be determined using longitudinal profile data.

8) Flood-prone width: Determined by doubling the maximum depth in the bankfull channel and measuring the width of the valley at that elevation, W_{fpa} (see Figure 2.2). If the flood-prone width is greater than 2.2 times the bankfull width, the stream is considered to be slightly entrenched or confined and the stream has ready access to its floodplain. A stream is classified as entrenched if its flood-prone width is less than 1.4 times the bankfull width.

9) Entrenchment Ratio: The entrenchment ratio used in the Rosgen classification system is the flood-prone width of the valley divided by the bankfull width of the channel:

$$ER = W_{fpa}/W_{bkf} \qquad (2.4)$$

Entrenchment ratio describes the vertical containment of the stream and the degree to which it is incised in the valley floor. It is, therefore, a measure of how accessible a flood plain is to the stream (Rosgen 1996).

2.1.3 Level III Analysis

The physical characteristics of streams that are defined by Rosgen's level II criteria, such as longitudinal profile, cross-section, and planform features, are influenced by a number of biological, ecological, hydrologic, and human factors. Level III analysis incorporates of all these factors for the assessment of existing stream condition (Rosgen 1996). Stream condition relates to the stream potential, stream stability and function. Rosgen's Level III analysis further describes existing conditions that influence the response of channels to imposed change and provide specific information for prediction methodologies (such as stream bank erosion calculations, etc.). Common inputs into this characterization may be riparian vegetation, deposition pattern, debris occurrence, meander pattern, confinement features, fish habitat indices, channel stability rating, sediment supply, bed stability, width to depth ratio, bank erosion potential, stream size and order, flow regime, and altered dimensions, patterns, profiles and materials. Hence, Level III analysis requires extensive field visits, measurements and analyses of valley, river, and riparian features. The objectives of Level III analyses are to (Rosgen 1996):

- Provide a quantitative basis for comparing streams that have similar morphologies, but are in different states or condition.
- Determine the departure of a stream's existing condition from the reference baseline of a stable natural stream.
- Document and evaluate additional field parameters that influence stream condition, including flow regime, stream size, sediment supply, channel stability, bank erodibility, and direct channel disturbances.
- Provide a framework for integrating related studies (e.g., fish habitat indices; composition and density of riparian vegetation).
- Develop and/or refine channel stability predictions.
- Provide the basis for efficient Level IV validation sampling and data analysis.

The integration of related inventories with the additional variables that influence stream state is shown in Figure 2.3.

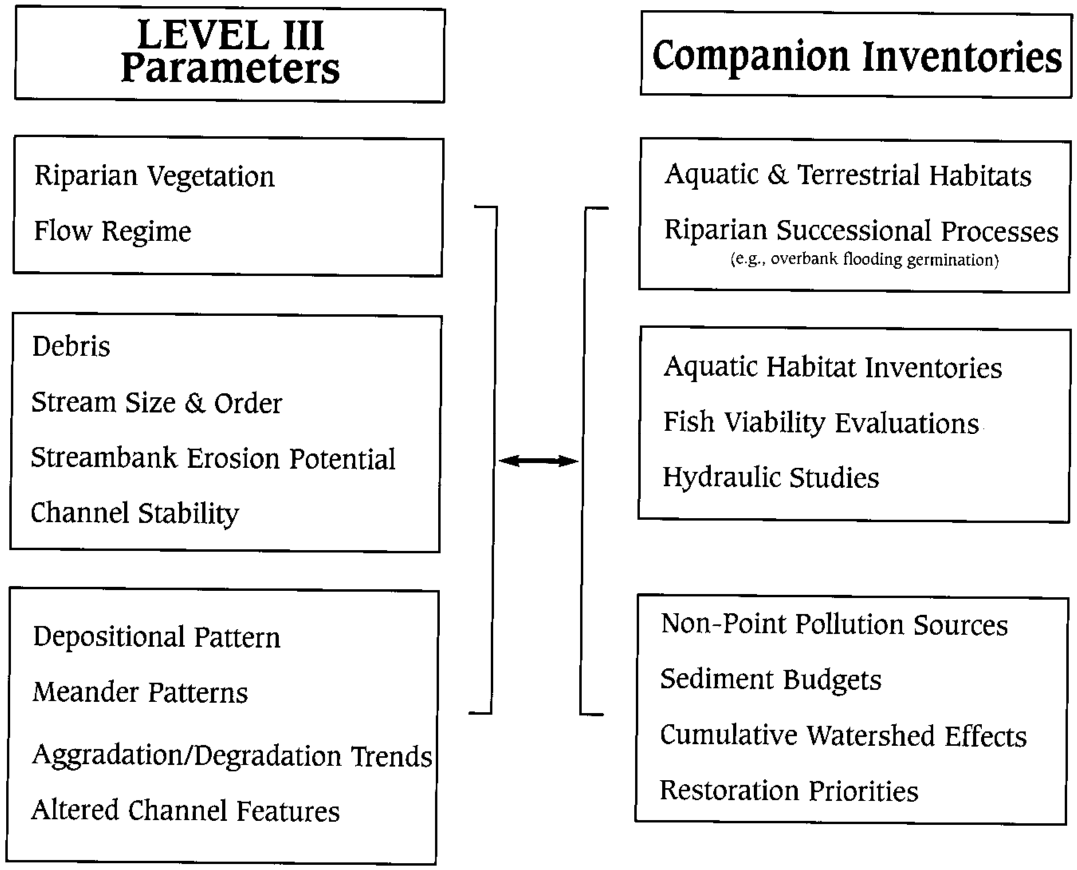

Figure 2.3: Primary relationships between Level III parameters and companion inventories (Rosgen 1996).

2.2 Development of Restoration Plans

A key ingredient in developing a restoration plan is to first have a full understanding of the restoration objectives. The objectives may have various aspects, including flood control, streambank stabilization, fisheries, aesthetics, sediment reduction, and recreational boating and safety issues. Once objectives are understood and agreed to, the summary from the assessment is used to develop the initial alternatives (Rosgen 1996).

The specification of goals for restoration projects is frequently described as the most important component of a project, because it sets expectations, drives the detailed plans for actions, and determines the kind and extent of post-project monitoring. Restoration can be oriented around particular species, can address community composition, or may be focused on whole ecosystems or landscapes. Goals may also be stated in terms of ecosystem services. The recent attempt to place a dollar value on such services has emphasized the interest in using services as a basis for goal–setting (Ehrenfeld 2000).

2.2.1 Stream Condition and Stream Departure Analysis

A stable channel will distribute flow and sediment to maintain its pattern, profile and dimension. Channel stability is influenced by channel and watershed factors of hydrologic, biological, ecological and human nature. When a channel maintains its own stability and has a good ecologic condition, it is considered to be operating at its full potential. While Level III analysis attempts to compare a channel's existing condition with its full potential, this section focuses mainly on issues of stability. Streams functioning at full potential have stability characteristics that can be described quantitatively in terms of channel size and shape, including low erodibility factors, low lateral migration rates and comparatively low rates of sediment supply. The departure of an existing stream condition from its full operating potential can be determined in several ways (Rosgen 1996):

a) Existing stream conditions can be compared to a geomorphologic data base for similar type streams in a stable natural condition (called "reference reaches") to see if one or more key stability or condition criteria are outside the desired range of characteristic values.

b) The same stream reach can be compared at different points in time through examination of historical photos. This may also help to identify the factors that caused the change in river condition.

c) Finally, departures from potential or desired condition can be determined by comparing river condition at locations upstream and downstream from the reach of interest.

2.2.2 Restoration Methods

Stream restoration, or rehabilitation, is the return of a degraded stream ecosystem to a condition close to its remaining natural potential. A stream corridor is a complex and valuable ecosystem which includes the land, plants, animals, and network of streams within it (FISRWG 1998). Designing the reconstructed channel alignment involves selecting a channel right of way that produces appropriate bed slope and meander geometry (Shields 2003).

Structures are often placed in rivers in an attempt to correct some of the adverse effects of channel adjustment due to instability. Various instream devices or structures can be used to restore natural stream characteristics, including: deflectors – used on alternate banks to produce a meandering thalweg or to stabilize a meandering stream; small weirs or sills – used to reestablish pool-riffle sequences; boulder placement and fish shelters; and methods for replacement of natural bed sediments. These structures can be designed and installed to: establish grade control; reduce streambank erosion; facilitate sediment transport; provide for irrigation diversion structures; enhance fish habitat; maintain width/depth ratio; improve recreational boating; maintain river stability;

dissipate excess energy; withstand large floods; maintain channel capacity; be compatible with natural channel design; and be visually acceptable to the public. Instream structures reduce erosion risk by shifting high velocity gradients away from the stream banks. Properly placed in-stream structures are generally less expensive than more traditional stability methods, such as rip-rap (Rosgen 2006), and can assist in maintaining stable dimensions, pattern and profile (Rosgen 1996). Some of the most common structures are cross vanes (Figures 2.4 to 2.6), J-hooks (Figure 2.7), and root wads (Figure 2.8).

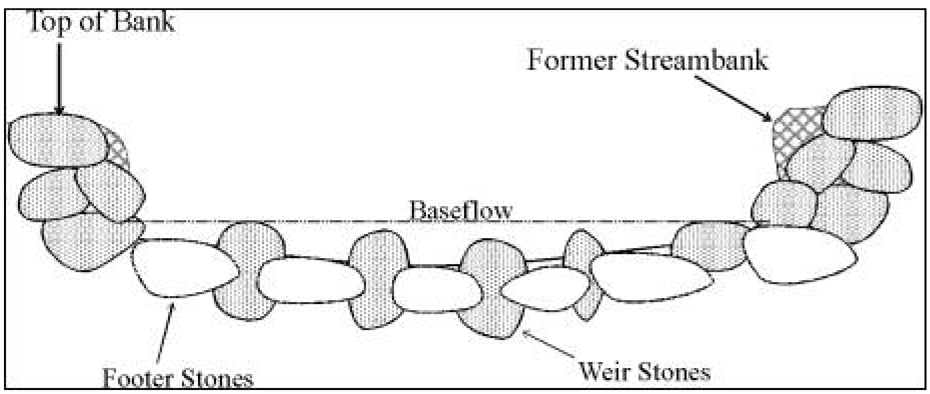

Figure 2.4 Section view of rock vortex weir (SMRC, 2010).

Figure 2.5 Cross vane (Steady Stream Hydrology, Inc.).

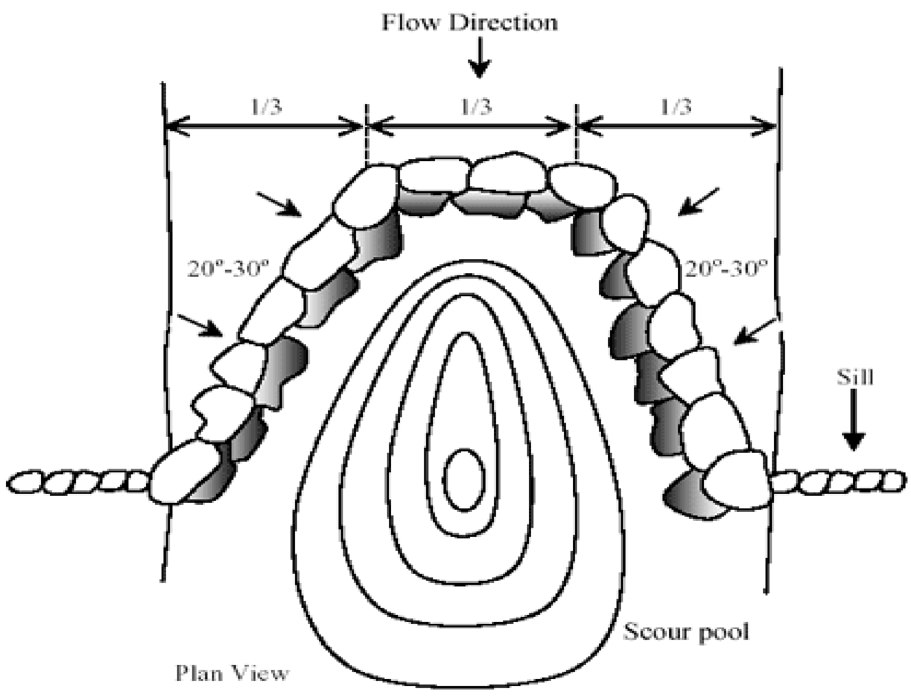

Figure 2.6 Cross vane structure (Rosgen 2001).

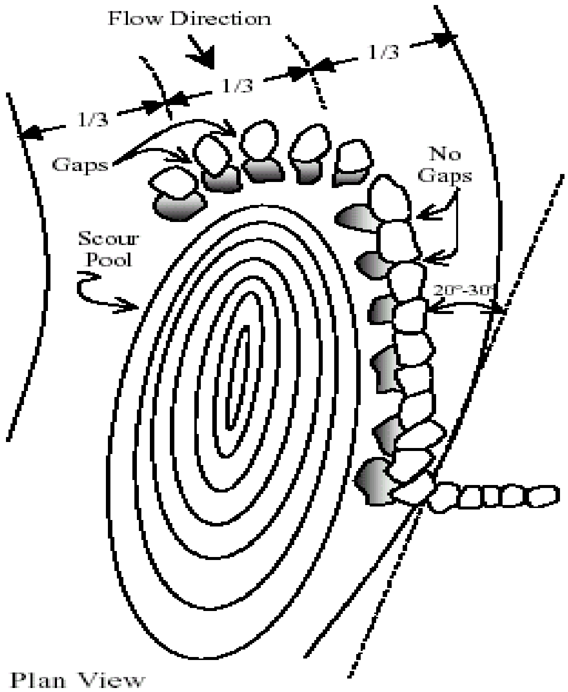

Figure 2.7 J hook structure (Rosgen 2001).

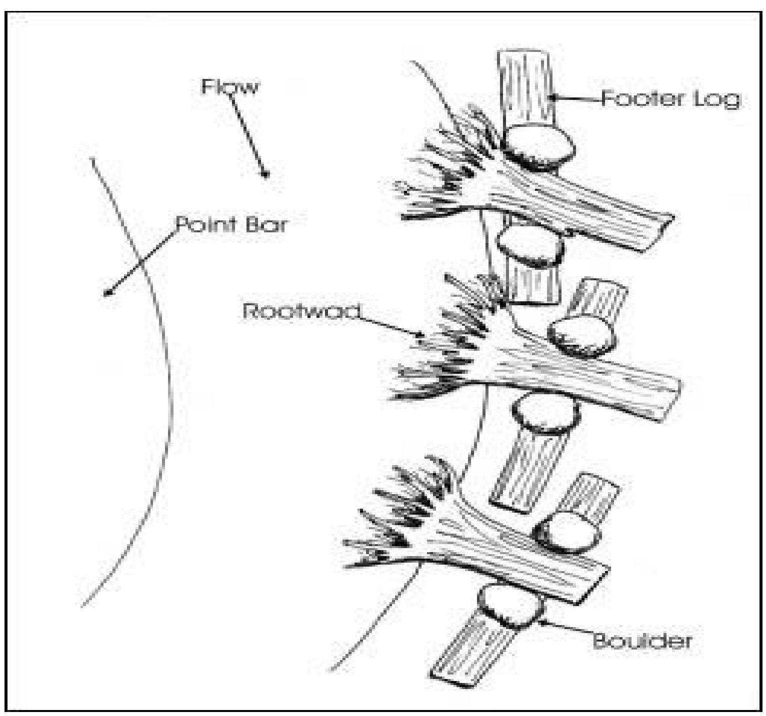

Figure 2.8 Root wads (SMRC, 2010).

2.3 Level III Field Parameters: The Stream Channel Influence Variables

The Level III field inventory uses ten additional parameters to describe stream condition. They are: 1) riparian vegetation, 2) stream flow regime, 3) stream size and stream order, 4) organic debris and/or channel blockage, 5) depositional patterns, 6) meander patterns, 7) streambank erosion potential, 8) aggradation/degradation potential, 9) channel stability rating, and 10) altered channel materials and dimensions. These listed parameters are not included in the Level II stream typing process because this would result in an unworkable number of stream types. Keys developed by Rosgen (1996) to aid in interpreting and classifying the Level III parameters are shown in Tables 2.1 through 2.8. Many of these keys just provide a format for documenting qualitative stream characteristics that are related to stability. The Pfankuch Channel Stability Evaluation form shown in Table 2.7 provides a quantitative system for ranking channel stability.

Table 2.1 Riparian vegetation inventory/condition survey (Rosgen 1996).

RIPARIAN VEGETATION

Existing Vegetation:

Composition: ______________________________

Vigor, Density: ______________________________

Potential: ______________________________

Summary Categories (Identify individually and/or in combination)

1. Bare		RV 1
2. Forbs only -	Low density	2a
	Moderate density	2b
3. Annual grass with forbs -	Low density	3a
	Mod. density	3b
	High density	3c
4. Perennial grass -	Low density	4a
	Mod. density	4b
	High density	4c
5. Rhizomatous grasses (bluegrass, grasslike plants, sedges, rushes)	Low density	5a
	Mod. density	5b
	High density	5c
6. Low brush -	Low density	6a
	Mod. density	6b
	High density	6c
7. High brush -	Low density	7a
	Mod. density	7b
	High density	7c
8. Combination grass/brush -	Low density	8a
	Mod. density	8b
	High density	8c
9. Deciduous overstory -	Low density	9a
	Mod. density	9b
	High density	9c

10. Deciduous with brush/ grass understory	Low density	10a
	Mod. density	10b
	High density	10c
11. Perennial overstory -	Low density	11a
	Mod. density	11b
	High density	11c
12. Wetland vegetation community	Low density	12a
	Mod. density	12b
	High density	12c

Table 2.2 Categories of flow regime for specification in Level III inventories (Rosgen 1996).

FLOW REGIME

General Category

E. Ephemeral stream channels – flows only in response to precipitation. Often used in conjunction with intermittent.

S. Subterranean stream channel – flows parallel to and near the surface for various seasons – a subsurface flow which follows the same stream bed.

I. Intermittent stream channel – one which flows only seasonally, or sporadically. Surface sources involve springs, snow melt, artificial controls, etc. Often this term is associated with flows that reappear along various locations of a reach, then run subterranean.

P. Perennial stream channels. Surface water persists year long.

Specific Category

1. Seasonal variation in streamflow dominated primarily by snowmelt runoff.
2. Seasonal variation in streamflow dominated primarily by stormflow runoff.
3. Uniform stage and associated streamflow due to spring fed condition, backwater, etc.
4. Streamflow regulated by glacial melt.
5. Ice flows, ice torrents from ice dam breaches.
6. Alternating flow/backwater due to tidal influence.
7. Regulated streamflow due to diversions, dam release, dewatering, etc.
8. Altered due to development, such as urban streams, Cut-over waterseds, vegetation conversions (forested to grassland) that changes flow response to precipitation events.

Table 2.3 Categories of stream size as indicated by bankfull surface width and stream order (Rosgen 1996).

STREAM SIZE

S-1	Bankfull width less than .305 m (1 foot)
S-2	Bank full width .3-1.5 m (1-5 feet)
S-3	Bankfull width 1.5-4.6 m (5-15 feet)
S-4	Bankfull width 4.6-9 m (15-30 feet)
S-5	Bankfull width 9-15 m (30-50 feet)
S-6	Bankfull width 15-22.8 m (50-75 feet)
S-7	Bankfull width 22.8-30.5 m (75-100 feet)
S-8	Bankfull width 30.5-46 m (100-150 feet)
S-9	Bankfull width 46-76 m (150-250 feet)
S-10	Bankfull width 76-107 m (250-350 feet)
S-11	Bankfull width 107-150 m (350-500 feet)
S-12	Bankfull width 150-305 m (500-1000 feet)
S-13	Bankfull width greater than 305 m (1000 feet)

STREAM ORDER

Add categories in parenthesis for specific stream order of reach. For example a third order stream with a bankfull width of 6.1 meters (20 feet) would be indexed as: S-4(3).

Table 2.4 Categories of depositional features (bars) in a channel reach (Rosgen 1996).

DEPOSITIONAL FEATURES (BARS)	
B-1	Point Bars
B-2	Point Bars with Few Mid Channel Bars
B-3	Many Mid Channel Bars
B-4	Side Bars
B-5	Diagonal Bars
B-6	Main Branching with Many Mid Bars and Islands
B-7	Mixed Side Bars and Mid Channel Bars Exceeding 2-3X width
B-8	Delta Bars

Table 2.5 Categories representing various meander patterns of alluvial rivers (Rosgen 1996).

MEANDER PATTERNS	
M-1	Regular Meander
M-2	Tortuous Meander
M-3	Irregular Meander
M-4	Truncated Meanders
M-5	Unconfined Meander Scrolls
M-6	Confined Meander Scrolls
M-7	Distorted Meander Loops
M-8	Irregular with Oxbows, Oxbow Cutoffs

Table 2.6 Debris and channel blockages categorized by size and extent (Rosgen 1996).

STREAM CHANNEL DEBRIS/BLOCKAGES		
DESCRIPTION/EXTENT		Materials, which upon placement into the active channel or floodprone area may cause an adjustment in channel dimensions or conditions, due to influences on the existing flow regime.
D1	NONE	Minor amounts of small, floatable material.
D2	INFREQUENT	Debris consists of small, easily moved, floatable material; i.e. leaves; needles, small limbs, twigs, etc.
D3	MODERATE	Increasing frequency of small to medium sized material, such s large limbs, branches and small logs that when accumulated effect 10% or less of the active channel cross-sectional area.
D4	NUMEROUS	Significant build-up of medium to large sized materials, i.e. large limbs, branches, small logs or portions of trees that may occupy 10 to 30% of the active channel cross-section area.
D5	EXTENSIVE	Debris "dams" of predominantly larger materials, i.e. branches, logs, trees, etc., occupying 30 to 50% of the active channel cross-section; often extending across the width of the active channel.
D6	DOMINATING	Large, somewhat continuous debris "dams," extensive in nature and occupying over 50% of the active channel cross-section. Such accumulations may divert water into the floodprone areas and form fish migration barriers, even when flows are at less than bankfull.
D7	BEAVER DAMS - FEW	An infrequent number of dams spaced such that normal streamflow and expected channel conditions exist in the reaches between dams.
D8	BEAVER DAMS - FREQUENT	Frequency of dams is such that backwater conditions exist for channel reaches between structures; where streamflow velocities are reduced and channel dimensions or conditions are influenced.
D9	BEAVER DAMS - ABANDONED	Numerous abandoned dams, many of which have filled with sediment and/or breached, initiating a series of channel adjustments such as bank erosion, lateral migration, evulsion, aggradation and degradation.
D10	HUMAN INFLUENCES	Structures, facilities, or materials related to land uses or development located within the floodprone area, such as diversions or low-head dams, controlled by-pass channels, velocity control structures, and various transportation encroachments that have an influence on the existing flow regime, such that significant channel adjustments occur.

Table 2.7 Channel stability evaluation (Pfankuch, 1975) with a conversion of the channel stability rating to a reach condition by stream type (Rosgen 1996).

CHANNEL STABILITY (PFANKUCH) EVALUATION AND STREAM CLASSIFICATION SUMMARY (LEVEL III)

Reach Location__________ Date__________ Observers__________

Stream Type __________

	Category	EXCELLENT	
UPPER BANKS	1 Landform Slope	Bank Slope Gradient <30%	2
	2 Mass Wasting	No evidence of past or future mass wasting.	3
	3 Debris Jam Potential	Essentially absent from immediate channel area.	2
	4 Vegetative Bank Protection	90%+ plant density. Vigor and variety suggest a deep dense soil binding root mass.	3
LOWER BANKS	5 Channel Capacity	Ample for present plus some increases. Peak flows contained. W/D ratio <7.	1
	6 Bank Rock Content	65%+ with large angular boulders. 12"+ common.	2
	7 Obstructions to Flow	Rocks and logs firmly imbedded. Flow pattern without cutting or deposition. Stable bed.	2
	8 Cutting	Little or none. Infreq. raw banks less than 6".	4
	9 Deposition	Little or no enlargement of channel or pt. bars.	4
BOTTOM	10 Rock Angularity	Sharp edges and corners. Plane surfaces rough.	1
	11 Brightness	Surfaces dull, dark or stained. Gen. not bright.	1
	12 Consolidation of Particles	Assorted sizes tightly packed or overlapping.	2
	13 Bottom Size Distribution	No size change evident. Stable mater. 80-100%	4
	14 Scouring and Deposition	<5% of bottom affected by scour or deposition.	6
	15 Aquatic Vegetation	Abundant Growth moss-like, dark green perennial. In swift water too.	1
		TOTAL	

	Category	GOOD	
UPPER BANKS	1 Landform Slope	Bank Slope Gradient 30-40%	4
	2 Mass Wasting	Infrequent. Mostly healed over. Low future potential.	6
	3 Debris Jam Potential	Present, but mostly small twigs and limbs.	4
	4 Vegetative Bank Protection	70-90% density. Fewer species or less vigor suggest less dense or deep root mass.	6
LOWER BANKS	5 Channel Capacity	Adequate. Bank overflows rare. W/D ratio 8-15	2
	6 Bank Rock Content	40-65%. Mostly small boulders to cobbles 6-12"	4
	7 Obstructions to Flow	Some present causing erosive cross currents and minor pool. filling. Obstructions newer and less firm.	4
	8 Cutting	Some, intermittently at outcurves and constrictions. Raw banks may be up to 12"	6
	9 Deposition	Some new bar increase, mostly from coarse gravel.	8
BOTTOM	10 Rock Angularity	Rounded corners and edges, surfaces smooth, flat.	2
	11 Brightness	Mostly dull, but may have <35% bright surfaces.	2
	12 Consolidation of Particles	Moderately packed with some overlapping.	4
	13 Bottom Size Distribution	Distribution shift light. Stable material 50-80%.	8
	14 Scouring and Deposition	5-30% affected. Scour at constrictions and where grades steepen. Some deposition in pools.	12
	15 Aquatic Vegetation	Common. Algae forms in low velocity and pool areas. Moss here too.	2
		TOTAL	

	Category	FAIR	
UPPER BANKS	1 Landform Slope	Bank slope gradient 40-60%	6
	2 Mass Wasting	Frequent or large, causing sediment nearly year long.	9
	3 Debris Jam Potential	Moderate to heavy amounts, mostly larger sizes.	6
	4 Vegetative Bank Protection	<50-70% density. Lower vigor and fewer species from a shallow, discontinuous root mass.	9
LOWER BANKS	5 Channel Capacity	Barely contains present peaks. Occasional overbank floods. W/D ratio 15 to 25.	3
	6 Bank Rock Content	20-40% with most in the 3-6" diameter class.	6
	7 Obstructions to Flow	Moder. frequent, unstable obstructions move with high flows causing bank cutting and pool filling.	6
	8 Cutting	Significant. Cuts 12-24" high. Root mat overhangs and sloughing evident	12
	9 Deposition	Moder. deposition of new gravel and course sand on old and some new bars.	12
BOTTOM	10 Rock Angularity	Corners and edges well rounded in two dimensions.	3
	11 Brightness	Mixture dull and bright, ie 35-65% mixture range.	3
	12 Consolidation of Particles	Mostly loose assortment with no apparent overlap.	6
	13 Bottom Size Distribution	Moder. change in sizes. Stable materials 20-50%	12
	14 Scouring and Deposition	30-50% affected. Deposits & scour at obstructions, constrictions, and bends. Some filling of pools.	18
	15 Aquatic Vegetation	Present but spotty, mostly in backwater. Seasonal algae growth makes rocks slick.	3
		TOTAL	

Table 2.8 Channel stability evaluation (Pfankuch, 1975; Rosgen 1996).

CHANNEL STABILITY (PFANKUCH) EVALUATION AND STREAM CLASSIFICATION SUMMARY (LEVEL III)

	Category	POOR	
UPPER BANKS	1 Landform Slope	Bank Slope Gradient 60%+	8
	2 Mass Wasting	Frequent or large causing sediment nearly year long or imminent danger of same.	12
	3 Debris Jam Potential	Moder. to heavy amounts, predom. larger sizes.	8
	4 Vegetative Bank Protection	<50% density, fewer species and less vigor indicate poor, discontinuous and shallow root mass.	12
LOWER BANKS	5 Channel Capacity	Inadequate. Overbank flows common. W/D ratio >25	4
	6 Bank Rock Content	<20% rock fragments of gravel sizes, 1-3" or less.	8
	7 Obstructions to Flow	Sediment traps full, channel migration occurring.	
	8 Cutting	Almost continuous cuts, some over 24" high. Failure of overhangs frequent.	16
	9 Deposition	Extensive deposits of predom. fine particles. Accelerated bar development.	16
BOTTOM	10 Rock Angularity	Well rounded in all dimensions, surfaces smooth.	4
	11 Brightness	Predom. bright, 65%+ exposed or scoured surfaces.	4
	12 Consolidation of Particles	No packing evident. Loose assortment easily moved.	8
	13 Bottom Size Distribution	Marked distribution change. Stable materials 0-20%.	16
	14 Scouring and Deposition	More than 50% of the bottom in a state of flux or change nearly year long.	24
	15 Aquatic Vegetation	Perennial types scarce or absent. Yellow-green, short term bloom may be present.	4
		TOTAL	

Stream Width ______ x avg. depth ______ x mean velocity ______ = Q ______ cfs

Gauge Ht ______ Reach Gradient ______ Stream Order ______ Sinuosity Ratio ______

Width $_{bkf}$ ______ Depth $_{bkf}$ ______ W/D Ratio ______ Discharge (Q_{bkf}) ______

Drainage Area ______ Valley Gradient ______ Stream Length ______ Valley Length ______

Sinuosity ______ Entrenchment Ratio ______ Length Meander (Lm) ______ Belt Width ______

Sediment Supply	Stream Bed Stability	Width/Depth Ratio Condition	
Extreme ______	Aggrading ______	Normal ______	Stream Type
Very High ______	Degrading ______	High ______	
High ______	Stable ______	Very High ______	
Moderate ______			Pfankuch Rating
Low ______	TOTAL SCORE for Reach	E ____ = G ____ + F ____ + P ____ =	
Remarks ______		from table	Reach Condition

CONVERSION OF STABILITY RATING TO REACH CONDITION BY STREAM TYPE*

Stream Type	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4	B5	B6
GOOD	38-43	38-43	54-90	60-95	60-95	50-80	38-45	38-45	40-60	40-64	48-68	40-60
FAIR	44-47	44-47	91-129	96-132	96-142	81-110	46-58	46-58	61-78	65-84	69-88	61-78
POOR	48+	48+	130+	133+	143+	111+	59+	59+	79+	85+	89+	79+
Stream Type	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**D3**	**D4**	**D5**	**D6**		
GOOD	38-50	38-50	60-85	70-90	70-90	60-85	85-107	85-107	85-107	67-98		
FAIR	51-61	51-61	86-105	91-110	91-110	86-105	108-132	108-132	108-132	99-125		
POOR	62+	62+	106+	111+	111+	106+	133+	133+	133+	126+		
Stream Type	**DA3**	**DA4**	**DA5**	**DA6**	**E3**	**E4**	**E5**	**E6**				
GOOD	40-63	40-63	40-63	40-63	40-63	50-75	50-75	40-63				
FAIR	64-86	64-86	64-86	64-86	64-86	76-96	76-96	64-86				
POOR	87+	87+	87+	87+	87+	97+	97+	87+				
Stream Type	**F1**	**F2**	**F3**	**F4**	**F5**	**F6**	**G1**	**G2**	**G3**	**G4**	**G5**	**G6**
GOOD	60-85	60-85	85-110	85-110	90-115	80-95	40-60	40-60	85-107	85-107	90-112	85-107
FAIR	86-105	86-105	111-125	111-125	116-130	96-110	61-78	61-78	108-120	108-120	113-125	108-120
POOR	106+	106+	126+	126+	131+	111+	79+	79+	121+	121+	126+	121+

**Generalized relations ... need additional Level IV data to expand data base for validation.*

Table 2.9 Field summary form for Level III inventory for stream classification (Rosgen 1996).

SUMMARY OF "CONDITION" CATEGORIES FOR LEVEL III INVENTORY

Stream Name ____________________
Location ____________________
Riparian Vegetation ____________________
Stream Size, Stream order ____________________
Meander pattern ____________________
Channel stability rating (Pfankuch) __________

Sediment supply (check appropriate category):
- Extreme __________
- Very high __________
- High __________
- Moderate __________
- Low __________

Streambed (vertical) stability
- Aggrading __________
- Degrading __________
- Stable __________

Width/depth ratio condition:
- Normal (stable) __________
- High __________
- Very high __________

Streambank erosion Potential:

Bank erodibility:	Near-bank stress:
Extreme ______	Extreme ______
High ______	High ______
Moderate ______	Moderate ______
Low ______	Low ______

Observers ____________________
Stream Type __________ Date __________
Flow regime ____________________
Depositional pattern ____________________
Debris/channel blockages ____________________
Altered Channel State: ____________________

Dimension/shape:
- Width __________
- Depth __________
- Width/depth ratio __________

Patterns: (*show as funct. of W_{bkf}):
- Meander length* __________
- Radius of curve* __________
- Belt width* __________
- Sinuosity __________

Profile:
- Water surface slope __________
- Valley slope __________
- Bed features:
- Riffle/pool ______
- Step/pool ______
- Conver./divrg. ______
- Plane bed ______
- Other ______
- Spacing* ______
- Describe alterations: ____________________

General Remarks

____
____
____
____
____
____
____
____

Attach photographs taken mid-stream looking up and downstream. Make site map.

Attach vicinity map of reach and/or aerial photo for specific location.

Note any permanent cross-sections for level IV verification of cross-section stability, actual erosion rates, change in pebble counts, deposition studies, sediment sampling, etc.

Attach copy of: stream classification field form, channel stability rating form, bank erosion rating form, profiles, cross-sections, pebble counts, etc.

2.4 Background on Study Locations

Two different stream reaches were evaluated by the Rosgen (1996) Stream Classification System to achieve the objectives of this research. The study sites were:

1. Austintown Park Site – An unnamed tributary (UNT) to Meander Creek within Austintown Township Park, Mahoning County, Ohio; and
2. Indian Run Site – Officially, an unnamed tributary (UNT) to Pine Hollow Run (a tributary to the Shenango River), in Hermitage, Pennsylvania. The stream is known locally as Indian Run.

Both streams were restored by Wallace and Pancher, Inc., of Hermitage, PA. The primary intent of both stream restoration projects was stabilization of the stream channel to prevent further bank erosion (Wallace, personal communication, 2010). The best way to obtain a sound design is to quantitatively evaluate the principal morphological features of a stream type and valley type nearby that is natural or stable (the reference reach) and restore the natural combination of dimension and form such as slope, width, meander etc. to the impaired channel (Keystone Stream Team 2003).

2.4.1 Austintown Park

The Austintown Township Parks retained Wallace and Pancher, Inc. (WPI), to prepare documents meeting the requirements for a Nationwide Permit #27, for "Aquatic Habitat Restoration, Establishment, and Enhancement Activities", from the United States Army Corps of Engineers, as well as to perform the design and construction work. The project area is located along Kirk Road at the entrance to the Austintown Township Park (Figure 2.9).

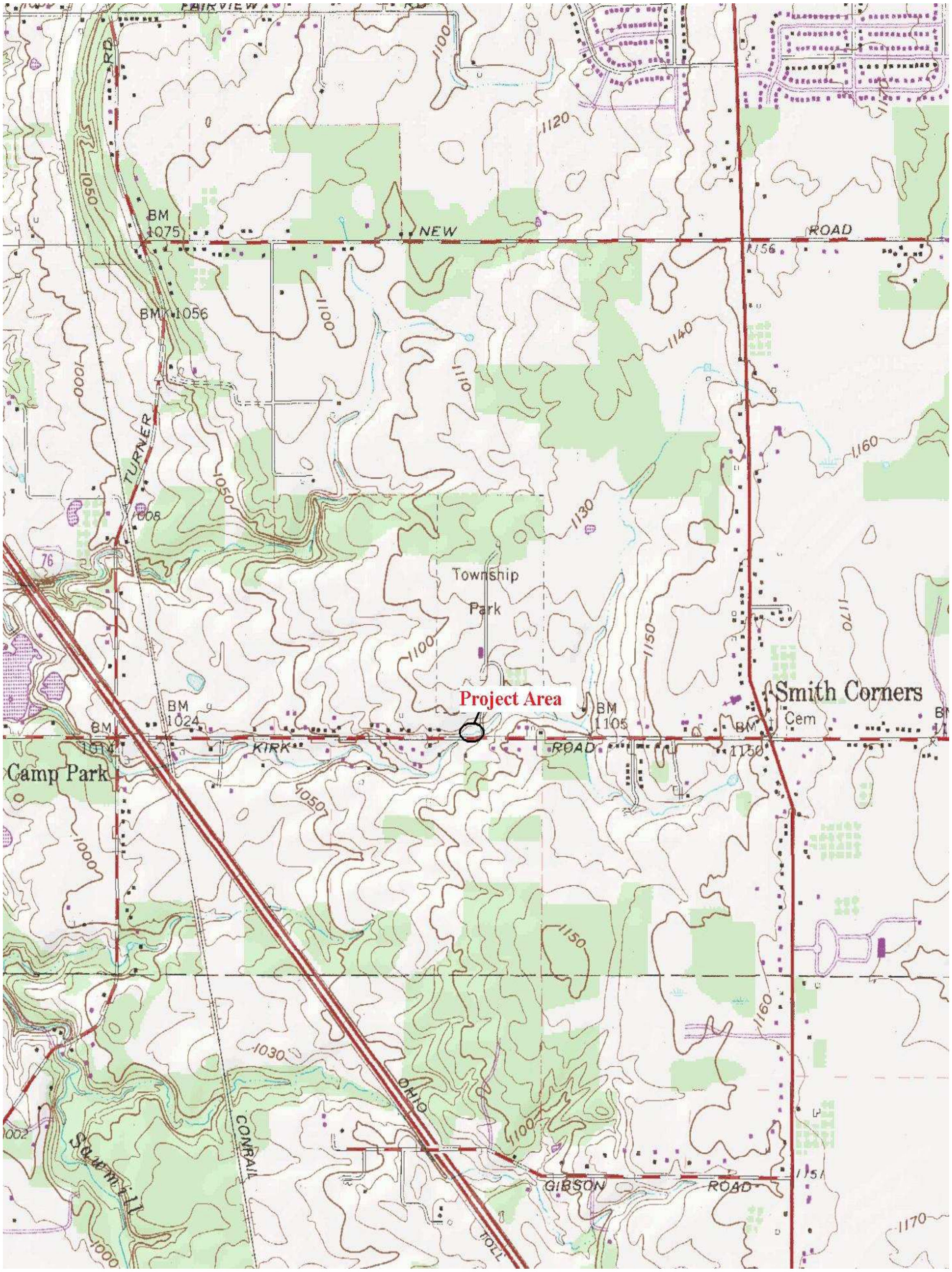

Figure 2.9 Austintown Park project location (USGS, 2010).

The stream, an unnamed tributary (UNT) to Meander Creek, flows east-to-west across the project site, running roughly parallel to Kirk Road. The project site slopes gradually downhill to the west. The stream turns to the southwest and crosses under Kirk Road through two 48” corrugated metal pipe culverts anchored by a concrete headwall. The entrance road to the park crosses the stream via a precast concrete bridge structure. The stream enhancement was completed on 230 linear ft of stream between the entrance road bridge and the headwall for the culvert under Kirk Road. The bridge served as the upstream limit of the project area and the culvert head wall served as the downstream limit of the project area. Prior to restoration, stream banks near the park entrance road bridge were eroding badly and deposition of sediment in the channel caused an increase in stream width and decrease in stream depth (see Figure 2.10 and 2.11).

Figure 2.10 Bank erosion and collapse on the north bank of the Austintown Park stream (WPI 2007).

Figure 2.11 Sliding and eroding bank on the north bank of the Austintown Park stream (WPI 2007).

The stream enhancement consisted of the following activities: (1) removal of foreign materials (e.g. large concrete pieces); (2) stream bank excavation to create appropriate bankfull width for the stream and appropriate floodplain area; (3) installation of cross vane structures, (4) moderate re-alignment of the stream channel at its junction with the culvert, (5) planting of appropriate riparian seed mixes and shrubs, and (6) placement of armoring where necessary to reduce erosion and scouring. Excavation was done along the entire length of the project site on both banks of stream. The north bank of the stream was excavated to create a wider pooling area at the inlet of the culverts in order to increase the angle at which the stream approaches and enters the culvert. Stone armoring was placed at both the eastern and western ends of the headwall to further prevent erosion and scouring and subsequent structural damage to the culvert and headwall. Five (5) stone cross vane structures were placed throughout the length of the enhancement area. The riparian zones of the stream were stabilized through the planting of shrubs and a selected seed mix. The floodplain seed mix was applied within the newly created floodplain areas. Construction of the project was performed in September, 2007. Construction photos are shown in Figures 2.12, 2.13 and 2.14.

Figure 2.12 Widening of stream channel for Austintown Park restoration project (WPI 2008).

Figure 2.13 Finished cross vane structure for Austintown Park project (WPI 2008).

Figure 2.14 Planting riparian vegetation for Austintown Park project (WPI 2008).

2.4.2 Indian Run

The Hermitage School District obtained funds to advance the Pine Hollow Run Tributary Stream Restoration Project to Phase 2 of the project, which was construction. Phase 1 of the project was funded by the Growing Greener Program, formally known as the Hermitage School District Environmental Education Center, and included: 1) data collection; 2) data analysis; 3) stream restoration design; and 4) various educational materials. The project was supported by the Hermitage School Board, City of Hermitage Planning and Development Office, Hermitage School Parent Teacher Organization, Shenango River Watchers (local watershed group), and the Boy/Girl Scout Troops (WPI 2003). The project site is located behind (west of) Artman Elementary School (Figure 2.15).

WPI was the general contractor for this project. According to the project designer (WPI), their assessment of the stream determined that the geomorphic processes that define a stream were out of balance in this reach. Because the stream was trying to regain its meander pattern, most of the right bank (looking downstream) was severely eroded (WPI 2003), as shown in Figures 2.16 and 2.17. The stream banks were approximately 4 ft to 7 ft in height and vertically eroded with little vegetation at the top of the banks. WPI estimated the average bank erosion rate of 0.5 to 1.0 feet per year along the 1,900 ft long section. The sediment loading rate into the stream from the right bank only was estimated to be 6,000 ft^3 per year (WPI 2003).

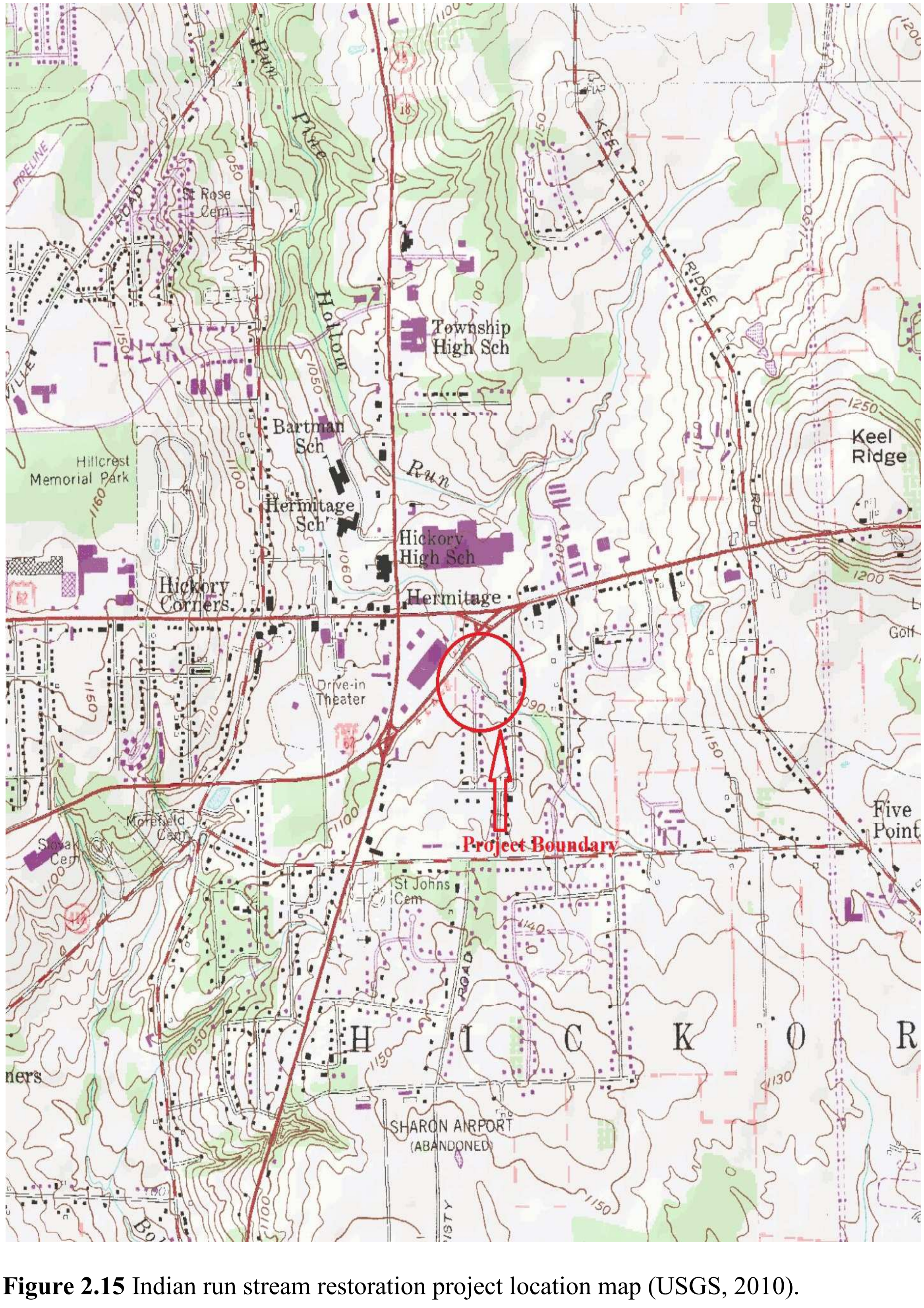

Figure 2.15 Indian run stream restoration project location map (USGS, 2010).

Figure 2.16 Bank erosion on the right side of Indian Run, looking upstream (WPI 2003).

Figure 2.17 Bank erosion on the right side of Indian Run, looking downstream (WPI 2003).

The intent of the restoration plan was to provide a stable stream and riparian corridor that is self-maintaining. The specific goal and scope of the project, according to WPI, was to restore the degraded stream channel using natural channel design techniques and reduce or eliminate the non-point source pollution entering Pine Hollow Run. The definition of a stable stream, as they explained, is the following:

"A channel that is able to develop and maintain a stable dimension, pattern and profile such that, over time, channel features are maintained and the stream system neither aggrades nor degrades." (Rosgen 1996)

The restoration work included the stabilization of 1900 linear ft of degraded stream channel using natural channel design techniques, establishment of 0.23 miles of riparian buffer, installation of 20 aquatic habitat structures. This project also provided an educational outreach program that reached 2300 students and faculty, and involved one watershed group. Construction of the project was performed from May to July, 2004. Photos of the construction are shown in Figures 2.18 to 2.20.

Figure 2.18 Widening of Indian Run stream channel (WPI 2004).

Figure 2.19 Finished log cross vane structure in Indian Run (WPI 2004).

Figure 2.20 Planting riparian vegetation along Indian Run (WPI 2004).

CHAPTER 3

METHODS AND PROCEDURES

3.1 Field Survey Procedures

3.1.1 Reconnaissance Survey

As the first step of the survey, the field team (Rajesh Poudel, Santosh Pant, and Dr. Scott Martin) walked along the bank of each selected restored stream to identify the exact location of the project and restoration features such as cross vanes, vegetation, etc. We drew a rough sketch of each stream through the study reach. The longitudinal distance of the study reach was identified in the reconnaissance survey using a 300-foot tape. The measuring tape was run along the thalweg with the beginning (zero mark) of the tape at the upstream end. We made notes about the different types of vegetation used during the restoration process. We also looked for consistent bankfull stage indicators and representative cross-section locations for stream classification. We selected cross-sections throughout the entire study reach to represent the range in morphological characteristics of the stream.

Next, we walked the selected reach and marked probable indicators of bankfull stage (using chaining pins) along both banks. We identified bankfull stage using indicators like break in slope on bank, floodplains, highest active depositional feature, slope breaks or change in particle size distribution, evidence of an inundation feature such as small benches, exposed root hairs below an intact soil layer indicating exposure to erosive flow, changes in vegetation, scour lines or stain markings on abutments or rocks, small benches on streambanks, or tops of point bars or mid-channel bars for entrenched streams; if not entrenched, bankfull is near or at the top of the bank. During the process, we visualized the water surface at bankfull stage and noted channel features such as bars, boulders, and root wads that may affect water surface elevation or direct current.

3.1.2 Longitudinal Profile

A longitudinal profile survey was performed to determine the length of stream section and slopes of the stream bed and bankfull water surface. The following procedure was followed in the field:

1) A 300-foot tape was laid along the centerline of the channel to obtain stream length stationing.
2) A Lietz surveyor's level was set up on a tripod with a clear line of sight to a benchmark and leveled. It was placed at an elevation higher than the highest feature required for the survey.
3) The benchmark was backsighted – a fiberglass surveyor's rod was placed on the benchmark and a rod reading (BS) obtained. The height of the instrument (HI) was determined from the equation:

   $$\text{HI} = \text{BM elevation} + \text{BS rod reading} \quad (3.1)$$

4) The rod was placed at the thalweg at station 0 + 00 on the tape. The rod reading was obtained and recorded in the foresight (FS) column of the field notebook. Rod readings were also taken at the water surface, bankfull and lowest bank elevations perpendicular to the tape at station 0 + 00, and recorded in the field notebook.

5) Step 4 was repeated for many additional stations, continuing downstream. Measurements were taken at the start, mid-point and end of major bed features such as riffles, pools, and cross-vanes. Notes about these features were recorded in the field notebook.
6) At cross-section intersection locations, the distance (station) was noted on the tape.

   Elevations were calculated by the equation:

   $$\text{Elevation} = HI - FS \qquad (3.2)$$

3.1.3 Cross-Section

The cross-section data provides a majority of the morphological parameters required for stream classification, including bankfull cross-sectional area, bankfull width, mean bankfull depth, maximum bankfull depth, width/depth ratio and entrenchment ratio. Cross-section surveys were performed in riffle sections of the streams by the following procedure:

1) The Lietz level was set up in a location where the entire cross-section could be viewed. The instrument was placed at an elevation higher than the highest feature required for the survey.
2) The tape was stretched across the channel making sure it was perpendicular to the direction of flow.
3) A benchmark was backsighted (BS) and the rod reading recorded. The height of instrument (HI) was determined by equation 3.1.

4) Foresight (FS) rod readings were obtained at major breaks in bed elevation and key features, such as left bankfull (LBF), left edge of water surface (LEW), thalweg (THL), right edge of water surface (REW) and right bankfull (RBF).
5) The distance on the tape (station), the corresponding rod reading and feature were noted in the cross-section data forms. The elevation of each point was calculated by equation 3.2.

3.1.4 Pebble Count

Pebble count characterizes the channel and bed material present through a given study reach. The representative pebble count procedure is a stratified, systematic sample method to proportionally sample all the bed features present within the bankfull channel through a designated reach and is used to determine the stream type (Rosgen 2008).

Each stream reach was divided into two categories - pools and riffles. The total distance of the reach was divided into total pool length and total riffle length. To stratify the sample, a minimum of 100 observations were collected proportionally based on bed features. Particles were collected randomly across the entire bankfull channel along the reach. The intermediate axis (B in Figure 3.1) of each particle was measured with a ruler in the field and was recorded in millimeters.

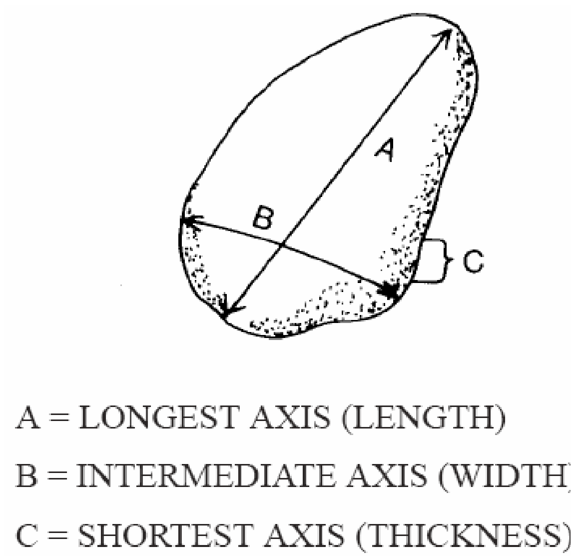

Figure 3.1 Comparison of the three axes of a particle (West Virginia Department of Environmental Protection, 2009).

3.2 Calculations

Calculations of Level II parameters were performed by Santosh Pant (2010) as part of a related project. The longitudinal survey data were entered in a Microsoft Excel spreadsheet and the longitudinal profile was plotted. A trendline was drawn through the water surface data points from top of riffle to top of riffle. A best-fit line was also drawn through the bankfull data points. Average water surface slope and bankfull slope were determined by equation 3.3. The average water surface slope and the bankfull slope should be similar to each other.

$$\text{Slope, } S = \text{Elevation drop} / \text{Stream length} \tag{3.3}$$

The cross-section was also plotted in an Excel spreadsheet. The bankfull cross-sectional area, bankfull width, mean bankfull depth, width/depth ratio, maximum bankfull depth, width of flood-prone area, and entrenchment ratio were calculated by the equations presented in Chapter 2. Pant (2010) also estimated bankfull discharge using Manning's equation and a worksheet provided by Rosgen (2006).

The pebble count data were transferred to a form developed by Rosgen and Silvey (2007), and then to an Excel spreadsheet. The upper limit of each particle size class and the corresponding cumulative percent finer than values were plotted on the X-axis and Y-axis, respectively. The D_{50}, and D_{84} values were determined.

3.3 Assessments of Level III Parameters

1) **Riparian Vegetation:** A general descriptive riparian evaluation (Table 2.1) was used to document riparian condition. Field visits during summer 2008 to summer 2010, observation of past photographs and aerial photograph were used to identify current patterns and historical trends in riparian communities. The alpha-numeric descriptor for riparian vegetation is added following the stream type designation.

2) **Flow Regime:** Table 2.2 lists the categories of streamflow recommended for documenting a Level III condition. Streamflow categories include General Category with alphabetic symbols and Specific Category with numeric symbols. Assessment of stream flow was done by field visits, including dry summer conditions from summer 2008 to summer 2010, review of USGS topographic maps, and past photographs.

3) **Size and Stream Order:** Both stream size and stream order were used to further describe the state of a given stream type. Bankfull width is primarily used to describe stream size, since it is the most directly observable stream dimension and many hydrologic and geomorphic interpretations can be derived from width measurements (Rosgen 1996). Table 2.3 lists thirteen channel bankfull width categories. Stream order

simply is a numbering sequence which starts when two first order channels join - they form a second order stream, and so on.

4) **Depositional Patterns (Sediment):** Depositional patterns can be easily observed in the field. These features are helpful for interpreting stream condition. Field observations were done to assess depositional patterns. Aerial photographs can also be used to assess depositional features. Table 2.4 lists the categories of depositional features (bars) in a channel reach.

5) **Meander Patterns (Channel):** Categories of meander patterns are listed in Table 2.5. Meander patterns of the channel reaches were determined by observing aerial photographs, past photographs and, field visits.

6) **Debris and Channel Blockages:** These are the materials, which upon placement into the active channel or flood prone area may cause an adjustment in channel dimensions or conditions, due to influences on the existing flow regime (Rosgen 1996). As shown in Table 2.6, debris is categorized by relative size and extent along a reach. Stream channel debris/blockages were determined by field observation and study of past photographs available.

7) **Stream Channel Stability:** The Pfankuch (1975) channel stability rating system was used to rate channel stability. All fifteen categories: Landform Slope, Mass Wasting, Debris Jam Potential, Vegetative Bank Protection, Channel Capacity, Bank Rock Content, Obstructions to Flow, Cutting, Deposition, Rock Angularity, Brightness, Consolidation of Particles, Bottom Size Distribution, Scouring and Deposition and, Aquatic Vegetation for all upper banks, lower banks and, bottom were observed in the field and given rating values according to their condition. The good, fair, and poor rating

values obtained with the Pfankuch method have been adjusted by stream type, as shown additionally in Table 2.8. The stream type conversion with the rating values from the original channel stability rating system reflects the naturally inherent and differing value ranges for each stream type. The values shown are simply an index to channel stability. To determine actual stability, the data collection methods outlined in the Level IV analysis process would be implemented.

8) Summary of Level III Assessments of Stream Condition: A summary form for documenting Level III assessments of stream condition is shown in Table 2.9. The form summarizes the important conclusions regarding stream condition, including: stream type, stream size and order, flow regime, riparian vegetation, meander pattern, modified channel stability rating, depositional pattern, debris or other blockages, sediment supply, vertical stability, streambank erosion potential, near-bank stress, width/depth ratios, meander lengths, radius of curvature, belt width, sinuosity, water surface slope, valley slope, and bedform features.

The above parameter list helps to quantitatively assess existing and potential stream condition, and to evaluate the significance of instability thresholds. The summary form was completed by compiling information from the previous Level II and III analyses.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Summary of Level II Assessment

As part of a related project, calculations were performed by Santosh Pant (2010). A summary of morphological characteristics and Level II classification of both of the streams is presented below in Tables 4.1 through 4.4.

Table 4.1 Morphological parameters for the classification of the unnamed stream in Austintown Township Park (Pant, 2010).

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

Table 4.2 Morphological parameters for the classification of Indian Run (Pant, 2010).

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

Table 4.3 Level II classification of the unnamed stream in Austintown Township Park (Pant, 2010).

Stream: Unnamed Tributary to Meander Creek		
Basin:	Drainage Area: acres	mi^2
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**

Table 4.4 Level II classification of Indian Run (Pant, 2010).

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:	

Parameter	Value	Unit
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**

4.2 Level III Classification Results and Discussion

Condition categories were determined from field inspection and measurement of stream channel characteristics. Specific categories were evaluated and documented based on the criteria for each variable. The seven categories and associated variables evaluated are: a) Riparian vegetation, (composition, density, and potential, climax riparian communities); b) Sediment deposition patterns (8 patterns); c) Debris occurrence (includes large woody debris); d) Meander patterns (8 patterns); e) Stream size/Stream order; f) Flow regime (perennial, ephemeral, intermittent, subterranean, snowmelt, stormflow, rain-on-snow, spring-fed, glacial-fed, tidal, diversions, or reservoir regulated), and; g) Altered states due to direct disturbance (dimension, pattern, profile and materials such as, channelization, straightening, levees, concrete, rip-rap, etc.). These seven major condition states provide insight into the stability of the stream.

4.2.1 Austintown Park

Described below are the Level III channel influence variables for the unnamed stream in Austintown Township Park. Some features of the site are shown in Figure 4.1.

Figure 4.1 Austintown Township Park site (Google Earth 2010).

Riparian Vegetation: Past photographs (Figure 2.11) and aerial photos of the Austintown Park site indicate that there was only a narrow strip of riparian vegetation (grasses and small shrubs) along both banks of the stream before restoration. Grass on the adjacent land was mowed up to the edge of steeply sloping banks. There were no trees on the right bank (looking downstream) and only two trees on the left bank. After the restoration of the stream section, there is a 10 to 15 ft wide, moderate density combination of grass and brush on both banks. Although there are a few small trees, the combination of grass/brush is dominant (Figure 4.2). Hence, the riparian vegetation of the Austintown Park Site is rated as 8b (combination grass/brush – moderate density).

Figure 4.2 Riparian vegetation in restored reach of Austintown Park site (June 2010).

Flow Regime: Our field visits during different seasons indicate that the stream is of perennial type. On a U.S. Geological Survey (USGS) topographic map, the stream is shown in a solid blue colored line. Also, information from U.S. Geological Survey (USGS) website showed that the surface water in this stream persists all year and is dominated by stormflow. Hence, from Table 2.2, the hydrologic regime of the Austintown Park Site can be categorized as (P:2).

Size and Stream Order: From cross-sectional surveys of the stream, the bankfull surface width (W_{bkf}) was found to be 9.95 feet (Table 4.3). Hence, from Table 2.3 we can conclude that the Stream Size is classified as S-3. Looking at the U.S. Geological Survey (USGS) topographic map, two first order streams are combined together about 1550 feet upstream of the restored section to form a second order stream (Figures 2.9 and 4.1). Hence, the stream can be categorized as S-3(2).

Depositional Patterns (Sediment): Field observations were done at different stages to determine in-channel bar features. We observed small point bars with no mid-channel bars in the restored stream reach of the Austintown Park Site (Figure 4.3). Hence, referring to Table 2.4, the depositional pattern in this case can be designated as type B-1.

Meander Patterns: Meandering of the Austintown Park stream within the project site follows an irregular meander pattern (Figure 4.3). Hence, from Table 2.5, the meander pattern of the stream can be categorized as type M-3. Although the stream is classified as B4c type (Pant, 2010), from the longitudinal profile survey, channel sinuosity (k) was found to be only 1.02 (Table 4.3). According to Rosgen Level II classification key, for a B4c type stream, the expected sinuosity should have been greater than 1.2. The sinuosity was not changed significantly by the restoration work. Since Kirk Road runs close to the left bank of the stream (looking downstream), and because of the limitations in work space due to the presence of a bridge and culvert at the upstream and downstream project limits, respectively, the project designer could not achieve the expected sinuosity.

Figure 4.3 Depositional pattern and meander pattern in channel reach of Austintown Park site (June 2010).

Debris and Channel Blockages: Debris and channel blockages were determined by field visits and study of photographs. No significant large debris or channel blockages were seen at the Austintown Project site. Debris consisted of small, easily movable, floatable materials such as leaves, small limbs, and twigs. Due to the lack of large trees in the riparian zone and periodic maintenance by Park staff, channel debris and blockages were also infrequent prior to restoration. But human influences, such as transportation encroachments by the construction of the Kirk Road on the left bank of the river (looking downstream), a bridge and a culvert on the upstream and downstream ends of the study reach, respectively (Figure 4.4), have influenced the existing flow regime. As A result, the stream could not maintain its own natural flow path, and the meander pattern and significant channel adjustments have occurred. Hence, referring to Table 2.6, stream channel debris and channel blockages can be categorized as type D2 and D10.

Figure 4.4 Debris and channel blockages in restored channel reach looking upstream at Austintown park site (June 2010).

Stream Channel Stability: The channel stability evaluation (Pfankuch, 1975), with a conversion of the channel stability rating to a reach condition by stream type, for Austintown Township Park site is shown in Tables 4.5 and 4.6. For a B4 type stream, the total Pfankuch rating score of 75 falls in the middle of the “Fair” range of stream stability.

Table 4.5: Channel stability (Pfankuch) evaluation and stream classification summary - Level III (Rosgen, 1996).

Reach Location **Austintown Township Park** Observers Rajesh

Stream Type **B4c**

		Category	EXCELLENT	
UPPER BANKS	1	Landform Slope	Bank Slope Gradient <30%	2
	2	Mass Wasting	No evidence of past or future mass wasting.	3
	3	Debris Jam Potential	Essentially absent from immediate channel area.	2
	4	Vegetative Bank Protection	90%+ plant density. Vigor and variety suggest a deep dense soil binding root mass.	3
LOWER BANKS	5	Channel Capacity	Ample for present plus some increases. Peak flows contained. W/D ratio <7.	1
	6	Bank Rock Content	65%+ with large angular boulders. 12"+ common.	2
	7	Obstructions to Flow	Rocks and logs firmly imbedded. Flow pattern without cutting or deposition. Stable bed.	2
	8	Cutting	Little or none. Infreq. raw banks less than 6".	4
	9	Deposition	Little or no enlargement of channel or pt. bars.	4
BOTTOM	10	Rock Angularity	Sharp edges and corners. Plane surfaces rough.	1
	11	Brightness	Surfaces dull, dark or stained. Gen. not bright.	1
	12	Consolidation of Particles	Assorted sizes tightly packed or overlapping.	2
	13	Bottom Size Distribution	No size change evident. Stable mater. 80-100%	4
	14	Scouring and Deposition	<5% of bottom affected by scour or deposition.	6
	15	Aquatic Vegetation	Abundant Growth moss-like, dark green perennial. In swift water too.	1
			TOTAL	2

		Category	GOOD	
UPPER BANKS	1	Landform Slope	Bank Slope Gradient 30-40%	4
	2	Mass Wasting	Infrequent. Mostly healed over. Low future potential.	6
	3	Debris Jam Potential	Present, but mostly small twigs and limbs.	4
	4	Vegetative Bank Protection	70-90% density. Fewer species or less vigor suggest less dense or deep root mass.	6
LOWER BANKS	5	Channel Capacity	Adequate. Bank overflows rare. W/D ratio 8-15	2
	6	Bank Rock Content	40-65%. Mostly small boulders to cobbles 6-12"	4
	7	Obstructions to Flow	Some present causing erosive cross currents and minor pool. filling. Obstructions newer and less firm.	4
	8	Cutting	Some, intermittently at outcurves and constrictions. Raw banks may be up to 12"	6
	9	Deposition	Some new bar increase, mostly from coarse gravel.	8
BOTTOM	10	Rock Angularity	Rounded corners and edges, surfaces smooth, flat.	2
	11	Brightness	Mostly dull, but may have <35% bright surfaces.	2
	12	Consolidation of Particles	Moderately packed with some overlapping.	4
	13	Bottom Size Distribution	Distribution shift light. Stable material 50-80%.	8
	14	Scouring and Deposition	5-30% affected. Scour at constrictions and where grades steepen. Some deposition in pools.	12
	15	Aquatic Vegetation	Common. Algae forms in low velocity and pool areas. Moss here too.	2
			TOTAL	64

		Category	FAIR	
UPPER BANKS	1	Landform Slope	Bank slope gradient 40-60%	6
	2	Mass Wasting	Frequent or large, causing sediment nearly year long.	9
	3	Debris Jam Potential	Moderate to heavy amounts, mostly larger sizes.	6
	4	Vegetative Bank Protection	<50-70% density. Lower vigor and fewer species from a shallow, discontinuous root mass.	9
LOWER BANKS	5	Channel Capacity	Barely contains present peaks. Occasional overbank floods. W/D ratio 15 to 25.	3
	6	Bank Rock Content	20-40% with most in the 3-6" diameter class.	6
	7	Obstructions to Flow	Moder. frequent, unstable obstructions move with high flows causing bank cutting and pool filling.	6
	8	Cutting	Significant. Cuts 12-24" high. Root mat overhangs and sloughing evident	12
	9	Deposition	Moder. deposition of new gravel and course sand on old and some new bars.	12
BOTTOM	10	Rock Angularity	Corners and edges well rounded in two dimensions.	3
	11	Brightness	Mixture dull and bright, ie 35-65% mixture range.	3
	12	Consolidation of Particles	Mostly loose assortment with no apparent overlap.	6
	13	Bottom Size Distribution	Moder. change in sizes. Stable materials 20-50%	12
	14	Scouring and Deposition	30-50% affected. Deposits & scour at obstructions, constrictions, and bends. Some filling of pools.	18
	15	Aquatic Vegetation	Present but spotty, mostly in backwater. Seasonal algae growth makes rocks slick.	3
			TOTAL	9

Table 4.5 Channel stability (Pfankuch) evaluation and stream classification summary - Level III (Rosgen, 1996) – *Continued.*

	Category	POOR	
UPPER BANKS	1 Landform Slope	Bank Slope Gradient 60%+	8
	2 Mass Wasting	Frequent or large causing sediment nearly year long or imminent danger of same.	12
	3 Debris Jam Potential	Moder. to heavy amounts, predom. larger sizes.	8
	4 Vegetative Bank Protection	<50% density, fewer species and less vigor indicate poor, discontinuous and shallow root mass.	12
LOWER BANKS	5 Channel Capacity	Inadequate. Overbank flows common. W/D ratio >25	4
	6 Bank Rock Content	<20% rock fragments of gravel sizes, 1-3" or less.	8
	7 Obstructions to Flow	Sediment traps full, channel migration occurring.	
	8 Cutting	Almost continuous cuts, some over 24" high. Failure of overhangs frequent.	16
	9 Deposition	Extensive deposits of predom. fine particles. Accelerated bar development.	16
BOTTOM	10 Rock Angularity	Well rounded in all dimensions, surfaces smooth.	4
	11 Brightness	Predom. bright, 65%+ exposed or scoured surfaces.	4
	12 Consolidation of Particles	No packing evident. Loose assortment easily moved.	8
	13 Bottom Size Distribution	Marked distribution change. Stable materials 0-20%.	16
	14 Scouring and Deposition	More than 50% of the bottom in a state of flux or change nearly year long.	24
	15 Aquatic Vegetation	Perennial types scarce or absent. Yellow-green, short term bloom may be present.	4
		TOTAL	0

TOTAL SCORE for the Reach	Excellent	Good	Fair	Poor	Pfankuch Rating
	2	64	9	0	**75**

Table 4.6 Conversion of stability rating to reach condition by stream type (Rosgen, 1996).

CONVERSION OF STABILITY RATING TO REACH CONDITION BY STREAM TYPE*

Stream Type	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4	B5	B6
GOOD	38-43	38-43	54-90	60-95	60-95	50-80	38-45	38-45	40-60	40-64	48-68	40-60
FAIR	44-47	44-47	91-129	96-132	96-142	81-110	46-58	46-58	61-78	65-84	69-88	61-78
POOR	48+	48+	130+	133+	143+	111+	59+	59+	79+	85+	89+	79+
Stream Type	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**D3**	**D4**	**D5**	**D6**		
GOOD	38-50	38-50	60-85	70-90	70-90	60-85	85-107	85-107	85-107	67-98		
FAIR	51-61	51-61	86-105	91-110	91-110	86-105	108-132	108-132	108-132	99-125		
POOR	62+	62+	106+	111+	111+	106+	133+	133+	133+	126+		
Stream Type	**DA3**	**DA4**	**DA5**	**DA6**	**E3**	**E4**	**E5**	**E6**				
GOOD	40-63	40-63	40-63	40-63	40-63	50-75	50-75	40-63				
FAIR	64-86	64-86	64-86	64-86	64-86	76-96	76-96	64-86				
POOR	87+	87+	87+	87+	87+	97+	97+	87+				
Stream Type	**F1**	**F2**	**F3**	**F4**	**F5**	**F6**	**G1**	**G2**	**G3**	**G4**	**G5**	**G6**
GOOD	60-85	60-85	85-110	85-110	90-115	80-95	40-60	40-60	85-107	85-107	90-112	85-107
FAIR	86-105	86-105	111-125	111-125	116-130	96-110	61-78	61-78	108-120	108-120	113-125	108-120
POOR	106+	106+	126+	126+	131+	111+	79+	79+	121+	121+	126+	121+

**Generalized relations ... need additional Level IV data to expand data base for validation.*

4.2.2 Indian Run

The restoration designer, Wallace and Pancher, Inc. considered the restored section of Indian Run to be 1900 ft long. In this project, we only studied the first 1200 ft, next to Artman Elementary School, where the major restoration work was performed. Downstream of the study reach, the stream flows about 700 ft through forest before passing under State Route 3014.

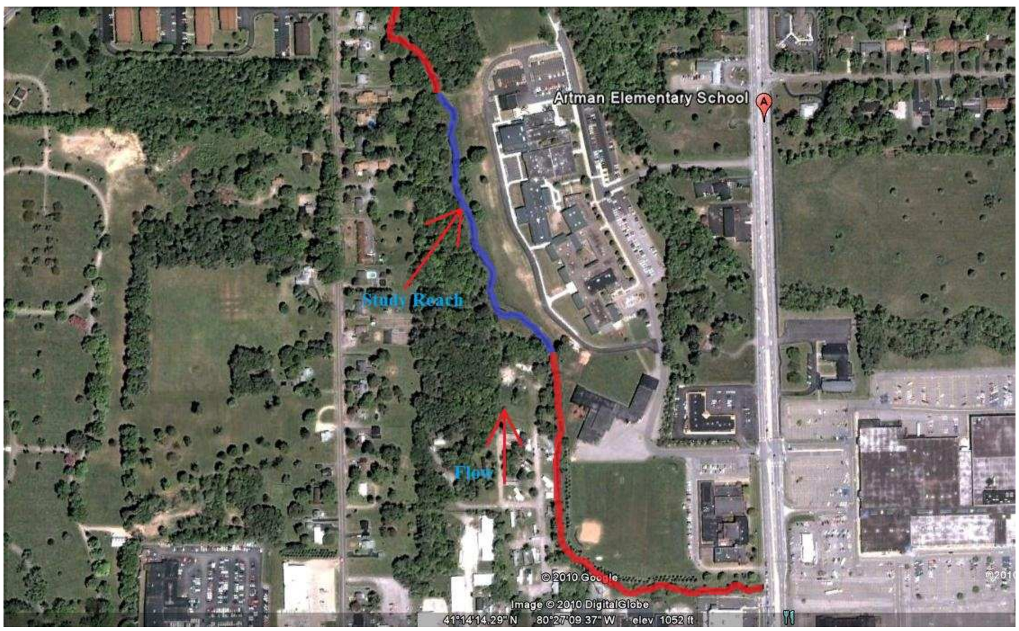

Figure 4.5 Indian Run site (Google Earth 2010).

Riparian Vegetation: Looking at past photographs (Figures 2.16 and 2.17) and aerial photos of the Indian Run site, we can conclude that, before restoration, the only riparian vegetation along the right bank (looking downstream) of the study section was a narrow (5-10 ft) strip of grass and brush. There was a wide (150-250 ft) forested riparian zone, with large trees, brush, and some grass on the left bank. After the restoration of the stream section, the riparian vegetation on the right (east) bank of the study reach is about

10 to 20 feet wide from top of the stream, and includes a very dense mixture of grass, shrubs, and small trees (Figure 4.6). The additional 5 feet of grass buffer has also laid in the riparian buffer development. The riparian vegetation on the right bank can be categorized as 8c (Table 2.1). Riparian vegetation on the left bank was not modified significantly by the restoration, and can be classified as category 10b (Table 2.1) – moderate density deciduous with brush/grass understory (Figure 4.7).

Figure 4.6 Riparian vegetation on the right bank of the Indian Run site (July 2010).

Flow Regime: Based on a number of field visits during different seasons, it was concluded that the stream is of perennial type. On the U.S. Geological Survey (USGS) topographic map, the stream is shown in a solid blue colored line. Also, information from U.S. Geological Survey (USGS) website showed that the surface water in Indian Run persists year long and is dominated by stormflow. Hence, from Table 2.2, the hydrologic regime of the Indian Run Site can be categorized as (P:2).

Figure 4.7 Riparian vegetation on the left bank of the stream reach looking upstream at the Indian Run site (July 2010).

Size and Stream Order: From cross-sectional surveys of the stream, the average bankfull surface width (W_{bkf}) was found to be 13.88 feet. Hence, from Table 2.3, we can conclude that the Stream Size is of S-3 type. Looking at the U.S. Geological Survey (USGS) topographic map, no other streams were found combined upstream of the restored section (Figure 4.5). Hence, the stream is first order and can be categorized as S-3(1).

Depositional Patterns (Sediment): Field observations were done at different stages to determine in-channel bar features. We observed point bars with a few mid-channel bars in the restored stream reach of the Indian Run Site (Figure 4.8). Hence, referring to Table 2.4, the depositional pattern in this case can be designated as type B-2.

Figure 4.8 Depositional pattern in the restored reach of Indian Run (July 2010).

Meander Patterns: Meandering of Indian Run at the study site follows an irregular pattern (Figure 4.9). Hence, from Table 2.5, the meander pattern of the stream can be categorized as type M-3. Although the stream is classified as B4c type (Pant, 2010), from the longitudinal profile survey, channel sinuosity (k) was found to be only 1.06 (Table 4.4). According to the Rosgen Level II classification key (see Appendix), the expected sinuosity for a B4c type stream is greater than 1.2. The sinuosity of the study reach is currently more typical of a much steeper type A stream. In designing the stream restoration, Wallace and Pancher, Inc., could not increase the sinuosity much due to the steep right bank.

Figure 4.9 Meander pattern in restored reach of Indian Run (WPI 2004).

Debris and Channel Blockages: Debris and channel blockages were determined by visual observations during several field visits. Debris consisted of occasional small to medium sized material, such as tree branches and small logs that affect 10% or less of the active channel cross-sectional area (Figure 4.10). Hence, referring to Table 2.6, stream channel debris and channel blockages can be categorized as type D3 (Moderate).

Figure 4.10 Debris and channel blockages in the restored reach of Indian Run (July 2009).

Stream Channel Stability: The overall stability of the study reach of Indian Run is summarized in Tables 4.7 and 4.8. For a B4 type stream, the total Pfankuch rating score of 82 falls in the “Fair” range of stream stability.

Table 4.7 Channel stability (Pfankuch) evaluation and stream classification summary for the Indian Run site - Level III (Rosgen, 1996).

Reach Location **Indian Run Site** Observers Rajesh

Stream Type **B4c**

		Category	EXCELLENT	
UPPER BANKS	1	Landform Slope	Bank Slope Gradient <30%	2
	2	Mass Wasting	No evidence of past or future mass wasting.	3
	3	Debris Jam Potential	Essentially absent from immediate channel area.	2
	4	Vegetative Bank Protection	90%+ plant density. Vigor and variety suggest a deep dense soil binding root mass.	3
LOWER BANKS	5	Channel Capacity	Ample for present plus some increases. Peak flows contained. W/D ratio <7.	1
	6	Bank Rock Content	65%+ with large angular boulders. 12"+ common.	2
	7	Obstructions to Flow	Rocks and logs firmly imbedded. Flow pattern without cutting or deposition. Stable bed.	2
	8	Cutting	Little or none. Infreq. raw banks less than 6".	4
	9	Deposition	Little or no enlargement of channel or pt. bars.	4
BOTTOM	10	Rock Angularity	Sharp edges and corners. Plane surfaces rough.	1
	11	Brightness	Surfaces dull, dark or stained. Gen. not bright.	1
	12	Consolidation of Particles	Assorted sizes tightly packed or overlapping.	2
	13	Bottom Size Distribution	No size change evident. Stable mater. 80-100%	4
	14	Scouring and Deposition	<5% of bottom affected by scour or deposition.	6
	15	Aquatic Vegetation	Abundant Growth moss-like, dark green perennial. In swift water too.	1
			TOTAL	0

		Category	GOOD	
UPPER BANKS	1	Landform Slope	Bank Slope Gradient 30-40%	4
	2	Mass Wasting	Infrequent. Mostly healed over. Low future potential.	6
	3	Debris Jam Potential	Present, but mostly small twigs and limbs.	4
	4	Vegetative Bank Protection	70-90% density. Fewer species or less vigor suggest less dense or deep root mass.	6
LOWER BANKS	5	Channel Capacity	Adequate. Bank overflows rare. W/D ratio 8-15	2
	6	Bank Rock Content	40-65%. Mostly small boulders to cobbles 6-12"	4
	7	Obstructions to Flow	Some present causing erosive cross currents and minor pool. filling. Obstructions newer and less firm.	4
	8	Cutting	Some, intermittently at outcurves and constrictions. Raw banks may be up to 12"	6
	9	Deposition	Some new bar increase, mostly from coarse gravel.	8
BOTTOM	10	Rock Angularity	Rounded corners and edges, surfaces smooth, flat.	2
	11	Brightness	Mostly dull, but may have <35% bright surfaces.	2
	12	Consolidation of Particles	Moderately packed with some overlapping.	4
	13	Bottom Size Distribution	Distribution shift light. Stable material 50-80%.	8
	14	Scouring and Deposition	5-30% affected. Scour at constrictions and where grades steepen. Some deposition in pools.	12
	15	Aquatic Vegetation	Common. Algae forms in low velocity and pool areas. Moss here too.	2
			TOTAL	64

		Category	FAIR	
UPPER BANKS	1	Landform Slope	Bank slope gradient 40-60%	6
	2	Mass Wasting	Frequent or large, causing sediment nearly year long.	9
	3	Debris Jam Potential	Moderate to heavy amounts, mostly larger sizes.	6
	4	Vegetative Bank Protection	<50-70% density. Lower vigor and fewer species from a shallow, discontinuous root mass.	9
LOWER BANKS	5	Channel Capacity	Barely contains present peaks. Occasional overbank floods. W/D ratio 15 to 25.	3
	6	Bank Rock Content	20-40% with most in the 3-6" diameter class.	6
	7	Obstructions to Flow	Moder. frequent, unstable obstructions move with high flows causing bank cutting and pool filling.	6
	8	Cutting	Significant. Cuts 12-24" high. Root mat overhangs and sloughing evident	12
	9	Deposition	Moder. deposition of new gravel and course sand on old and some new bars.	12
BOTTOM	10	Rock Angularity	Corners and edges well rounded in two dimensions.	3
	11	Brightness	Mixture dull and bright, ie 35-65% mixture range.	3
	12	Consolidation of Particles	Mostly loose assortment with no apparent overlap.	6
	13	Bottom Size Distribution	Moder. change in sizes. Stable materials 20-50%	12
	14	Scouring and Deposition	30-50% affected. Deposits & scour at obstructions, constrictions, and bends. Some filling of pools.	18
	15	Aquatic Vegetation	Present but spotty, mostly in backwater. Seasonal algae growth makes rocks slick.	3
			TOTAL	18

Table 4.7 Channel stability (Pfankuch) evaluation and stream classification summary for the Indian Run site - Level III (Rosgen, 1996) - *Continued.*

	Category	POOR	
UPPER BANKS	1 Landform Slope	Bank Slope Gradient 60%+	8
	2 Mass Wasting	Frequent or large causing sediment nearly year long or imminent danger of same.	12
	3 Debris Jam Potential	Moder. to heavy amounts, predom. larger sizes.	8
	4 Vegetative Bank Protection	<50% density, fewer species and less vigor indicate poor, discontinuous and shallow root mass.	12
LOWER BANKS	5 Channel Capacity	Inadequate. Overbank flows common. W/D ratio >25	4
	6 Bank Rock Content	<20% rock fragments of gravel sizes, 1-3" or less.	8
	7 Obstructions to Flow	Sediment traps full, channel migration occurring.	
	8 Cutting	Almost continuous cuts, some over 24" high. Failure of overhangs frequent.	16
	9 Deposition	Extensive deposits of predom. fine particles. Accelerated bar development.	16
BOTTOM	10 Rock Angularity	Well rounded in all dimensions, surfaces smooth.	4
	11 Brightness	Predom. bright, 65%+ exposed or scoured surfaces.	4
	12 Consolidation of Particles	No packing evident. Loose assortment easily moved.	8
	13 Bottom Size Distribution	Marked distribution change. Stable materials 0-20%.	16
	14 Scouring and Deposition	More than 50% of the bottom in a state of flux or change nearly year long.	24
	15 Aquatic Vegetation	Perennial types scarce or absent. Yellow-green, short term bloom may be present.	4
		TOTAL	0

TOTAL SCORE for the Reach	Excellent	Good	Fair	Poor	Pfankuch Rating
	0	64	18	0	**82**

Table 4.8: Conversion of stability rating to reach condition by stream type (Rosgen 1996).

CONVERSION OF STABILITY RATING TO REACH CONDITION BY STREAM TYPE*												
Stream Type	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4	B5	B6
GOOD	38-43	38-43	54-90	60-95	60-95	50-80	38-45	38-45	40-60	40-64	48-68	40-60
FAIR	44-47	44-47	91-129	96-132	96-142	81-110	46-58	46-58	61-78	65-84	69-88	61-78
POOR	48+	48+	130+	133+	143+	111+	59+	59+	79+	85+	89+	79+
Stream Type	C1	C2	C3	C4	C5	C6	D3	D4	D5	D6		
GOOD	38-50	38-50	60-85	70-90	70-90	60-85	85-107	85-107	85-107	67-98		
FAIR	51-61	51-61	86-105	91-110	91-110	86-105	108-132	108-132	108-132	99-125		
POOR	62+	62+	106+	111+	111+	106+	133+	133+	133+	126+		
Stream Type	DA3	DA4	DA5	DA6	E3	E4	E5	E6				
GOOD	40-63	40-63	40-63	40-63	40-63	50-75	50-75	40-63				
FAIR	64-86	64-86	64-86	64-86	64-86	76-96	76-96	64-86				
POOR	87+	87+	87+	87+	87+	97+	97+	87+				
Stream Type	F1	F2	F3	F4	F5	F6	G1	G2	G3	G4	G5	G6
GOOD	60-85	60-85	85-110	85-110	90-115	80-95	40-60	40-60	85-107	85-107	90-112	85-107
FAIR	86-105	86-105	111-125	111-125	116-130	96-110	61-78	61-78	108-120	108-120	113-125	108-120
POOR	106+	106+	126+	126+	131+	111+	79+	79+	121+	121+	126+	121+

**Generalized relations ... need additional Level IV data to expand data base for validation.*

A summary table of the Level III parameters is shown in Table 4.9.

Table 4.9: Summary of level III parameters for Austintown Park and Indian Run sites.

	Channel Influence Variables	Austintown Park	Indian Run
1.	**Flow Regime**	Perennial	Perennial
2.	**Stream Size and Order**	S-3(2): 5 to 15ft./Second	S-3(1): 5 to 15 ft./First
3.	**Sediment Depositional Features**	B1: Point bars	B2: Point bars + Few mid channel bars
4.	**Meander Pattern**	M3: Irregular	M3: Irregular
5.	**Debris and Channel Blockages**	D-2: Infrequent D-10: Human influences	D-3: Moderate
6.	**Riparian Vegetations**	8-b: Moderate density grass + brush	10-b: Moderate density deciduous with grass + brush understory
7.	**Stream Channel Stability**	Fair: Refer Tables 4.5 and 4.6	Fair: Refer Tables 4.7 and 4.8

4.3 Success of Stream Restoration

From the field observations and surveys it was found that the installation of rock cross vane structures in case of Austintown Park site and log cross vane structures in case of Indian Run site has helped a lot to concentrate the flow of river water in the center of the channel preventing possible bank erosions, scouring and undercutting. These structures have not only helped to form pools, both above and below the structure itself, and riffles in the stream reach, but also played a very important role in dissipating the high energy of river flow during the storm activities. Installation of cross vane structures in both cases has helped in creating dynamic equilibrium along the stream reach. Cross vanes focus the flow and keep the water moving through the channel, thus allowing the sediment in the stream waters to be transported downstream, rather than settling out and embedding the substrate or creating depositional obstructions. This has made the habitat more suitable for aquatic biota. Although both streams have begun to re-establish a proper meander pattern, sinuosity is still much less than expected.

Establishment of riparian vegetation by planting of different kind of trees, shrubs and a selected seed mix such as black willow, red-osier dogwood, American elderberry, silky dogwood etc. along the river banks has made the banks and slope more stable in both the sites. Through the stabilization of the stream banks and the creation of floodplain area, the proposed stream enhancement projects have benefited the streams ecologically and benefited park patrons; Artman Elementary school students, teachers and all other associated people by providing a safer environment for the recreational and educational utilization of these restored sections. Restoration of the streams has helped in balancing the geomorphic variables and returning the streams dimension, pattern, and profile to a stable condition.

According to the project designer, the primary intent of restoration for both streams studied was to eliminate stream bank erosion. But, based upon field visits, stream classification, and evaluation of the stability of the restored streams using the Level III analysis, the restored sections of both streams are not at their optimum natural condition. Some important features identified in the Pfankuch table that have influenced the stability of the restored streams are described below.

From the cross-sectional survey of Austintown Park site, we obtained the width/depth ratio of 22.46 (Table 4.3). The higher width/depth ratio means that, the channel capacity is low and barely contains peaks. Even after the restoration of the stream there is still some intermittent bank erosion at outcurves and just below the bridge at the upstream end. During a field visit in June 2010, raw banks were observed, cutting up to a foot deep (Figure 4.11). Mass wasting is infrequent and mostly healed over. There is low future potential of mass wasting in the stream reach. Although there is a small amount of debris present in the channel, the debris jam potential in the restored section is very low. Most of the debris found was small twigs and limbs. From the field visit, some newly formed bars were observed in the restored stream reach, as compared to the old photographs, mostly from coarse gravel. The only aquatic vegetation in the stream channel is algae formed in low velocity and pool areas. Seasonal algae growth has made rocks slick.

Figure 4.11 Bank cutting at Austintown Park site (June 2010).

From the field observations and cross-sectional survey of Indian Run site, we obtained the average bank slope gradient of more than 40%. Some of the segments on the left and right bank of the restored section are very steep (Figure 4.12 and 4.13). This high steepness in gradient has resulted in bank erosion and also caused the high potential for instability of earth. From the cross-sectional survey, an average width/depth ratio of 34.06 was obtained (Table 4.4). Although there is a high width to depth ratio at bankfull stage, the channel capacity was found to be adequate as we observed a rare bank overflow during the field visit. Even after the restoration of the stream, there are still some intermittent lower bank cuttings along the right bank. During a field visit in July 2010, raw banks cutting up to two feet deep were observed (Figure 4.14 and 4.15). Mass wasting is infrequent and mostly healed over. There is low future potential of mass wasting in the stream reach. Although moderate debris was present in a few locations (Figure 4.16), the debris jam potential in the restored section is low. Most of the debris found was small twigs and limbs. From the field visit, some new bars were found in the restored stream reach, as compared to the old photographs, mostly from coarse gravel. Most of the aquatic vegetation was algae formed in low velocity and pool areas. Some are present in backwater and seasonal algae growth has made rocks slick.

Figure 4.12 Steep gradient on left bank of Indian Run (July 2010).

Figure 4.13 Steep gradient on right bank of Indian Run (July 2009).

Figure 4.14 Bank cutting on left bank of Indian Run (July 2010).

Figure 4.15 Bank cutting on right bank of Indian Run (July 2010).

Figure 4.16 Debris jams on restored reach of Indian Run (July 2010).

After identification of the field condition of different features of study stream reaches, the Pfankuch Evaluation and Stream Classification Summary table was completed. Total Pfankuch scores of 75 for the Austintown Park site, and 82 for the Indian Run site were obtained. Hence, referring to the table for conversion of stability rating to reach condition by stream type (Rosgen, 1996), it can be concluded that both of the B4c type study reaches have a fair stability condition. However, the Indian Run site has a total Pfankuch score very close to the lower end of the Poor range (85). Based on the Pfankuch score, the stability of the Austintown Park site appears slightly better than the Indian Run site.

For both sites, most of the categories in the channel stability (Pfankuch) evaluation table fall under good condition. However, after conversion of the overall stability rating to reach condition for a B4 stream type, both of the studied stream reaches were categorized in fair condition. Since different stream types have their own different channel stabilities, the single average stability rating value cannot reflect the true stability of the particular stream (Rosgen 1996). According to Rosgen, "the objective of a stream type conversion with the rating values from the original channel stability rating system is to reflect the naturally inherent and differing value ranges for each stream type. It is important to remember that the values shown are simply an index to channel stability. To determine actual stability, the data collection methods outlined in the Level IV analysis process would be implemented." (Rosgen 1996). Comparing past photographs to present field conditions, restoration improved bank stability by reducing the landform slope, minimized bank cutting, reduced deposition of bars, and stabilized channel bed material at both sites.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Two restored streams were chosen for a study of stream condition, stability, and departure from potential following restoration. One is an UNT to Meander Creek near the Austintown (OH) Township Park, restored in September, 2007; and the other is an UNT to Pine Hollow Run (known locally as Indian Run) located behind the Artman Elementary School in Hermitage, PA, restored in 2004. Both of the streams were restored by Wallace and Pancher Inc. of Hermitage, Pennsylvania.

Rosgen Level III analysis was adopted to evaluate stability of the restored streams. As a component of Level III analysis, different stream channel influence variables were determined from field surveys, observation of past photographs, maps and background materials provided by the project designer, websites such as USGS and Google map, and various books and journal articles. Channel stability evaluation was performed, with conversion of the channel stability rating to a reach condition by stream type using the Pfankuch Stability Evaluation and Stream Classification Summary Table. Rosgen Level I and Level II analyses and calculations for several morphological parameters were performed by Mr. Santosh Pant as part of a related project. Field surveys were done during the Summer of 2008 and 2009 to collect the necessary data.

Based on these studies, the following conclusions were drawn:

1. Both of the streams were classified as type B4c (Pant 2010).

2. The Pfankuch stability rating procedure gave total scores of 75 for the Austintown Park site and 82 for the Indian Run site. Comparing these scores with stream type in the conversion table, the channel stability condition for the both sites is classified as Fair. Hence, it can be concluded that the restored sections of both streams are not at their optimum natural condition.
3. At the Austintown Park site, the designer has established a good density and fair width of riparian vegetation with diverse species of plants along the stream banks. This, in combination with several cross-vane structures, has reduced bank erosion. However, because of the presence of Kirk Road along the left bank of the stream, and limitations in work space due to the presence of a bridge and culvert at the upstream and downstream project limits, respectively, the project designer could not achieve the expected sinuosity. This has in turn increased the slope of the stream bed and velocity of flow. Even after the restoration of the stream, there is still some intermittent bank erosion at outcurves and just below the bridge at the upstream end.
4. At the Indian Run site, because of the presence of the school property along the right bank and dense woods along the left bank of the restored stream, the project designer could not create the desired sinuosity in the restored section. Even after the restoration of the stream, there is still some intermittent cutting along the lower banks up to two feet deep.
5. As compared to the pre-restoration stage, installation of cross vane structures at both sites has helped to concentrate the flow of river water in the center of the channel. This has greatly decreased the possibility of severe bank erosions, scouring and

undercutting. These structures have also helped in creating riffles and pools in the streams, which may make the habitat more suitable for aquatic biota.

6. Both stream channels have remained stable since restoration, with desirable sedimentation occurring on the inside of meanders, resulting in decreases to the width-depth ratios. Riparian vegetation and stream banks are recovering.

5.2 Recommendations

The following recommendations are suggested regarding the success of the restoration for both of the study reaches:

1. Since sinuosity of both of the streams was found to be low, more meandering is desirable both cases.
2. Since Rosgen's Level IV analysis, which is also the validation level, was beyond the scope of this project, it is recommended to perform the Level IV analysis for field data verification of both of the project sites. This will complete all four levels of Rosgen's hierarchical assessment of channel morphology of both of the study reaches.
3. Post-project monitoring should be performed on a regular basis. Following stream restoration, monitoring of the shape, channel, habitat, and biota of the stream is recommended to assess the effectiveness of the restoration efforts in reaching the project designers stated goals.

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